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Sprinkler Irrigation-Pesticide Best Management Systems

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Introduction

Pesticides reduce crop losses due to insects, pathogens, weeds and other pests, but can contaminate ground water. Ground water refers to water in the saturated portion of the soil material. Water in an unsaturated region of the soil is termed soil moisture.

Pesticide contamination of ground water is well documented (Ranjha et al., Fact Sheet EL 256, June 1991). Ground-water contamination by pesticides is of special concern in Utah, where most of the rural population is entirely dependent on ground water for its domestic needs.

Ground-water contamination by pesticides depends on such factors as agricultural practices, soils, plant uptake, geology, hydrology, climate, topography and pesticide properties.

The major objective of this fact sheet is to present an integrated approach for developing, selecting, and using Best Management Practices (BMPs) for minimizing ground-water contamination by pesticides. BMPs, such as efficient sprinkler irrigation design and selection of less leachable pesticides, can be integrated into a Best Management System (BMS). Use of a BMS will result in safer use of pesticides than less integrated approaches.

Pesticide Movement in the Soil

Pesticides either move with the soil (soil erosion) or with water in the soil. In this fact sheet we are concerned only with pesticide moving downward with water (leaching) through the soil. Deep percolation from irrigation can move pesticides into the ground water. Percolated pesticides can reach ground water if the water table (top of the saturated zone in an aquifer) is close enough to the ground surface.

Two properties of a pesticide affect the amount of pesticide that reaches the ground water. The sorption coefficient of the pesticide indicates its tendency to be adsorbed to soil particles, the greater the adsorption the less movement. The half-life of the pesticide is the time (days) required for half the present pesticide concentration to biodegrade.

Reducing deep percolation can increase the time required for a pesticide to reach a specific depth in the soil profile. Irrigation management that reduces deep percolation generally decreases pesticide movement into the ground water.

The following illustrates pesticide movement through the soil. Assume a particular soil with a total water holding capacity of 18 inches in a 6 foot alfalfa root zone. When irrigation amounts exceed water deficits in the root zone of a crop, the excess infiltrating irrigation water moves through the soil and carries pesticides below the root zone. The amount of excess irrigation water infiltrating determines the pesticide travel time for a particular situation.

The travel time is the time elapsed between pesticide application and its arrival at a specific depth. Because of degradation (expressed through the half-life), travel time affects how much pesticide remains in the soil profile when it reaches some specific depth. Frequently, the depth of most interest is the depth to the water table.

An irrigation schedule which moves the pesticide through the unsaturated zone in 20 days carries more pesticide into the ground water than a schedule that moves it through in 40 days. Irrigation amount and timing affect pesticide movement into the ground water.

Sprinkler Irrigation Uniformity and Pesticide Movement

Ideally, sprinklers would apply a uniform depth of water to all areas in a field. This would make it possible to meet crop and leaching requirements without excessive deep percolation. Unfortunately sprinkler systems do not apply water uniformly. Different areas in the field receive varying irrigation depths. A common measure of the uniformity of application is the uniformity coefficient (UC) developed by Christensen (1942).

Hart and Reynolds (1965), assumed that spatially varying water depths on a sprinkler irrigated field can be described using a normal statistical distribution. This normal distribution is generally statisti-
cally expressed by a factor termed the distribution coefficient (Ha). For a given sprinkler irrigation uniformity (UC), the Ha is used to compute the irrigation application depth (Z) that will adequately irrigate a desired fraction (%) of a field area to replenish the required water depth (Zreq) in the root zone. The depth of irrigation to be applied is computed using the following relationship:

\[
\text{Depth of irrigation} = \frac{\text{depth of water required (Zreq) in the root zone}}{\text{distribution coefficient (Ha)}}
\]

(1)

Hart and Reynolds (1965) developed Ha values for different combinations of UC and fractions of a field area adequately irrigated. See columns 1,2 & 3 of Table 1. In a normal distribution, a fraction (%) of a field receives an irrigation depth equal to or greater than the average depth while the rest receives a depth less than the average. Even if the average irrigation depth applied is the crop irrigation requirement, a fraction (%) of the field is adequately or over-irrigated while the rest is under-irrigated.

Because under-irrigation reduces ET and yield, it is generally not economical to have a large fraction (%) of the field under-irrigated. It is also impossible to fully irrigate all the field because of the cost of water and the possible detrimental effects on yields in those areas which will be over-irrigated. Therefore, the best strategy to consider an efficient and realistically feasible sprinkler irrigation system design as discussed below.

Irrigation system design greatly affects pesticide leaching in irrigated areas. Pesticide leaching can be significantly reduced by efficient sprinkler irrigation design. Figure 1 illustrates how irrigation distribution coefficient (Ha) and the relative amount (RA) of pesticide remaining in the soil are affected by design parameters. Considered parameters are the fraction of area adequately irrigated (%) and uniformity coefficient ( UC).

In the following example we have compared field average deep percolation values and their respective predicted pesticide leaching. Average deep percolation refers to the spatial average amount of infiltrating water that percolates below the root zone. Deep percolation is the difference between the amount of water infiltrated into the soil and the amount of water stored in the root zone of a crop after each irrigation.

Table 1: Effect of selected sprinkler design parameters (UC) and fraction of field adequately irrigated on the average applied water depth, average deep percolation and RA.

<table>
<thead>
<tr>
<th>UC</th>
<th>Fraction of area adequately irrigated (%)</th>
<th>Average deep percolation (in/m)</th>
<th>Average water application depth (in/m)</th>
<th>RA (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>100</td>
<td>0.33</td>
<td>0.33</td>
<td>98</td>
</tr>
<tr>
<td>70</td>
<td>90</td>
<td>0.36</td>
<td>0.36</td>
<td>92</td>
</tr>
<tr>
<td>80</td>
<td>80</td>
<td>0.39</td>
<td>0.39</td>
<td>85</td>
</tr>
</tbody>
</table>

Figure 1: Effect of Uniformity Coefficient (UC) and Percent of Area Adequately Irrigated on Distribution Coefficient (Ha) and on the Relative Amount (RA) of Hexachloroethane Remaining at 6.6 ft (2 m) Soil Depth Under Alfalfa Irrigation Schedule.

Chosen are three selected combinations of UC and fraction of area adequately irrigated, (96%, 100%), (80%, 70%) and (60%, 60%). Respectively these represent the upper, middle and lower range design parameter values for the three considered sprinkler systems (Table 1). The purpose of selecting these three combinations is to show that although each has the same average depth of water (2.1 inches) applied at each irrigation, not all are environmentally, economically, or practically the same.

As shown in Table 1, with an ideal UC of 96 percent and almost 100 percent of the field area adequately irrigated, the average deep percolation is 0.33 inch per irrigation. With a more realistic UC of 80 percent and 70 percent of the field area adequately irrigated, the average deep percolation is 0.37 inch per irrigation. With a poor UC of 60 percent and 60 percent of the field area adequately irrigated, the average deep percolation is 0.56 inch per irrigation. With the lower uniformities less water is available for crop use, crop yield is less (larger area under-irrigated) and more water percolates below the root zone. Therefore, poor sprinkler irrigation uniformities are environmentally and economically undesirable.

The average relative amount (RA) of pesticide reaching the 6.6 feet soil depth (Figure 1) is 0.43, 0.43 and 0.49 for the respective combinations of UC and percent area adequately irrigated (96%, 100%), (80%, 70%) and (60%, 60%). The RA for the first two combinations (96%, 100%) and (80%, 70%) is the same because the time required for the pesticide to move 6.6 feet deep into the soil profile is the same. Environmentally, either of these two combinations of UC and percent area adequately irrigated (96%, 100%) and (80%, 70%) is the same because the time required for the pesticide to move 6.6 feet deep into the soil profile is the same. Environmentally, either of these two combinations of UC and percent area adequately irrigated (96%, 100%) and (80%, 70%) is the same because the time required for the pesticide to move 6.6 feet deep into the soil profile is the same.

Thus, for a given UC, the effect of increasing the fraction of area adequately irrigated is increased water depth and increased average deep percolation and pesticide leaching. On the other hand, reducing the fraction of area adequately irrigated reduces average deep percolation and probably the yield. This may be environmentally beneficial, but can be unprofitable.

The best combination of sprinkler design parameters considers both environmental and economic issues. Assume a UC of 96%, in the example. The most desirable fraction of area adequately irrigated is probably 70% (Figure 1). From that point RA increases rapidly with increasing percent area adequately irrigated, and is unchanged with decreasing percent area adequately irrigated.

Pesticide Alternatives

A second situation exists when the irrigation system and schedule are in place and farmers must select an appropriate pesticide. Farmers usually have several pesticides to choose from. Each has different values of pesticide coefficient (Kp) and half life (t1/2). To develop a sample decision support nomogram, many simulations were performed in which Kp varied from 1 to 100 mg/L and t1/2 varied from 10 to 100,000 days. We assumed alfalfa was irrigated using a 1986 irrigation schedule in Cache County, Utah. RA remaining when the pesticide reaches to soil depths of 1.6 (0.5 m) and 6.6 (2 m) were predicted (Figures 2 and 3 respectively).

Figure 2 illustrates that for low Kp values, as the t1/2 decreases, the RA remaining at 1.6 (0.5 m) soil depth also decreases. For a given t1/2, as the Kp increases, the RA remaining at 1.6 (0.5 m) soil depth decreases. For higher Kp values (greater than 72 mg/L), the predicted RA is 60% regardless of t1/2. This shows that all alfalfa pesticides having Kp = 75 mg/L are safe to use in this situation even t1/2 = 100,000 days.

Figure 3 shows similar results for RA values for pesticides reaching a 6.6 ft (2 m) soil depth (below the alfalfa root zone). No pesticide with t1/2 of 10 days or less percolates to that depth. That depth of soil adsorbs more pesticides than the 1.6 (0.5 m) depth.

In summary, only the pesticides with lower Kp values (15 mg/L or less) and longer t1/2 (>100 days) will leach below the alfalfa root zone. Ground-water contamination is more likely to occur from such pesticides.

Effect of Soil Texture on Pesticide Movement

The greater the clay and organic carbon content, the greater a soil’s tendency to adsorb pesticides and the smaller the risk of ground-water contamination. Pesticides require more travel time when moving through heavy soils, e.g. clay soils, than through lighter soils, e.g. sand. The travel time, in turn, determines the time available for pesticide degradation from the time of application to the time of predicted soil movement, Figure 4 illustrates how soil texture affects aldicarb RA values. Much more aldicarb reaches 6.6 ft (2 m) depth in sand than in the heavier soils.
Summary

Procedures were developed for aiding environmentally safe pesticide/sprinkler irrigation management. These required simulation of effects of sprinkler irrigation design, pesticide characteristics (partition coefficient and half life), and soil type on pesticide leaching. The first procedure is design of a sprinkler irrigation system for a particular site and pesticide. This permits determination of combinations of the uniformity coefficient and percent area adequately watered that avoid excessive pesticide movement. The second procedure is selection of appropriate pesticides for a particular site, crop and sprinkler design. This permits determining the threshold partition coefficients or half lives for environmental safety at a particular site.

The finer the soil texture, the less potential for pesticide leaching. Pesticides move much less easily in clay soils or soils with high organic content than in sandy soils or soils with less organic content.

An integrated use of BMPs such as: efficient sprinkler irrigation design and management, and selection of less leachable pesticides will reduce potential for ground-water contamination more than less integrated approaches.

Footnotes

1Uniformity Coefficient (%) indicates the uniformity of irrigation application. If each point of a field receives an irrigation depth very close to the overall field average depth, the UC is higher (closer to 100 %) than otherwise.

2Distribution Coefficient (Ha) is a factor (less than or equal to 1) used for computing the average depth of water to be applied which will adequately irrigate a desired fraction (%) of a field area for a known sprinkler irrigation uniformity (UC).

3Relative Amount (RA) is the fraction of the amount of the initially applied chemical that exists within a specified soil depth at a certain time after application.

4The organic carbon (OC) partition coefficient (Koc), ml/g OC is a measure of the tendency of an organic pesticide to be adsorbed to soil particles.

5The half life (t1/2) is the length of time (days) required for one-half of the present pesticide mass to be biodegraded.

References


