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EFFECTS OF ALTERNATIVE FURROW IRRIGATION PARAMETERS ON PESTICIDE MOVEMENT IN CROPPED AREAS IN UTAH

by

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SUMMARY: The effects of irrigation water-storage efficiencies, furrow irrigation system design and soil types on pesticide leaching were studied. Water-storage efficiencies lower than 50% present higher risk for ground-water contamination when pesticides with longer half-life and lower partition coefficients are used.Higher inflow rates, shorter furrow lengths and heavy texture soils such as silty clays have shown a significant reduction in pesticide leaching and in relative amounts found in soil profiles.

KEYWORDS: water-storage efficiency, furrow irrigation system, gound-water contamination,soil texture, relative amounts.

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ABSTRACT

Production of adequate supplies of food and fiber currently requires that pesticides be used to limit crop losses caused by insects, pathogens, weeds and other pests. Although pesticides are necessary in today's agriculture, they can be a serious problem if they reach and contaminate ground water, especially where drinking water needs are met by ground water.

The relative reduction of potential ground-water contamination due to agricultural use of pesticides was analyzed for particular sites in Utah. The potential reduction of pesticides in ground water was considered by utilizing alternative irrigation systems, water management practices and pesticides.

A one-dimensional simulation model, CMLS (Chemical Movement in Layered Soils), was utilized to simulate the movement of pesticides through soils. A hydraulic irrigation model (Kinematic-wave) was used to estimate water infiltration through the soil profile for alternative furrow lengths and inflow rates.

The study indicates that a reduction in the likelihood of ground-water contamination due to agricultural use of pesticides can be achieved with careful use of pesticides, efficient irrigation system designs and improved water management techniques.

INTRODUCTION

Production of adequate supplies of food and fiber currently requires that pesticides be used to limit crop losses from insects, pathogens, weeds and other pests. The term pesticide refers to a large number of chemical compounds. Pesticides include acaricides, fungicides, herbicides, insecticides, nematicides, algicides, antiseptics, arboricides and zoocides.

The Environmental Protection Agency (USEPA, 1987) reported that more than 45,000 registered products, manufactured from one or more of 1,400 chemical compounds, are used against weeds, plant diseases and pests attacking wildlife and food crops. Comparing these with earlier numbers, 34,500 registered products from 900 chemical compounds (USEPA 1972), an extraordinary increase in this activity is seen.

Pimentel and Levitan (1986) reported that use of pesticides, primarily synthetic organic pesticides, reaches almost 500 million kg in the United States each year. Of the total pesticides used, approximately 60 percent are herbicides, 24 percent insecticides and 16 percent fungicides. About 341 million kg of pesticides are used on agricultural land, 55 million kg on government and industrial lands, 4 million kg on forest lands and 55 million kg on household lands.

Pesticides are an integral and indispensable part of today's agriculture. Pimentel and Levitan (1986) concluded that for every $3 billion invested in the United States in controlling pests with pesticides about $12 billion is returned.

Zaki et al. (1982) found aldicarb, a carbamate pesticide, in ground water in Suffolk County, New York, in August 1979. The study showed that 13.5 percent of the 8,404 tested wells exceeded the state-recommended guidelines. Sum (1986) reported a USEPA finding that 17 pesticides have been detected in the ground water of 23 states. Concentrations range from a mere trace to several hundred parts per million. Lau and Mink (1987) reported that several essential wells were taken out of service on Oahu, Hawaii because of ground-water contamination by pesticides used in pineapple production and aviation fuels. Oki and Giambelluca (1987) concluded that the contamination of ground water by pesticides on Oahu is derived from nonpoint and/or point sources related to nematicide use in pineapple cultivation. Pionke et al. (1988) found atrazine contamination at extremely low concentrations in 14 of 20 wells tested in the Mahantango Creek watershed, Pennsylvania.

Ground-water contamination by pesticides, fertilizers or other organic or inorganic materials can be of great importance, especially in places where drinking water needs are supplied from ground water. Leonard et al. (1988) reported that ground water meets drinking needs of about 50 percent of the U.S. population. Waddell (1987) reported that

63 percent of Utah's population depends on ground water for its drinking water needs. Rural areas are almost totally dependent on ground water for domestic supply.

The risk of potential contamination of ground water by pesticides depends on different factors. Pesticide properties, soil, agricultural practices, plant uptake, hydrology, geology, climate and topography are important.

The major objective of this study is to determine the relative reduction of potential ground-water contamination due to agricultural use of pesticides for selected sites in Utah. The reduction of pesticides in ground water can be achieved by utilizing alternative pesticides and efficient water management techniques. Use of alternative irrigation systems, water management practices and pesticides is considered in this study.

By comparing the potential contamination results among different farming practices, " best management systems" (BMSs) can be selected for Utah. If best management systems are implemented, the likelihood of ground-water contamination can be minimized.

METHODOLOGY

Site Identification and Overview

Eisele et al. (1989) identified and ranked sites with potential hazards for ground-water contamination for all 29 counties in the state of Utah. They initially used a rapid screening procedure, DRASTIC (Aller et al., 1985), for ranking places that show a high risk for ground-water contamination by chemicals. Eisele et al. (1989) subsequently used a one-dimensional simulation model, CMLS (Nofziger and Hornsby, 1986, 1988), to simulate the movement of pesticides in unsaturated soils in locations of higher risk.

Based on the intensive study by Eisele et al. (1989), six crop areas with a greater potential for ground-water contamination located in different counties in Utah were chosen. The selected counties are: Cache, Davis, Sevier, Utah, Washington and Weber.

The potential for contamination depends on agricultural practices, pesticide characteristics and time of application, as well as soil profile characteristics. Thus, necessary data were obtained and computer simulations performed for alternative water management practices, pesticides and crops for each of the selected sites. Results were compared based on potentials for ground-water contamination. (The schematic representation of the procedure to estimate the potential existence of pesticides in soils is shown in Figure 1).

Pesticide Movement Simulation Using CMLS

CMLS was considered the most appropriate pesticide transport model for this study in terms of accuracy, simulation time, input data requirements and output data presentation (Eisele et al., 1989). Pesticide movement predictions given by the CMLS model are based on the following assumptions (Nofziger and Hornsby, 1986, 1988):

1. All soil water residing in pore spaces participates in the transportation process. If this assumption is not valid and a preferential flow is present, a portion of the soil water will be bypassed during flow, and the model will underestimate the depth of the chemical front.
2. Water entering the soil redistributes instantaneously to field capacity. This assumption is approached for coarse-textured soils.
3. Water is removed by evapotranspiration from each layer in the root zone in proportion to the relative amount of water available in that layer. A uniform root distribution is assumed. This assumption will not be strictly valid for many situations. More precise schemes for dealing with evapotranspiration would require information about the root distribution and the soil hydraulic properties.
4. Upward movement of soil water does not occur anywhere in the soil profile. Water is lost from the root zone by evapotranspiration and is not replenished from below.
5. The adsorption process can be described by a linear, reversible equilibrium model. If the sorption coefficient is described by non-linear isotherm, the partition coefficient decreases with increasing concentration of the chemical. Thus the depth to which the chemical will be leached will depend upon the concentration. This aspect is probably not significant for the concentration

range of interest in most agricultural applications. When adsorption equilibrium is not instantaneous, the chemical will be leached to a greater depth than predicted here. Irreversible sorption would result in less leaching.

6. The half-life time for biological degradation of the chemical is constant with time and soil depth. Degradation rate coefficients are dependent upon a variety of environmental factors, primarily temperature and soil-water content. Hence, seasonal changes in rate coefficients can be expected. Also, with decreasing microbial activity at greater soil depths, the degradation rate coefficient may decrease with depth. Sufficient data are not available to formulate mathematical relationships to describe these effects.

CMLS considers two processes: (a) the movement of the chemical and (b) the degradation of the chemical. In this model, chemicals move only in the liquid phase in response to soil-water movement. Water movement is calculated using a volume balance approach. It is assumed that at the beginning of the simulation, each layer in the soil profile is at field capacity. Water is considered available for plants if the water content in any layer of the root zone is above permanent wilting point as expressed by the following relationship:

$$AW(j) = t(j) * [(\theta(j) - \theta_{pwp}(j)] \qquad (1)$$

where AW(j) is the available water in the layer j (mm), t(j) is the thickness of the layer j (mm), $\theta(j)$ is the volumetric water content of layer j and $\theta_{pwp}(j)$ is the volumetric water content at permanent wilting point of layer j. The total available water, AW_{total}, in the root zone is the sum of the amounts of water available in each layer. If AW_{total} is greater than the evapotranspiration (ET_{crop}) for a day, the water content of each layer in the root zone is depleted in proportion to the amount of water available in that layer as expressed by the following equation:

$$\theta(j) = \theta'(j) - [ET_{crop} * AW(j)] / [AW_{total} * t(j)] \qquad (2)$$

where $\theta'(j)$ is the volumetric water content of the layer j prior to adjustment. If the total available water is less than the evapotranspiration demand all the layers in the root zone are assumed equal to

$$\theta(j) = \theta_{pwp}(j) \qquad (3)$$

Equation 3 assumes no effect of soil water content on ET when the volumetric water content of the soil is approaching wilting point. However, ET will decrease due to stress long before θ_{pwp} is reached.

When an infiltration event (irrigation and/or rain) occurs, the water content of each layer is adjusted, starting with the layer closest to the surface (j=1). The soil-water deficit for that layer is determined using the equation

$$swd(j) = t(j) * [\theta_{fc}(j) - \theta(j)] \qquad (4)$$

where swd(j) is the soil-water deficit of the layer j (mm) and

$\theta_{fc}(j)$ is the volumetric water content of the layer j at field capacity. If the infiltrating amount, I(j), is greater than swd(j), then

$$\theta(j) = \theta_{fc}(j) \tag{5}$$

$$I(j + 1) = I(j) - swd(j) \tag{6}$$

If I(j) is less than swd(j), then

$$\theta(j) = \theta'(j) + I(j) / t(j) \tag{7}$$

$$I(j + 1) = 0 \tag{8}$$

Chemicals are exposed to adsorption processes and therefore advance less far in depth than water. A linear and reversible equilibrium adsorption model simulates the retardation of the chemical movement. The following equations are used to predict chemical movement:

$$\text{if } W_p > 0, \qquad d_s - d'_s = W_p / (RF * \theta_{fc}) \tag{9}$$

$$\text{if } W_p \leq 0, \qquad d_s - d'_s = 0 \tag{10}$$

$$RF = 1 + BD * K_d / \theta_{fc} \tag{11}$$

$$K_d = K_{oc} * OC \tag{12}$$

where W_p is the amount of water passing the depth d_s (mm), d_s is solute front depth (mm), d'_s is the solute front depth prior to the adjustment (mm), RF is the retardation factor, θ_{fc} is the soil-water content on a volume basis at field capacity, BD is soil bulk density (g/cm^3), K_d is the partition coefficient of the chemical in soil (ml/g soil), K_{oc} is the organic carbon partition coefficient (ml/g OC) and OC is the organic carbon content of the soil (OC fraction).

Chemicals are continuously exposed to degradation processes in soil. The CMLS model predicts the relative amount (RA) as the fraction of the applied chemical remaining in the entire soil profile:

$$RA = \exp[-tr * \ln(2) / t_{1/2}] \qquad (13)$$

where tr is the travel time since the chemical was applied (days) and $t_{1/2}$ is the biological degradation half-life of the chemical (days).

The inputs to the CMLS model are soil properties (bulk density, water content at field capacity and permanent wilting point and soil organic carbon content); chemical properties of the pesticide (partition coefficient and degradation half-life); climatic and cultural factors (plant root depth, daily rainfall + irrigation and daily evapotranspiration amounts). Model outputs include, among others, travel time (tr) for chemicals to move to selected depths and relative amount (RA) of pesticide remaining in the soil profile at those times.

Kinematic-wave irrigation model (Walker and Humpherys, 1983) was used to estimate the average depth of water infiltrated in a soil profile along the length of furrows for different inflow rates (1, 1.25, 1.5, 1.75, 2 and 2.5 l/s) and furrow lengths (80, 100 and 125 m). Two furrow slopes (0.006 and 0.002 m/m) were simulated. These furrow slopes were assumed to avoid the possibility of soil erosion from the selected soil types and to ensure the applicability of the kinematic-wave model. A Kostiakov-Lewis infiltration function for an average sandy soil (similar to the six selected soils) was assumed. The required application depth, at the end of the furrow was assumed 0.045 m^3/m (45 mm) for all simulations. By using this assumption, the number of simulations (using both kinematic-wave and CMLS models) could be drastically reduced. From all these kinamatic-wave model simulations results for alternative furrow irrigation parameters, it was inferred that for furrow slope of 0.002 m/m, as the furrow length increased from 80 to 125 m, the water-storage efficiency decreased from 91 to 62 % for an inflow rate of 2.5 l/s and for an inflow rate of 1.25 l/s, water-storage efficiency further decreased from 50 to 18 % respectively. Similarly, for a given furrow length (e.g. 80 m), the water-storage efficiency increased from 18 to 91 % as the inflow rate increased from 1.25 to 2.5 l/s respectively. Similar results were obtained when a furrow slope of 0.006 m/m was simulated in the kinamatic-wave irrigation model.

RESULTS AND DISCUSSION

Alternative Water Management Practices

Reduction in potential pesticide contamination can be achieved by improving the efficiency of water application. Increased efficiency can be obtained by adequate land leveling (especially important in surface irrigation systems), by changing furrow inflow rates or furrow lengths in surface irrigation systems and by increasing the uniformity coefficient (UC) in sprinkler irrigation systems. Efficient control of the time of irrigation and an adequate irrigation schedule will increase efficiency in most systems. Figures 2 and 3 indicate the influence of the irrigation water-storage efficiency on the relative amount of selected pesticides remaining in the soil profile.

Figure 2 shows an abrupt effect of water-storage efficiency on relative amounts (RA) of atrazine remaining in the soil when water-storage efficiency changes from 40 to 30 percent. This effect is related mainly to pesticide and soil characteristics.

Figure 3 depicts that low values of water-storage irrigation efficiency influence pesticides having lower K_{oc} values (metribuzin: K_{oc} = 41 ml/g OC) than pesticides having higher K_{oc} values (chlorpyrifos: K_{oc} = 6070 ml/g OC) for the same degradation half-life ($t_{1/2}$ = 30 days).

Alternative Furrow Irrigation Systems.

Irrigation system design can be critical in determining the amount of pesticide leaching in agricultural areas. With appropriate furrow system design, pesticide leaching can be reduced appreciably in relation to pesticides and sites characteristics. For example, Figures 4 and 5 depict a range of reduction between 10 to 90 percent in RA values. This reduction in RA values is attributed to the fact that as the furrow length decreases and/or the inflow rate increases, lesser amount of irrigation water is infiltrated to a depth of 2 meters or deeper, hence, lesser leaching of pesticides to ground water. Figure 4 shows decreasing RA values of carbofuran and hexazinone with decreasing furrow lengths. If the length of the furrow cannot be decreased, a significant reduction in RA values for these pesticides and site characteristics can be obtained by increased flow rates at the head of the furrow (Figure 5). Furrows that are too long and/or irrigated with small inflow rates will increase leaching of pesticide, particularly for the coarse textured soils considered in this study.

Sensitivity Analyses

Physical properties of soils and irrigation system design parameters were treated as variables for a sensitivity analysis. The results from this analysis are presented as follows:

Soil

Soils with high clay and organic carbon content have a tendency to adsorb pesticides to a great extent, thus, minimizing the risk of ground-water contamination. Pesticides require more travel time when moving through heavy soils (e.g. clay) with higher water content at field capacity, than through lighter soils (e.g. sand) with lower water content at field capacity. The travel time, in turn, determines the time available for pesticide attenuation via chemical and biological processes. Figures 6 and 7 clearly indicate the change in RA resulting from different soil textures. Figure 6 shows approximately 80 percent reduction in RA values when a silty clay soil is compared to a sandy soil. Differences in texture, organic carbon and water contents are the principal contributors to this contrast.

Furrow Irrigation

Values of depth of infiltrated water in every 10 percent increment of furrow length were obtained from the kinematic-wave model. Assumed is a 125 m long furrow on sandy soil with an inflow rate of 1.25 l/s at the furrow head. By using these furrow irrigation parameters, the kinametic-wave model predicts an average depth of 259 mm of the applied water. This furrow irrigation system is assumed because it yields the least uniform deep percolation and the greater variation in RA values among the considered alternative furrow irrigation parameters.

Table 1 shows the RA values predicted by CMLS results for these 10 infiltration depths and the average of those values. Table 1 also presents the RA values computed if only an average infiltration depth (259 mm) is used. The comparison shows that the average RA values for 10 incremental areas are about the same as RA values obtained when the average infiltration depth of 259 mm was simulated.

Selection of inflow rate and furrow length depends on site-specific water management practices. In the selection process, it is helpful to consider an efficiency criteria (such as that discussed in the methodology) that quantifies hydraulic performances. It is also beneficial if, in the selection process, the environmental impacts of using a particular irrigation water management alternative are estimated. Knowing that efficient water management practice greatly reduces pesticide leaching beyond the root zone, the farmer may decide to use a combination of improved irrigation management and alternative pesticides that have less hazardous environmental effects.

SUMMARY

The effects of irrigation water-storage efficiencies, furrow irrigation system design and soil types on pesticide leaching were studied. It was observed that the water-storage efficiency is an important factor in the leaching down of pesticides. Water-storage efficiencies do not affect the movement of pesticides in the same way.

Pesticides with K_{oc} smaller than 200 ml/g and half-life greater than 10 days present higher risk for potential ground-water contamination for water-storage efficiencies smaller than 50 percent.

Furrow irrigation system design and management are also important. Increasing flow rates at the head of the furrow or decreasing furrow length (within the acceptable design specifications) reduces the leaching of pesticides and the risk of potential ground-water contamination.

Study on pesticides leaching through different soil textures revealed upto 80 % reduction in RA values in silty clay soils as compared to sandy soils.

Environmental impacts should be considered when selecting from alternative pesticides to prevent ground-water contamination and unnecessary losses of pesticides.

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TABLE 1. Pesticide Movement Comparison Under Furrow Irrigation.

No	PESTICIDE NAME	AREA %	d (mm)	RELATIVE AMOUNT REMAINING 1.0 m	1.5 m	2.0 m	3.0 m
1	ALDICARB	10	302	0.3455	0.3455	0.2679	0.2679
2	ALDICARB	10	302	0.3455	0.2679	0.2679	0.2679
3	ALDICARB	10	302	0.3455	0.3455	0.2679	0.2679
4	ALDICARB	10	299	0.3455	0.3455	0.2679	0.2679
5	ALDICARB	10	292	0.3455	0.3455	0.2679	0.1984
6	ALDICARB	10	283	0.3455	0.3455	0.2679	0.1984
7	ALDICARB	10	267	0.3455	0.3455	0.2679	0.1984
8	ALDICARB	10	239	0.3455	0.2679	0.2679	0.1984
9	ALDICARB	10	193	0.3455	0.2679	0.1984	0.1649
10	ALDICARB	10	111	0.2679	0.1649	0.1371	0.0005
10	SUBAREAS AVERAGE		259	0.3377	0.3042	0.2479	0.1763
	ALDICARB	100	259	0.3455	0.3455	0.2679	0.1984

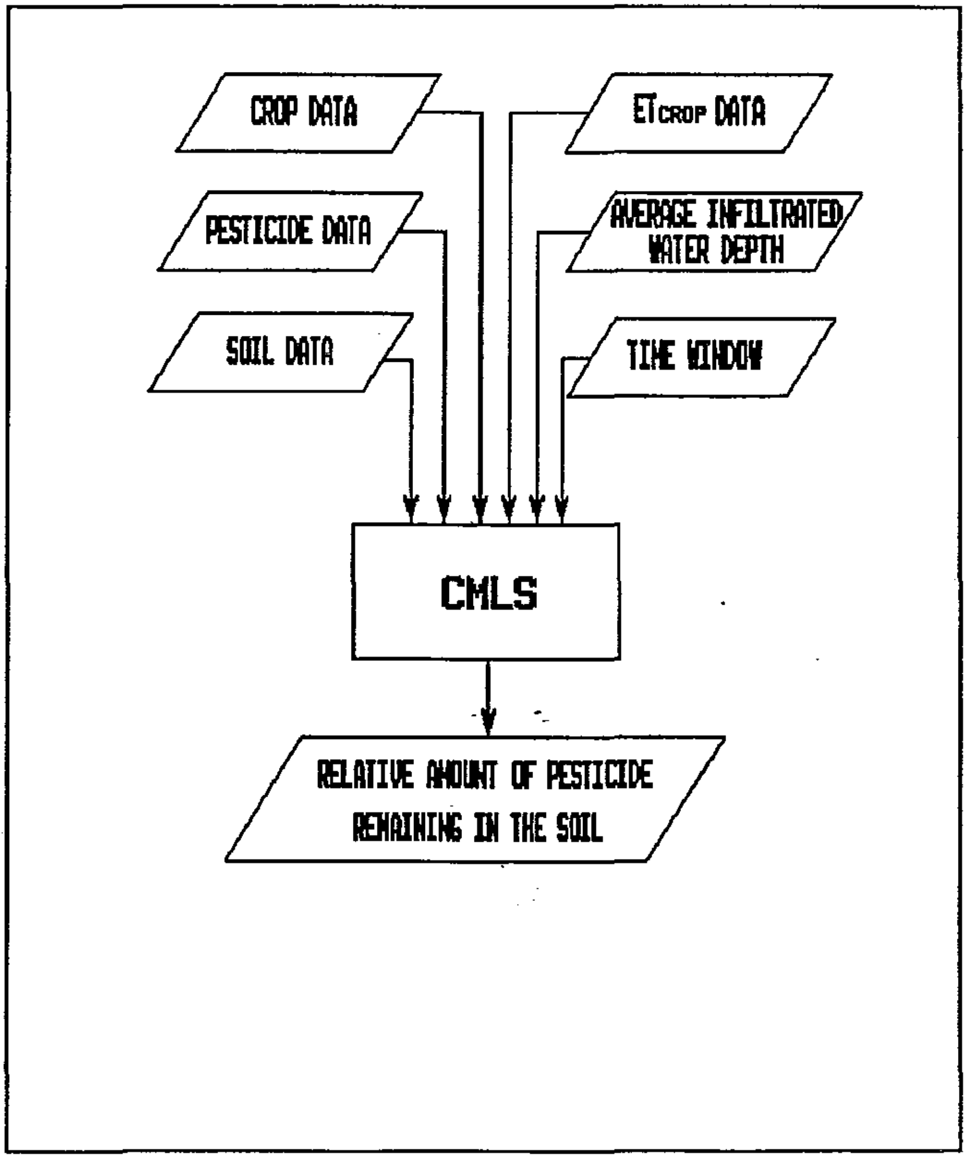

Figure 1: Schematic Representation of the Procedure to Estimate Relative Amount (RA) of Pesticides Remaining in the Soil.

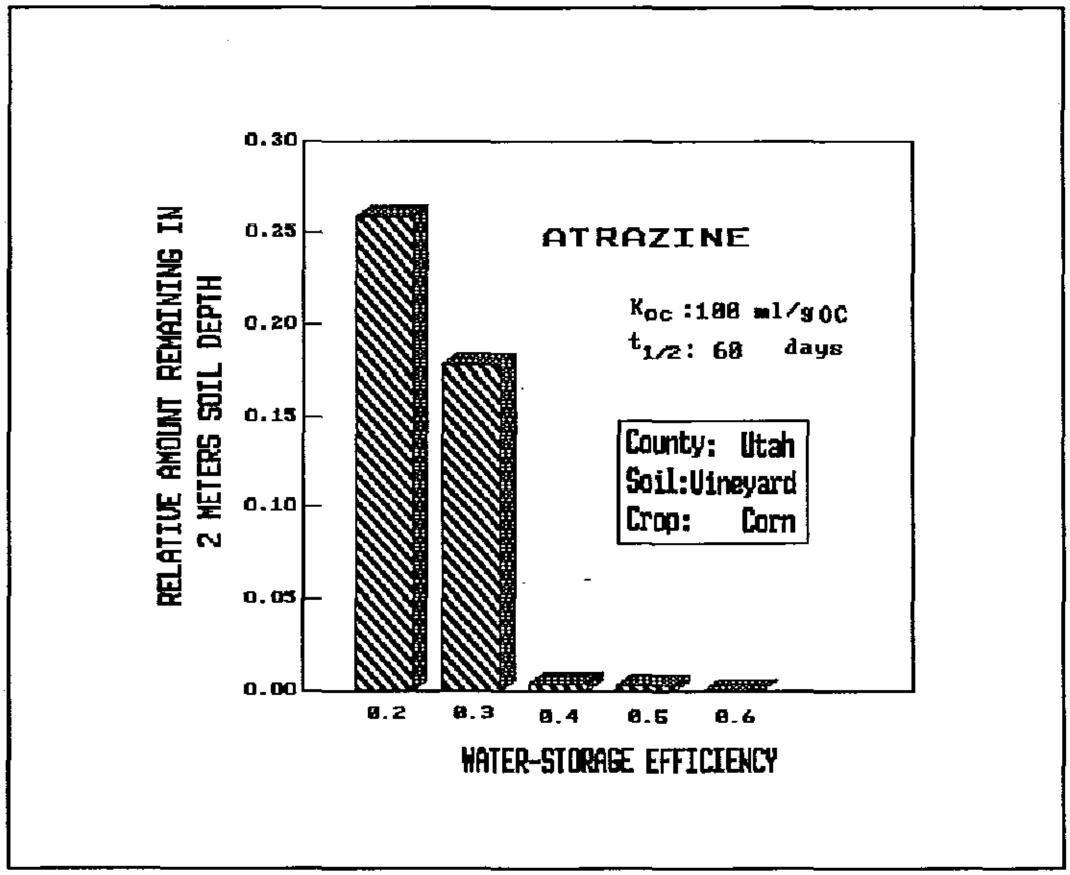

Figure 2: Effect on Relative Amount of Atrazine Remaining in the Soil when the Herbicide Reaches to a Depth of 2 Meters for Various Water-Storage Efficiencies.

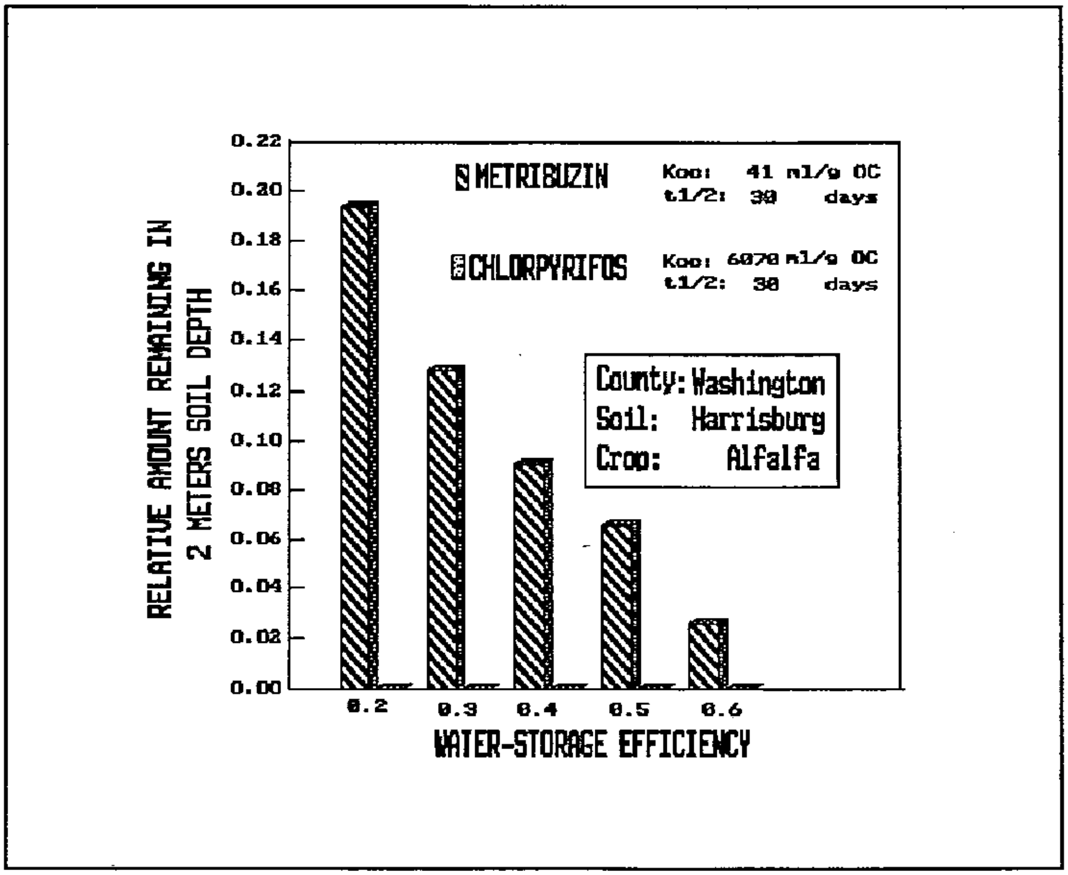

Figure 3: Effect on Relative Amount of Pesticides Remaining in the Soil when They Reach to a Depth of 2 Meters for Various Surface Irrigation Efficiencies.

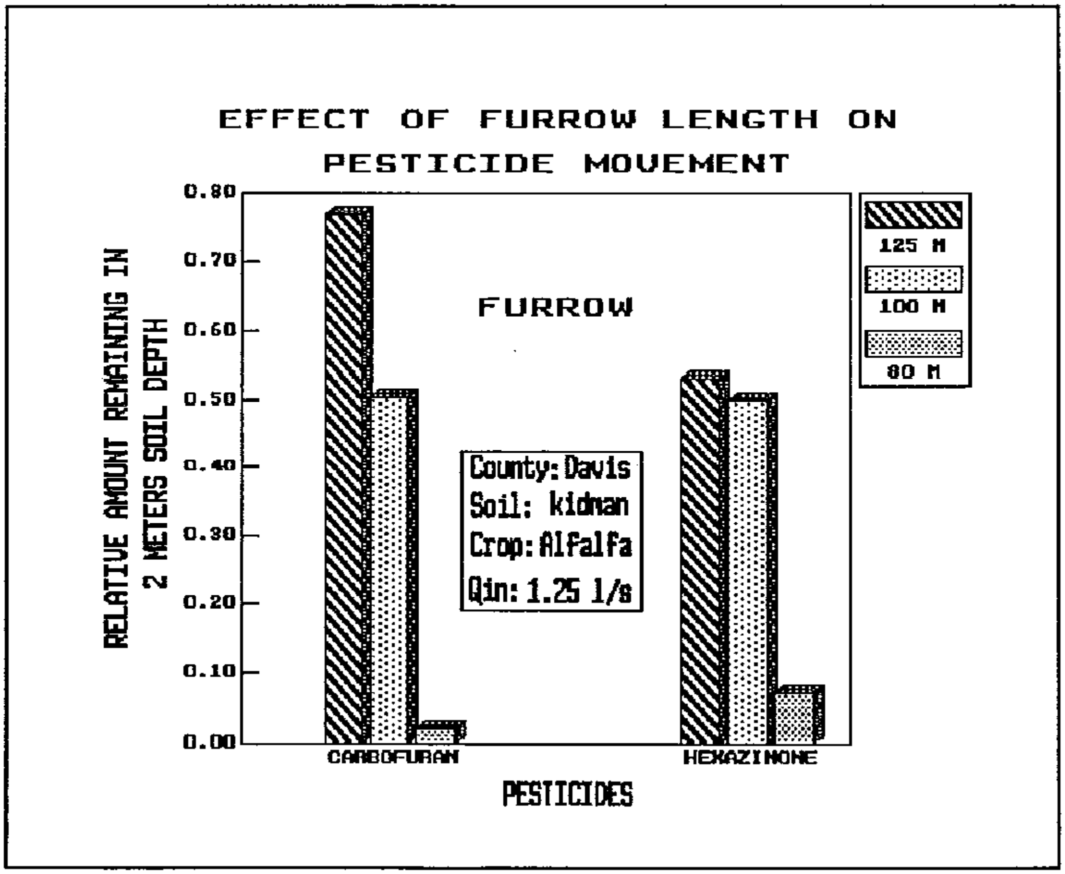

Figure 4: Effect of Furrow Lengths on Relative Amount of Pesticides Remaining in the Soil when They Reach to a Depth of 2 Meters.

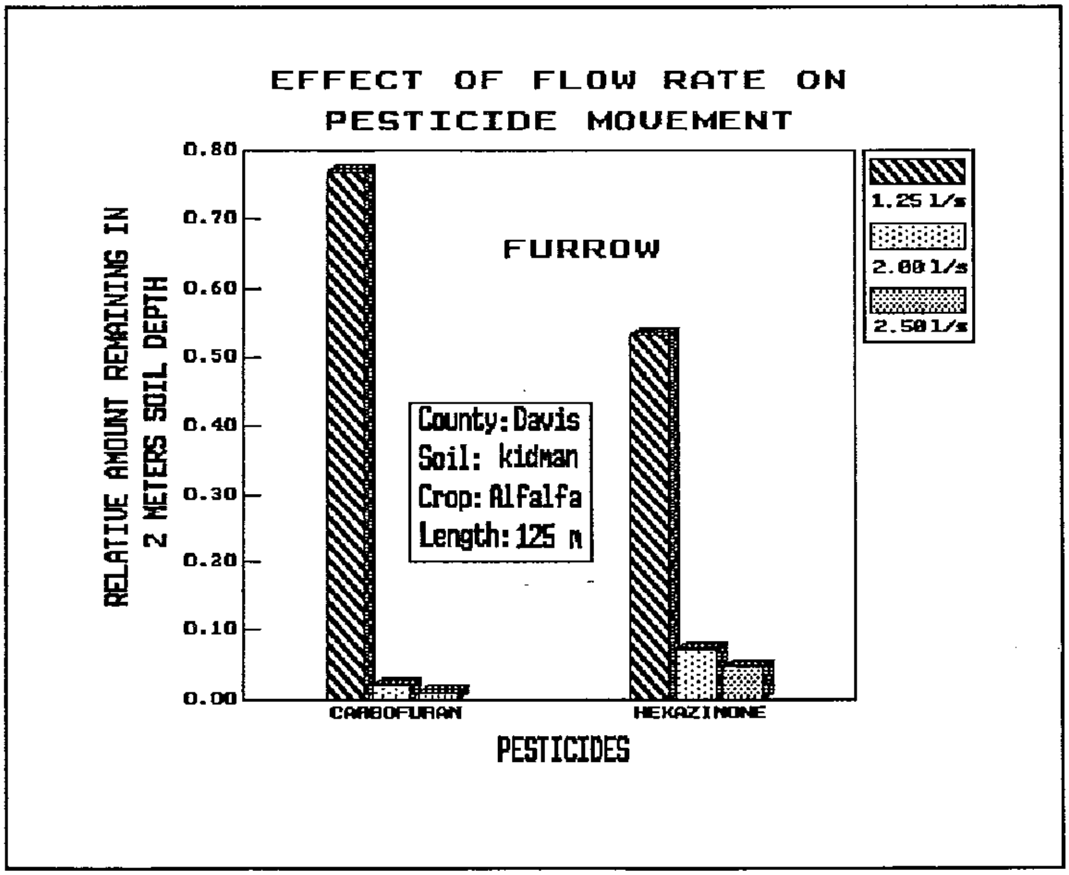

Figure 5: Effect on Relative Amount of Pesticides Remaining in the Soil when They Reach to a Depth of 2 Meters for Various Inflows Rates (Q_{in}) to the Furrow Head.

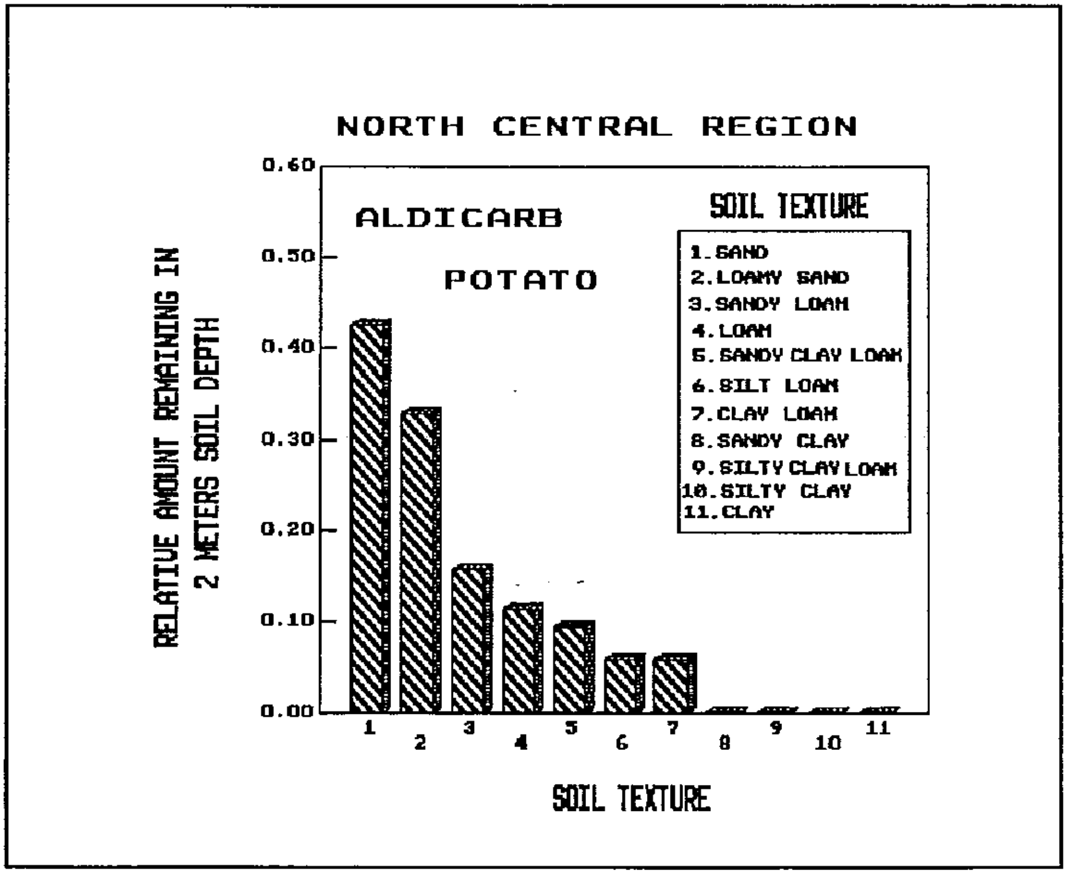

Figure 6: Effect of Various Soil Textures on Relative Amount of Aldicarb Remaining in the Soil when It Reaches to a Depth of 2 Meters.

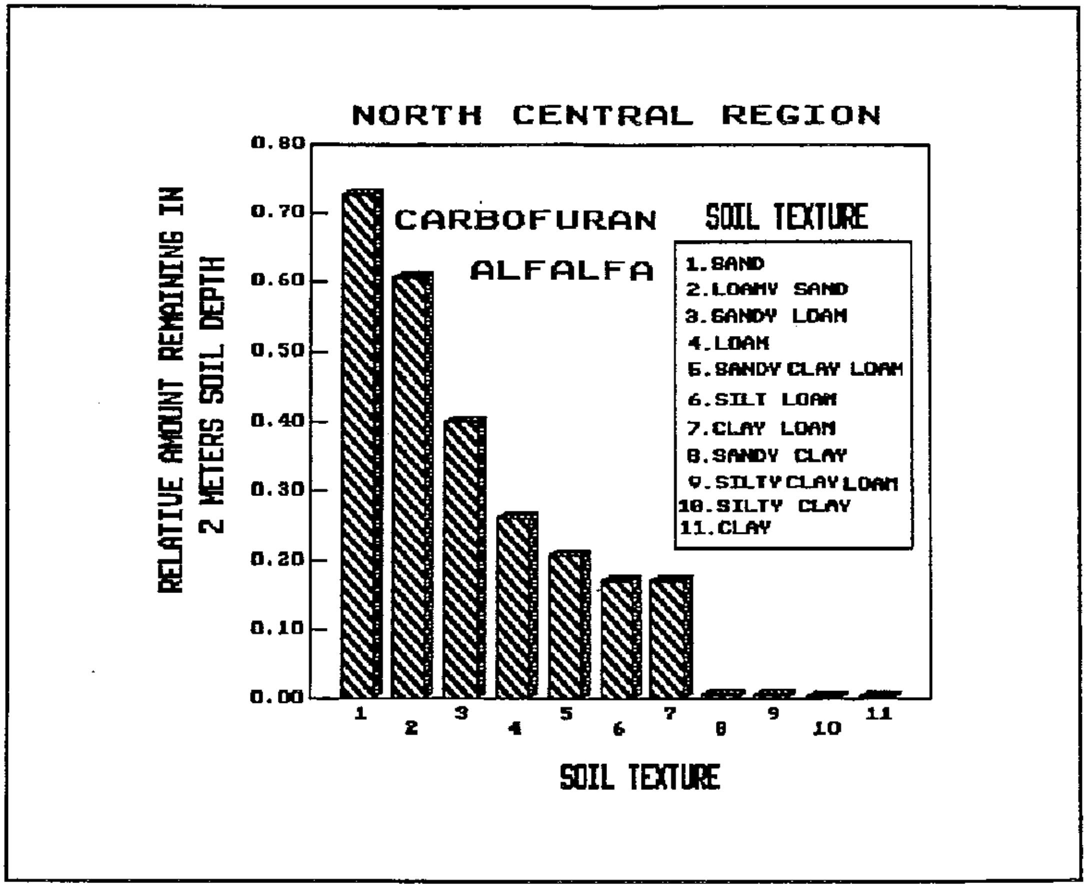

Figure 7: Effect of Various Soil Textures on Relative Amount of Carbofuran Remaining in the Soil when It Reaches to a Depth of 2 Meters.