Managing Fertilizer and Pesticide Leaching and Runoff in Bareroot Nurseries[1]

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Abstract.--Managing fertilizer and pesticide leaching and runoff in bareroot nurseries involves developing an understanding of the processes involved, the site characteristics, and the chemical properties which create the potential for leaching and runoff. A method for rating the loss potential for pesticides is discussed. Best Management Practices for controlling leaching and runoff are examined.

OUTLINE

1.0 INTRODUCTION

Managing fertilizer and pesticide leaching and runoff in bareroot nurseries is a complex subject. To understand it, one must be part chemist, hydrologist, and soil scientist. Fortunately, as nursery managers, we in fact are part chemist, hydrologist, and soil scientist, and a great many other things as well. So the subject, while involved and complicated, is one which we can decipher and can make real strives to manage with sound, reasonable practices.

In order to understand ways to manage the problem we first must develop an understanding of the processes that cause the problem to occur in the first place, what properties of a chemical create the potential for a problem, and what site factors contribute to the problem. We will then pull these together and identify ways to manage our nurseries in ways which lessen the potential for negative impacts to develop.

Runoff will only occur when the rate of added water, either rainfall or irrigation, exceeds the infiltration rate of the soil. Runoff pollution involves the loss of both soluble and insoluble fertilizers and/or pesticides. Chemicals of

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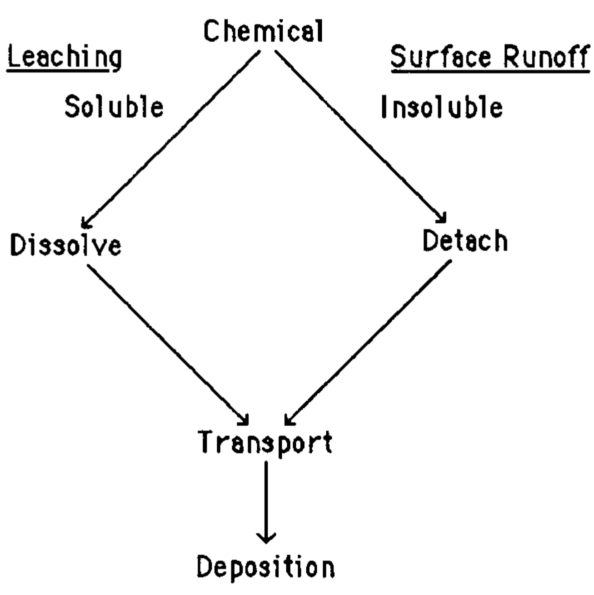
relatively high solubility will enter into solution with the excess water and will be lost through overland and subsurface flow. Insoluble chemicals are carried with the sediment phase, both soil and organic matter, of surface runoff. The movement of these chemicals involves detachment and transport of the chemical bound to the soil. First, the soil particle must be detached from the aggregate binding it to the soil as a whole. Second, this sediment must be transported from the field.

Leaching involves soluble fertilizer and/or pesticide losses carried with the soil water when moisture is applied in quantities greater than the water holding capacity of the soil, and the evapotranspirational losses occurring at any given time. This water, known as gravitational water, is water held with tensions of more than 1/3 bar, and will drain freely. Chemicals will move through the soil dissolved in water and by diffusion resulting from the random motion of molecules and ions, but only through gravitational flow will there be significant drainage of solutes (Jackson et al. 1987).

Therefore, in order for contamination of ground or surface waters to take place, four processes must occur. There must be a chemical present in the soil; it must either dissolve into the runoff or gravitational flow, or if insoluble, it must detach from the soil; it must be transported either downward with the gravitational flow or overland with the water or sediment phase of the runoff, and then it must enter a water resource (fig. 1).

Figure 1.-- Surface and Groundwater Pollution Pathways



There are four keys to controlling surface runoff and leaching in bareroot nurseries - Detachment, Transport, Deposition, and the chemical itself. There are numerous Best Management Practices (BMP's) available to nursery managers to reduce the potential for leaching and runoff losses. The inputs, fertilizers and pesticides, are managed with source controls. Many cultural practices and control structures are available to control detachment, transport, and deposition. We will first concentrate of the movement of potential pollutants and some cultural practices and control structures.

2.0 MOVEMENT OF POTENTIAL POLLUTANTS

2.1 Detachment

Detachment and transport require kinetic energy (energy of motion). The source of this energy may be either falling rain or blowing wind. I will concentrate on rain, for which being from Washington I am all too familiar with. The principals however, apply to wind as well. The energy in the falling rain is used to break the cohesive forces binding the soil into an aggregate, and to overcome the inertia necessary to move a soil particle. In this case the force is rain and/or wind. Since detachment is dependent on energy, the key is to lessen the amount energy reaching the soil surface, or, increasing the amount of energy required to detach the soil particles. The amount of energy in a drop of rain is a function of the size of the drop and rate of rainfall (fig. 2).

Figure 2.-- Kinetic Energy Equation.

$$K = \frac{1}{2} MV^2$$

where: K = kinetic energy
M = mass
V = velocity

By this formula you can see that anything which either reduces the mass or velocity of a raindrop will reduce its energy. Cover crops and mulches are used to intercept falling rain. This reduces the energy potential of raindrops to do work by requiring the energy in the rain to overcome the inertia of the litter, energy is lost when the rain bends a blade of grass. Cover crops and mulches also slow the velocity of rain drops. A drop intercepted by cover will hit the ground much slower than one that has reached terminal velocity falling from the sky. Likewise, when large drops are broken into smaller ones, energy is lost by utilizing the energy to break the bonds holding the water drop together. Again, less energy is available for detachment of soil particles.

Soil organic matter and organic mulches help to bind soil into larger aggregates. These require more energy for detachment, which lessens the amount of work any individual raindrop can accomplish. Organic matter also acts as a continuing supply for the cementing agents which bind the soil into aggregates.

Soil texture plays a role in detachment. Well aggregated, fine textured soils are less likely to detach than non-coherent coarse soils. Once detached though, fine textured soils are far more likely to be transported. The key for fine textured soils is to keep them well aggregated. Practices which decrease the likelihood of detachment include proper irrigation management, green manure or cover crops, and increasing soil organic matter. Practices which increase the likelihood of detachment include bare fallowing and losses in soil organic matter.

2.2 Transport

Transport of a chemical may take two pathways: overland flow to surface waters and gravitational flow to the groundwater. Each will be discussed separately.

2.2.1 Overland Flow

Overland flow is also energy dependent but requires less energy than detachment (Satterlund 1972). Overland flow only occurs when the infiltration rate of the soil is exceeded by the rate of rainfall or irrigation. Infiltration rate is strongly influenced by soil texture with coarse textures having superior infiltration than fine textured soils. Aggregation of fine textured soils increases soil infiltration capacity, reducing the potential for runoff. This can be accomplished by increasing soil organic matter.

For any given amount of overland flow, the amount of sediment that can be carried is a function of its velocity. The faster the runoff flows, the more sediment it can carry. If runoff is unavoidable, as it can be at times in the Pacific Northwest, the key is to control the velocity of water running off the field. Manning's Equation describes how various factors influence velocity of flow (fig. 3).

Figure 3.--Manning's Equation

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where: V = velocity
R = hydraulic radius
S = slope
n = Manning's coefficient of channel roughness

Decreasing the velocity of the flowing water can be achieved by decreasing the hydraulic radius of the flowing water, reducing the slope, and by increasing the roughness of the surface over which it flows. The hydraulic radius, while not particularly applicable to overland flow, is decreased by either decreasing the cross sectional area or increasing the wetted perimeter of the flowing water. This explains why once rills or gullies are formed, the amount of erosion increases. Reducing the slope will also reduce the erosive ability of flowing water. Manning's coefficient of channel roughness increases with increasing roughness. Packed clay has a coefficient of 0.03, while a light turf has a coefficient of 0.20 (Satterlund 1972). Any practice which increases the roughness of the soil will decrease the potential for overland flow. Practices which decrease the likelihood of overland flow include proper irrigation management; green manure or cover crops; applying a mulch to the soil surface; land leveling; and increasing the roughness of the soil by conservation tilling, chiseling, subsoiling, disking and plowing. Caution must be taken though, that the direction of disking or plowing to increase roughness does not channelize the water, because any water in channels will move much faster than non-channelized overland flow. Disking or plowing should be done at right angles to the direction of the slope. Bare fallowing, land smoothing, or channelizing runoff will increase the likelihood of overland flow.

2.2.2 Gravitational Flow

Gravitational water is that portion of the water that will drain freely from the soil by the force of gravity. Soil texture plays an important role in the water holding capacity of the soil. With increasing clay and organic matter contents, a soil's ability to hold water against the force of gravity is also increased. Most nursery soils are located on relatively coarse textured soils, so gravitational losses may account for a large percentage of the soil water losses. It is these same soil attributes which makes the site susceptible to leaching losses. Additions of finer textured soils to a nursery is not practical, or desirable, but organic matter additions may help in this regard.

Practices which decrease the likelihood and amount of gravitational flow include careful monitoring of irrigation amounts and timing, irrigation tailwater recovery systems, subsurface drainage systems and lined water and sediment control basins. Unfortunately, practices which are used to reduce surface drainage will increase the likelihood of gravitational flow merely by increasing the amount of time the extra water is present over a given area. These include most of the practices which decreased the likelihood of overland flow; green manure or cover crops, land leveling, and increasing the roughness of the soil by conservation tilling, chiseling, subsoiling, disking and plowing. To this list we can add unlined water and sediment control basins which add to the problem by concentrating the water and saturating the underlying soil.

2.3 Deposition

Deposition is simply where the overland flow of water, soil, and organic matter terminates. If it ends in surface water then pollution may occur. So the key is to keep the water and/or sediment from a surface water resource. This can be done by installation of irrigation tailwater recovery systems; diverting the excess to water and sediment retention basins or constructed wetlands (Landis et al. this publication); and erecting physical barriers, such as vegetation buffer strips, around surface waters. Surface and subsurface drainage systems which drain directly into surface waters only exacerbate the problem.

From this discussion it is apparent that cultural practices which aid in reducing possible surface water contamination problems may in fact exacerbate a potential groundwater problem. But contamination is also dependent on having a contaminate present, so now we will examine the site and pesticide properties of which make them more, or less, likely to contribute to the problem.

3.0 PESTICIDE MANAGEMENT

There are four keys to successful pesticide management. They are: 1) the properties of the chemical; 2) the specific site characteristics; 3) the timing, frequency, and rates of application; and 4) handling procedures. Each one of these will be discussed below.

3.1 Chemical Properties

Potential impacts to surface and groundwater from a chemical depend on the its ability to reach and move within the water, and the toxicity of the chemical (SCS 1989). In order to reduce the potential for negative impacts it is critical to understand what makes a chemical a potential leacher, or be lost through overland flow and erosion. There are a number of important chemical properties which influence the ability of the chemical to reach and move within the groundwater or contaminate surface waters. These include:

1) Soil Sorption
2) Solubility in Water
3) Persistence
4) Formulation

3.1.1 Soil Sorption

When a pesticide is applied to the soil some of the molecules will sorb to the soil (mainly the organic matter) and some will enter into solution with the soil water. This is known as the soil water partition coefficient. The tendency of a chemical to be adsorbed, by chemical or physical bonds, to soil particle surfaces is measured by the "Koc" value. The "Koc" value is the soil water partition coefficient divided by the organic carbon content in the soil (Jackson 1987). The higher the "Koc" value the greater the proportion of the applied molecules will sorb. Pesticides with high "Koc" values (>1000) have a strong attachment to the soil, and a lesser tendency for the pesticide to move, except with sediment movement. Conversely, chemicals with lower "Koc" values (300 to 500) will tend to move with water, and have a potential for deep percolation below the root zone, or being carried in surface runoff water. Chemicals with values between 500 to 1000 may be of concern depending on the influence of other factors Becker et al. 1989).

3.1.2 Solubility

The solubility of the chemical will strongly affect the ease of runoff and leaching through soil. In general, pesticides with water solubilities of 1 ppm or less will tend to stay at the soil surface and may be washed off the field in the sediment phase of runoff. Conversely, the more soluble the material the greater the risk of movement into the groundwater. Pesticides with a solubility greater than 30 ppm are more likely to leach. Pesticides with solubilities between 1 and 30 may be of concern depending on the influence of other factors (Becker et al. 1989). Generally speaking, solubility and sorption are inversely related.

3.1.3 Persistence

The persistence of chemicals in the soil is represented by the half-life (Ks). The longer a chemical persists, the greater the chance of movement into surface water or groundwater. Establishment of precise half-life values is impossible. Half-lives vary by a factor of three or more, depending on soil moisture, soil pH, air and soil temperature, oxygen status, soil microbial population and numerous other factors.

3.1.4 Formulation

The formulation is the physical form in which the product is packaged. Formulation type is important in predicting pesticide behavior. The initial fate (hours to days) is a function of formulation. Wettable powders are about 30 times more likely to be lost than emulsified concentrates if applied to ground which is immediately subjected to irrigation or rainfall (SCS 1989).

Contamination by highly soluble chemicals ($\geq$1 ppm) of either ground or surface waters has the highest potential for occurring from the use of pesticides which are characterized by having either a low soil sorption index; or a long half-life, or both. Low soluble chemicals which pose the greatest threat to loss with the sediment phase of surface runoff are characterized by having either a high soil sorption index, a long half-life or both.

This presents the nursery manager with some real problems. A chemical which is not likely to leach is more likely to be lost with overland flow.

3.2 Site Characteristics

Several site factors affect the movement of pesticides and fertilizers. These include:

3.2.1 Depth to Water Table

The shallower the water table the greater the concern for contamination. High water tables may also increase the rate and amount of surface runoff due to saturation of the soil.

3.2.2 Proximity to Surface Waters

The closer the surface water resource the greater the concern.

3.2.3 Hydrologic Soil Group

This is a grouping of soils based on runoff producing characteristics. The main consideration is the capacity of bare soil to permit infiltration. Soils are grouped from “A”-“D”. “A” soils are those with high infiltration rates with a low runoff potential. These soils would have a higher potential for contamination of groundwater. “D” soils have very slow infiltration rates with high runoff potentials. These soils are of low potential for negative impacts to groundwater unless accompanied by a high water table. “A” soils tend to be deep, and sandy to gravelly. “D” soils have a claypan or clay layers at or near the surface, or are shallow over nearly impervious bedrock.

3.2.4 Slope and Drainage Patterns

The greater the slope the greater the concern for surface runoff and erosion losses.

3.2.5 Organic Matter

Organic matter content is the single most important soil property affecting pesticide absorption (Sailus 1989). Organic matter will increase the infiltration rate of a fine textured soil and increase the water holding capacity of a coarse textured soil. Organic matter also will increase a soils Cation Exchange Capacity (CEC) allowing it to hold more cations such as ammonium (Donahue et al. 1977). Humus binds soil particles together which helps stabilize loose soils and reduces the potential for detachment. Micro-organisms which are responsible for the breakdown of pesticides are concentrated where plant residue and organic matter are found. Higher concentrations of organic matter equate to higher concentrations of these micro-organisms. Organic matter is also the major site where sorption of a pesticide takes place.

3.2.6 Soil Texture

The higher the clay content the greater the water holding capacity and the greater the surface area for sorption of pesticides. Conversely the higher the sand content the lower the water holding capacity and less surface area for sorption of pesticides. Hydraulic conductivity of the soil increases with pore size. Sandy soils will transmit water faster than clay soils which means the wetting depth of each irrigation or rainfall event will be greater on sandy soils (Donahue et al. 1977), which increases the likelihood of deep leaching.

3.2.7 Soil Structure

Single grain and granular soils have the greatest capacity for rapid movement of soil water in a downward direction. Blocky and prismatic soils have a moderate capacity for water movement. Platy and massive soils have the slowest capacity to move soil water (Jackson et al. 1987).

Although all these factors affect pesticide movement, the most important soil factors involved include soil type, slope, organic matter content, depth to a water-table or aquifer and the ability of the soil particles and organic matter to sorb to the chemical.

3.3 Pollution Potential

3.3.1 SCS Database

In order to merge chemical properties and site characteristics the Soil Conservation Service (SCS) has developed a Pesticide Database (SCS 1989) which rates the potential of a pesticide to be lost through leaching or with surface runoff and the potential of each soil type for leaching and surface runoff. Once known, the pesticide and soil type are combined to determine the potential for pesticide loss to either runoff or leaching.

To use the Database you first must know on what soil type(s) your nursery is located. This is easily done by locating the nursery on the aerial photos found in the back your county's soil survey and referring to the soil number written over the photo. Once the soil type is known, soil leaching and surface runoff potentials can be found by accessing the SCS "Soil Ratings for Determining Water Pollution Risks for Pesticides" sheets which have been developed for each county. Each soil is rated as having either a "High", "Intermediate", or "Low" potential for leaching or surface loss potential.

The next thing to do is to prepare a list of all pesticides presently used, or being considered for use. Your county Soil Conservationist can then check the database and rank each pesticide (if data is available) for soil leaching and surface runoff potentials. Each pesticide is rated as having either a "Large", "Medium", or "Small" potential for leaching loss, and a "Large", "Medium", or "Small" potential for surface runoff.

These ratings are independent of each other, so a chemical may be rated as having a "High" leaching loss potential but only a "Small" surface runoff potential. The SCS Pesticide Potential Loss Matrix is found in table 1. By checking the table for your soil's ranking against the pesticide ranking you can determine the potential for problems to develop.

Potential 1 indicates that the pesticide applied has a high probability of being lost. Potential 2 is a gray area. A pesticide in this ranking has a possibility of being lost. Potential 3 indicates a low probability of being lost. A Potential 3 pesticide posses little threat to either surface or groundwater resources (SCS 1989).

The ranking a chemical is given depends primarily on its solubility in water, its soil sorption properties, and its persistence. Rankings of four commonly used pesticides are found in table 2.

In general, chemicals with high soil sorption and low solubilities have a large surface loss potential and a small leaching potential. Oxyfluorfen (Goal) is an example of this (table 2). It has a low solubility 0.1 ppm and high soil sorption, so it has a large surface loss potential and a small leaching loss potential. On the other hand, chemicals with low sorption and high solubility have a small surface loss potential and a large leaching potential. Metalaxyl (Subdue) is an example of such a chemical. It is very soluble with a low sorption index so it has a large leaching loss potential, but a small surface loss potential (table 2). Persistance, as measured by the half-life, can modify these potentials. Acephate (Orthene) which has high solubility and low sorption should have a large leaching potential, but because its half-life is only 3 days it is rated as having a small leaching potential (table 2). Conversely, Benomyl (Benlate) is rated as having both a high surface loss and leaching loss potential because of its extremely long half-life (table 2).

The SCS Database recommends that soils with water tables within 6 feet be evaluated as to when the high water table occurs in conjunction to pesticide and nutrient application. A soil with a seasonal high water table should be adjusted to one higher Surface Loss and Leaching Loss Potential during the time of the high water table. The database is also adjusted for slopes greater than 15% to one higher Surface Loss Potential and one lower Leaching Loss Potential (SCS 1989).

Table 1 --Pesticide Potential Loss Matrix
Soil Conservation Service (SCS 1989)

Soil Leaching & Runoff Potential	Pesticide Leaching & Runoff Potential		
	Large	Medium	Small
High	Potential 1	Potential 1	Potential 2
Intermediate	Potential 1	Potential 2	Potential 3
Nominal	Potential 2	Potential 3	Potential 3

Table 2.-- SCS Database: Surface and leaching loss potential for selected chemicals (SCS 1989)

Chemical	Oxyflourfen	Metalaxyl	Acephate	Benomyl
Solubility (ppm)	0.01	7,100	818,000	2
Half-life (days)	35	21	3	240
Soil Sorption (Koc)	100,000	16	2	190
Surface Loss Potential	Large	Small	Small	Large
Leaching Loss Potential	Small	Large	Small	Large

3.3.2 Timing

Movement of pesticides is dependent on the amount available to be carried with excess water. Pesticides are most likely to leach if they are applied, or active ingredient is still present in the soil, during the period of time when groundwater recharge is greatest (Jackson et al. 1987). At IFA Nurseries we plan to have no more than 50% active ingredient in the soil after November 1. We chose November because it is the beginning of the time when recharge is most likely taking place. We take the half-life and count back that number of days prior to November 1 as the last date to apply. Some chemicals such as Benomyl (Benlate [half-life 240 days]) are no longer applied because there is no date we can apply the chemical and not have more than 50% active ingredient in the soil by November 1.

The timing of applications in conjunction to prevailing weather patterns can be critical. Use EC's instead of wettable powders if application times are near expected precipitation or irrigation events. Co-ordination with applications and irrigations are extremely important. Oregon State University has developed their own Pesticide Database (Vouge et al. 1991) which considers the Hydraulic Surplus, which is determined by the formula: Rainfall + Irrigation - Evapotranspiration - Runoff. A pesticides Movement Potential will move to a greater risk category as this surplus increases.

3.3.3 Frequency and Rates

One of the real keys to protecting groundwater from agricultural pesticides is to simply use less of them. Pesticides most often found in groundwater are those applied at high rates (>100 lbs/ac) such as soil fumigants (Vouge et al., 1991). Spraying pesticides when necessary and not just according to the calendar for insurance purposes will go a long way towards reducing the pesticide loading in the soil. Initiating an Integrated Pest Management program (IPM) is one way of doing this. While it is beyond the scope of this paper to discuss IPM, the reader is referred to recent works such as Hamm, et al. (1990), and Cordell et al. (1989), for discussions of IPM as it directly relates to forest nurseries. Another alternative to chemical control is bio-pesticides. Biofungicides, such as the antagonistic bacteria *Streptomyces* are being developed for the nursery trade (Lahdenpera 1991). This naturally occurring organism is non-toxic to man and biologically benign. Use of products such as this would reduce pesticide loading in the soil, thereby reducing the risk for loss.

Calibration of equipment is extremely important. Research has shown that unintended over spraying may be a significant problem (Jackson et al. 1987). The reasons for over spraying can be mistakes in calibration calculations, inaccurately marked tank volumes, inaccurate ground speed, worn nozzles, and faulty pressure gauges. All of these must be carefully monitored in order to avoid over spraying. Careful identification of the target area and subsequent calculation of the minimum amount of chemical and water necessary to complete the task will reduce the amount of mixed pesticide remaining in the tank after the target area is sprayed. This will reduce unnecessary pesticide loading of the soil when the tank is sprayed out. Under no circumstance should an excess tank mixture be dumped in a single area, but rather sprayed until empty.

3.3.4 Handling Procedures

Pesticide handling includes storing, mixing and loading, and disposal of empty containers. Pesticides should be stored in a cool, well ventilated location, away from wells or surface waters. The containers must be tightly sealed and should be checked for leakage. Pesticides must be stored in their original container with the label clearly visible. The date of purchase should be marked on each container in order to insure a first purchased, first used rotation of pesticides.

Mixing and loading present a threat because a spill at this time may overwhelm a soils ability to sorb, and or degrade, a pesticide. Even a number of small spills can lead to an accumulation of a pesticide and increase the potential for leaching or surface runoff (Jackson et al. 1987).

Closed systems for metering chemicals, which eliminate the need to open and handle pesticide containers are highly desirable. These systems measure and transfer pesticides directly from the container to the spray tank.

4.0 FERTILIZER MANAGEMENT

Concerns for surface runoff and leaching of fertilizer is mainly confined to Nitrogen, in the form of nitrate and Phosphorus. While some nitrate is lost during soil erosion and runoff, the major pathway for loss is through leaching (Jackson et al. 1987). Nitrate has a greater leaching potential than pesticides and is used as an indicator of potential problems. National levels of 10 ppm nitrate in water have been established but a level of 5 ppm should set off an alarm and you should start examining your Nitrogen management practices (Witt 1989). The idea is to minimize the amount of available N in the root zone except during the active growth phase of the crop. During this phase, practices that maximize growth will in turn maximize Nitrogen use, which in turn, will minimize the potential for nitrate leaching. Phosphorus losses are generally confined to surface runoff, and can be a leading cause of eutrophication of surface waters.

As with pesticides, there are three keys to successful fertilizer management.

1) Fertilizer Properties
2) Site Characteristics
3) Frequency, Rates and Timing of Application

4.1 Fertilizer Properties

Nitrogen is present in the soil in many forms, but the two we are most concerned with are nitrate ($N0_3^-$) and Ammonium (NH_4^+). Being an anion, nitrate is not held within the cation exchange sites of the soil nor is it affected by soil sorption and the normal degradation processes which work on chemicals making it the most leachable form of Nitrogen we use.

Ammonium, being a cation is held on exchange sites. Because of this it is not readily leachable. Ammonium is converted to nitrate by bacteria through the nitrification process. There are nitrification inhibitors on the m arket which slow the nitrification process which may reduce leaching losses of fall applied and possibly spring applied Nitrogen.

Phosphorus forms insoluble compounds with Aluminum and Iron so leaching is not a problem. It can move with the sediment phase of runoff.

4.2 Site Characteristics

The same site characteristics that make a pesticide more apt to leach are the same that make nitrate a potential leacher. Depth to the water table, hydrologic soil group, organic matter content, soil texture and soil structure all play a roll. The major source of naturally occurring soil Nitrogen is mineralization of organic matter. Organic matter contains approximately 5 percent Nitrogen, by weight and about 2-5 percent is mineralized each year. A soil containing 4 percent organic matter would release up to 120 pounds of ammonium each year (Donahue et al. 1977). Increasing soil organic matter therefore reduces the dependency of inorganic nitrate forms which are readily leached from the soil.

Erodibility of the soil, proximity to surface waters, slope, and drainage patterns are important factors affecting the potential for Phosphorus losses.

4.3 Frequency, Rates and Timing of Application

The main key to controlling losses is minimizing the amount of available N in the root zone, except during the period of active assimilation, and not over fertilizing during active growth. This is simple to state but difficult to accomplish. Timing of fertilizations should be by the phenology of the crop, rather than by the calendar. Fall applications of Nitrogen, as a source of N for the next growing season, are discouraged because nitrification during winter increases the likelihood of leaching (Jackson et al. 1987). Split applications of Nitrogen, instead of one large initial application, while labor intensive, offer a lowered chance of leaching loss. Incorporation reduces surface loss potentials of both Nitrogen and Phosphorus. Fall applications of either nutrient is discouraged because of the increased likelihood of leaching and runoff. And, as always, calibration of equipment is extremely important to avoid over application of fertilizer.

5.0 WHAT YOU SHOULD DO

First, test your wells and surface waters. Nitrate is the chemical most likely to show up first and is used as an indicator of potential problems. Nitrate concentrations greater than 5ppm may indicate a problem and if your water tests this high it's time to re-evaluate your management practices.

You should familiarize yourself with the chemicals you use and learn their half-lives, solubilities, soil sorption properties and toxicities. Learn the leaching and runoff potentials of your soil and combine the soil properties with the chemical properties to develop a management strategy.

You should develop a water management plan. Your plan should contain maps of the soil types, drainage patterns and systems, irrigation systems, and nearby surface waters. It should contain a narrative which includes a description of the nursery, its soils, irrigation and drainage systems, chemicals used. etc. Source controls and BMP's used to control surface and groundwater problems should be discussed. Add any supporting documentation such as photographs and engineers plans.

Lastly, you should discuss the monitoring program. At IFA we test our wells and surface waters once a year. We test for chemicals in the surface waters that have a large surface loss potential and for nitrate and Phosphorus. We test our wells for chemicals that have a large leaching loss potential plus nitrates.

6.0 Summary

This paper has considered some of the processes that contribute to surface and groundwater contamination from pesticide and fertilizer use in bareroot forest nurseries. Leaching and runoff require that the pollutant either dissolve in the soil water or detach with the eroding soil, be transported away from the soil and deposited into a water resource. Best management practices are used to control these processes. A thorough understanding of pesticide and fertilizer properties which contribute to potential losses is also critical to controlling pollution. By combining an understanding of leaching and runoff processes and, chemical and fertilizer properties, nursery managers have the tools to make sound cultural practice prescriptions, which not only benefit the crop, but also protect surface and groundwater resources.

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