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SPRINKLER IRRIGATION-PESTICIDE BEST MANAGEMENT SYSTEMS

by

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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 cultural 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 biode-de.

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[1] (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 statistically expressed by a factor termed the distribution coefficient[2] (Ha). For a given sprinkler irrigation uniformity (UC), the Ha is used to compute the irrigation application depth (Vi) 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:

$$\text{Depth of irrigation (Vi)} = \frac{\text{depth of water required (Zreg) in the root zone}}{\text{distribution coefficient (Ha)}} \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

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 impracticable 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 is 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[3] (RA) of pesticide remaining in the soil are affected by design parameters. Considered parameters are the fraction of area adequately irrigated (%) and uniformity coefficient (%).

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.

Soil nonhomogeneities and deviation from average deep percolation values may cause pesticides to leach more than predicted. Thus, presented results represent relative comparisons rather than exact predictions.

Example:

Consider a crop of alfalfa on Kidman (sandy loam) soil that is irrigated each time it requires (Zreq) 1.8 inches of the available soil water in its root zone. For illustration purposes, we assume three different sprinkler systems which require the same amount of irrigation water. In other words, each of them uses the same irrigation schedule and has the same average irrigation depth (Vi) to be applied at each irrigation. Each system has very similar distribution coefficients (Ha).

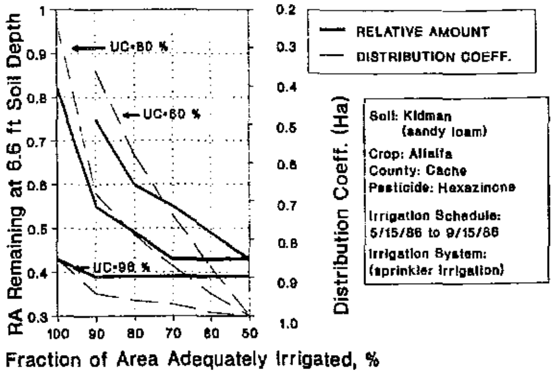

Figure 1: Effect of Uniformity Coefficient (UC) and Percent of Area Adequately Irrigated on Distribution Coefficient (Ha) and on the Relative Amount (RA) of Hexazinone Remaining at 6.6 ft (2 m) Soil Depth Under Alfalfa Irrigation Schedule.

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 10 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 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 ft deep into the soil profile is the same.

Environmentally, either of these two combinations of UC and percent area adequately irrigated (96%, 100%) or (80%, 70%) have the same impacts. However, economically and practically, the second combination of UC and percent area adequately irrigated (80% and 70%) is more feasible (less sprinkler hardware is required). To achieve an irrigation uniformity as high as 96 %, much sprinkler hardware is required.

Now let us consider the situation in which a system UC is fixed an an irrigator wishes to consider changing the area adequately irrigated. For a given UC, to adequately irrigate more of the field area, more

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.

Fraction of area adeq. irrigated	Distrib. coefficient (Ha)	Required depth (Zreq)	Applied water depth (Vi)	Storage effic. (Es)	Amount of water stored	Avg. deep percolation	RA at 6.6 ft soil depth	
(%)	(%)	(fraction)	(inch)	(inch)	(fraction)	(inch)	(inch)	(fraction)
1 given	2 given	3 given	4 given	5 (4/3)	6 given	7 (5X6)	8 (5-7)	9 predicted
60	100	-	1.80	-	-	-	-	-
60	90	.357	1.80	5.04	.333	1.68	3.36	.75
60	80	.578	1.80	3.11	.521	1.62	1.49	.60
60	70	.737	1.80	2.44	.641	1.56	0.88	.55
60	60	.873	1.80	2.06	.730	1.50	0.56	.49
60	50	1.000	1.80	1.80	.799	1.44	0.36	.43
80	100	.225	1.80	8.00	.225	1.80	6.20	.82
80	90	.679	1.80	2.65	.667	1.77	0.88	.55
80	80	.789	1.80	2.28	.761	1.74	0.54	.49
80	70	.869	1.80	2.07	.821	1.70	0.37	.43
80	60	.937	1.80	1.92	.865	1.66	0.26	.43
80	50	1.000	1.80	1.80	.900	1.62	0.18	.43
96	100	.845	1.80	2.13	.845	1.80	0.33	.43
96	90	.936	1.80	1.92	.933	1.79	0.13	.39
96	80	.958	1.80	1.88	.952	1.79	0.09	.39
96	70	.974	1.80	1.85	.964	1.78	0.07	.39
96	60	.987	1.80	1.82	.973	1.77	0.05	.39
96	50	1.000	1.80	1.80	.980	1.76	0.04	.39

Source for data in columns 1,2,3 & 6: Hart and Reynolds (1965).

ter needs to be applied. This results because as the fraction of area adequately irrigated increases, the Ha decreases (Table 1 and Figure 1). As the Ha decreases, the depth of irrigation water to be applied increases (equation 1). Furthermore, the irrigation application time increases as follows:

$$\text{Irrigation time} = \frac{\text{depth of irrigation (Vi)}}{\text{irrigation application rate}} \qquad \text{.............(2)}$$

Thus, for a given UC, the effect of increasing the fraction of area adequately irrigated is increased water and energy costs 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 80%, 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 partition coefficient[4] (K_{oc}) and half life[5] ($t_{1/2}$). To develop a sample decision support nomogram, many simulations were performed in which K_{oc} varied from 1 to 100 ml/g OC and $t_{1/2}$ ranged 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 ft (0.5 m) and 6.6 ft (2 m) were predicted (Figures 2 and 3 respectively).

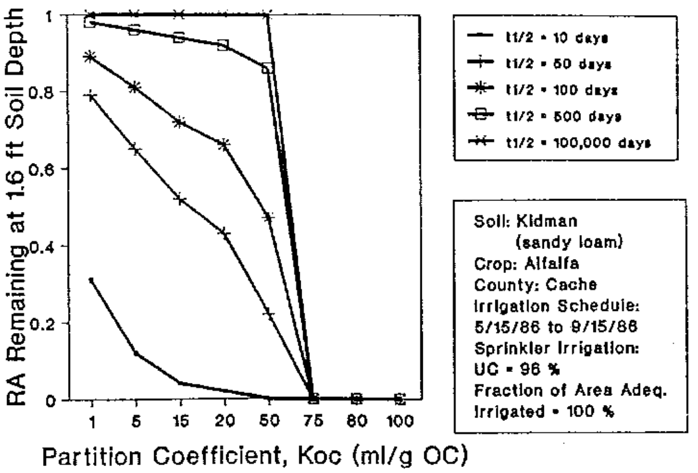

Figure 2: Effects of Pesticide Parameters on the Relative Amount (RA) Remaining when a Pesticide Reaches 1.6 ft (0.5 m) Soil Depth for Known Site, System and Irrigation Schedule.

Figure 2 illustrates that for low K_{oc} values, as the $t_{1/2}$ decreases, the RA remaining at 1.6 ft (0.5 m) soil depth also decreases. For a given $t_{1/2}$, as the K_{oc} increases, the RA remaining at 1.6 ft (0.5 m) soil depth decreases. For higher K_{oc} values (greater than 75 ml/g OC), the predicted RA is 0.00 regardless of $t_{1/2}$. This shows that all alfalfa pesticides having $K_{oc} > 75$ ml/g OC are safe to use in this situation even if $t_{1/2}$ is 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 $t_{1/2}$ of 10 days or less percolates to that depth. That depth of soil adsorbs more pesticides than the 1.6 ft (0.5 m) depth.

In summary, only the pesticides with lower K_{oc} values (15 ml/g OC or less) and longer $t_{1/2}$ (>10 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 via chemical and biological processes. 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.

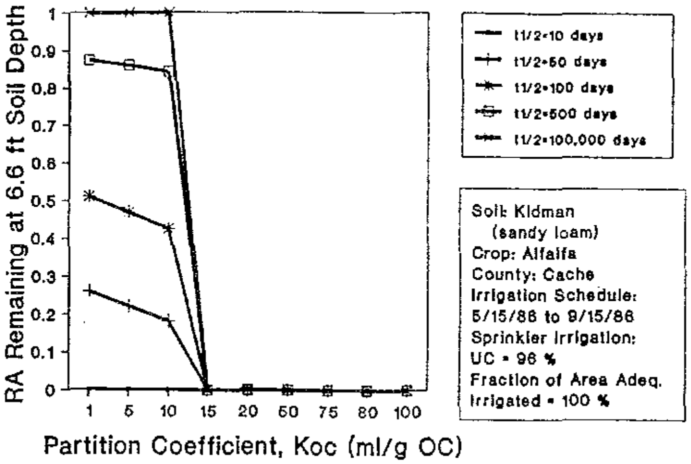

Figure 3: Effects of Pesticide Parameters on the Relative Amount (RA) Remaining when a Pesticide Reaches 6.6 ft (2 m) Soil Depth for Known Site, System and Irrigation Schedule.

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

[1] Uniformity 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.

[2] Distribution 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).

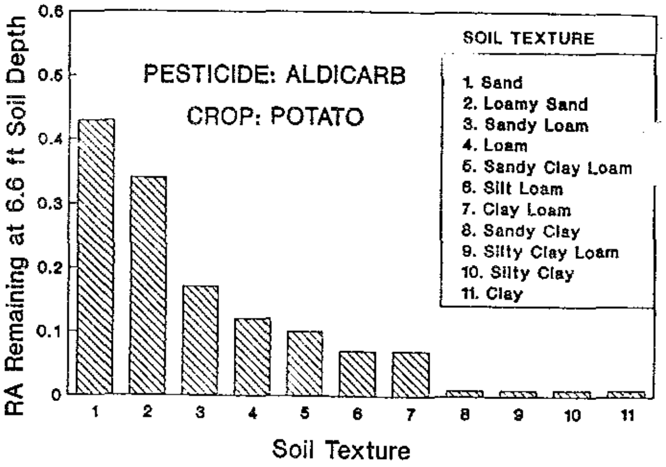

Figure 4: Effects of Various Soil Textures on Relative Amount (RA) of Aldicarb Remaining in the Soil when It Reaches to a Depth of 6.6 ft (2 m).

[3] Relative 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.

[4] The organic carbon (OC) partition coefficient (K_{oc}), ml/g OC is a measure of the tendency of an organic pesticide to be adsorbed to soil particles.

[5] The half life ($t_{1/2}$) is the length of time (days) required for one-half of the present pesticide mass to be biodegraded.

References

Aly, A.H. and Peralta, R.C. with Deer, H.M., Walker, W.R. and Hill, R.W. (1991). CANDI (Chemical and Irrigation Management Software), User's Manual, 27 pages. Irrigation Software Engineering Division, Department of Ag. & Irrigation Engineering, Utah State Univ., Logan, UT. 84322-4105.

Christensen, J.E. 1942. Irrigation by Sprinkler. California Agricultural Experiment Station, Bulletin 670.

Hart, W.E. and Reynolds, W.N. 1965. Analytical Design of Sprinkler Systems. Transaction of the American Society of Agricultural Engineers, Vol. 8 (1) pp 83-85, 89.

Nofziger, D.L., and Hornsby, A.G. 1986. A microcomputer-based management tool for chemical movement in soil, Applied Agricultural Research, Vol.1, No.1, pp. 50-56.

Nofziger, D.L., and Hornsby, A.G. 1988. Chemical movement in layered soils: User's Manual, Agricultural Experiment Station, Division of Agriculture, Oklahoma State University, Stillwater, OK.

Ranjha, A.Y., Peralta, R.C., Hill, R.W., and Deer, H.M. (1991). Pesticide Movement in Response to Furrow Irrigation and Pesticide Parameters. Cooperative Extension Service, Utah State University, Fact Sheet No. EL 256, June 1991.

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