

EFFECTS OF IRRIGATION RATE ON PESTICIDE AND NITROGEN LEACHING

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MOVEMENT PROCESSES

There are two basic processes by which pesticides and nutrients move through soils and in groundwater. These processes are diffusion and mass flow. Rate of movement by the process of diffusion is described by a "diffusion coefficient", (D), which has units of length squared. The larger the diffusion coefficient is, the greater the rate of movement by this process will be. Volatile pesticides and other organic chemicals such as industrial solvents move readily in the soils' air by diffusion. Anhydrous ammonia injected into soil as a fertilizer is lost to the atmosphere unless precautions are taken to reduce its movement.

The principal process of movement of pesticides and nutrients in soils and groundwater is mass flow. Dissolved constituents in water move through the soil matrix with the water. Water is the carrier of the contaminants. The rate of movement by the process of mass flow is described as the "flux" (v) which has units of length per unit area per time, for example: in/in²/hr or in/hr.

Both diffusion and mass flow processes are affected by properties of the contaminants, soil, aquifer and intermediate vadose zone (that area between the bottom of the root zone and groundwater table where both water and air occur in the soil pores). They are also affected by climatological factors, vegetation patterns, and irrigation practices. Properties of pesticides and nutrients that determine their movement and threat to water quality include: water solubility, tendency to adhere to soil materials, persistency, and toxicity. Properties of the porous media (soil, intermediate vadose zone, and aquifer) that affect rate of contaminant movement include: infiltration characteristics, pore size distribution, microbial population density and diversity, organic matter content, total porosity, ion exchange capacity, hydraulic properties, pH, and oxygen status.

Climatic factors include: temperature, wind speed, solar radiation, and frequency, intensity, and duration of rainfall. Vegetation may act as a sink for contaminants by uptake and/or assimilation, thus reducing the amount of contaminant available to be transported to groundwater. The geohydrology of the area also strongly affects these transport processes. Irrigation management (application rate and duration) also can cause excessive leaching if not matched to the soil-water deficit. All of these properties interact to determine the rate and amount of movement of contaminants in soils and groundwater.

PESTICIDES

Pesticide losses from areas of application and contamination of non-target sites such as surface- and ground-water represent a monetary loss to the farmer as well as a threat to the environment. Thus, careful management of pesticides in order to avoid environmental contamination is desired by both farmers and the general public.

Pathways of Pesticide Loss

There are four pathways by which properly-applied pesticides may dissipate from the application site. They are vaporization (volatilization) into the atmosphere, removal in the harvested plant, runoff and leaching. Runoff is the physical transport of pollutants overland by water or eroded soil caused by precipitation or irrigation which does not penetrate the soil. Leaching is a process whereby pollutants are flushed through the soil by rain or irrigation water that infiltrate the soil. In many areas of Florida, where soils are sandy and permeable, leaching is likely to be a more serious problem than runoff. We now have technology to help estimate the potential contamination of water from a given pesticide. To understand this technology, it is necessary to know how a pesticide behaves in soil and water.

Once applied to cropland, a number of things may happen to a pesticide. It may be taken up by plants or ingested and metabolized by animals, insects, worms, or microorganisms in the soil. It may move downward in the soil and either adhere to soil particles or dissolve. The pesticide may vaporize and enter the atmosphere, or break down via microbial and chemical pathways into other, less toxic compounds. Pesticides may be leached out of the root zone or washed off the surface of land by rain or excess irrigation water. In addition to the mass flow components controlled by climate and the water holding properties of the soil, the fate of a pesticide applied to soil depends largely on two of its properties: persistence and sorption.

Persistence

Persistence defines the duration and activity of a pesticide. Most pesticides degrade or become inactivated over time as a result of several chemical and microbiological reactions in soils. Sunlight breaks down some pesticides. Generally, chemical pathways result in only partial deactivation of pesticides, whereas soil microorganisms can completely break down many pesticides to carbon dioxide, water and other inorganic constituents. Some pesticides produce intermediate substances, called metabolites, as they degrade. The biological activity of these substances may also have environmental significance. Because populations of microbes decrease rapidly below the root zone, most pesticides leached beyond this depth are expected to degrade at much slower rates. However, some pesticides will continue to degrade by chemical reactions after they have left the root zone.

Persistence is expressed as a half-life. Half-life is the amount of time it takes for one-half the original amount of a pesticide applied to be deactivated in the soil. Half-life is sometimes defined as the time required for half the amount of applied pesticide to be completely degraded and released as carbon dioxide and water. Usually, the degradation half-life of a pesticide measured by the latter basis is longer than that based on deactivation only. This is especially true if toxic or non-toxic metabolites accumulate in the soil during the degradation process. Table 1 groups some of the pesticides used in agriculture by persistency, $T_{1/2}$, on the basis of their deactivation in surface soils. $T_{1/2}$ values in subsoils and in groundwater are usually larger. Thus, as pesticides are leached below the soil, their persistency increases. Likewise, persistency is affected by soil temperatures with increasing temperatures causing a reduction in $T_{1/2}$. Values for pesticide degradation, $T_{1/2}$, in subsoils and groundwater are scarce.

Sorption

Probably the single most important property influencing a pesticide's movement with water is its sorptivity to soil materials. When a pesticide enters soil, some of it will stick to soil particles, particularly organic matter, through a process called sorption and some will dissolve and mix with the water between soil particles, called "soil-water." As more water enters the soil through rainfall or irrigation, the solubilized pesticides will move down and the sorbed pesticide molecules may enter soil-water through a process called desorption. The relationship between water flow, sorption and desorption is a dynamic process. The solubility of a pesticide and its sorption on soil are generally inversely related; that is, increased solubility results in less sorption.

One of the most useful indices for quantifying pesticide sorption on soils is the partition coefficient (K_{oc}). The K_{oc} value is defined as the ratio of pesticide concentration bound to soil organic matter particles to that dissolved in the soil-water. Thus, for a given pesticide application, the smaller the K_{oc} value is, the greater the concentration of pesticide in soil water will be. Pesticides with small K_{oc} values are more likely to be leached compared to those with large K_{oc} values.

The partition coefficient can be used to estimate a pesticide's probability of being lost via runoff or leaching in a specific soil, via the formula:

$$K_p = K_{oc}(\%OM)(0.0058)$$

where K_p is the index for sorption of a given pesticide on a particular soil, % OM is the percent of organic matter in the soil, as determined by chemical analysis of the soil, and where K_{oc} is the partition coefficient.

Five important aspects of pesticide sorption by soils should be recognized:

For pesticides not adsorbed by soils, K_{oc} is equal to zero (or $K_p = 0$). Thus, such pesticides will move with the water and leach in a manner similar to inorganic ions such as nitrate which are also not adsorbed by most soils.

For a given pesticide, sorption is greater in soils with larger organic matter contents (% OM). Thus, pesticide leaching in soils with higher %OM is expected to be slower compared to soils low in organic matter.

In most soils %OM decreases rapidly with increasing depth. Thus, pesticide sorption decreases with increasing soil depth, and, as a consequence, leaching is likely to be more rapid in subsoils.

For a given soil, pesticides with smaller K_{oc} values are sorbed to a lesser extent, and are therefore more likely to be leached than pesticides having larger K_{oc} values.

For a given soil, pesticides with larger K_{oc} values are sorbed to a greater extent, and, when surface applied, are therefore more likely to be lost in surface runoff than pesticides having lower K_{oc} values.

NITROGEN

There are four major factors that affect the behavior of nitrogen in the environment and subsequently their potential to contaminate drinking water supplies. These factors include: 1) the amount and forms of nitrogen entering the soil; 2) the soils that overlie the aquifers; 3) assimilation of N by plants, microbes, and other soil organisms; and 4) local climatic conditions and irrigation practices. These factors interact to determine the fate of applied nitrogen fertilizers, animal wastes, sewage sludge and septage.

Characteristics of Nitrogen Fertilizers

The most common forms of N in fertilizers are (1) ammonium, (2) nitrate, (3) urea, and (4) natural organics. The aqueous solubility of ammonium and nitrate salts and urea are very high (70 -118g/100g water). These compounds are readily dissolved due to their high aqueous solubility. Moist soil conditions and rainfall and irrigations events solubilize these fertilizer materials. Organic forms of N contained in manure, sludge, septage and plant residues are usually less readily soluble in water. The complex N-compounds in such materials must be mineralized before the N can be taken up by plants. Organic N must be mineralized by a series of biological processes. The rates of transformation depends on soil moisture content, temperature, and microbial activity. The rate also greatly depends on environmental conditions. For example, decomposition is so slow under flooded (anaerobic) conditions that organic matter frequently accumulates.

Nitrogen can be lost from the soil by various pathways, some of which reduce the potential for nitrate to contaminate groundwater. Pathways of loss include plant uptake, microbial metabolism, leaching, and volatilization of ammonia, N_2 , NO, and N_2O as gases to the atmosphere. Nitrate-N is by far the most prevalent form of nitrogen leached below the plant root zone and into groundwater supplies. Nitrate-N is an anion, is very soluble in water and has an equivalent partition coefficient of 0 indicating that it will move with the water front as water infiltrates through the soil surface.

The Role of Soils in Nitrogen Transport

Soils are the medium in which we grow most of our crops. Soils provide a reservoir for nutrients, water, and microbes that are necessary for economic production of crops. Soils differ in their capacities to retain water and N and, thus, must be managed differently to maximize production and minimize water and nutrient leaching. Deep sandy soils require more frequent water and nutrient applications due to their very limited capacity to retain these inputs. Excessive leaching is the rule rather than the exception, unless very careful management practices are followed. No soil will retain heavy, continuous applications of N exceeding the crop requirement. Thus, high NO_3 leaching potentials occur under these conditions.

Poorly drained soils, on the other hand, may require artificial drainage to be productive. Leaching to groundwater may occur if confining layers are discontinuous or if drainage or irrigation ditches are cut through the confining layer. Nitrogen in surface discharges of drainage water is assimilated in the biota of drainage ditches, streams, and lakes. If the N loads are excessive, this may lead to eutrophication of these receiving streams. Medium and heavy textured soils and organic soils have good water and N retention capacities; nevertheless, careful management of water and N application practices is necessary.

The Effects of Climate and Irrigation on Nitrogen Leaching

Rainfall is dissipated by stream flows and groundwater recharge. The rainfall patterns vary with season in different regions of the state. Even in areas with ample annual rainfall, drought can occur causing production losses or failure unless irrigation is used. Soils with poor water retention capacity also may require frequent irrigation. Managing the soil-water deficit to prevent plant water stress and excess leaching of nutrients from the root zone is an onerous task in these soils. Management practices to reduce groundwater contamination must be based on a good understanding of the water-holding capacity of the soil in the production unit, good estimation of soil-water deficits, and irrigation systems that can deliver more precisely the amount of water required to replenish the soil-water deficit.

Nitrate Contamination of Aquifers

The nitrate ion is very soluble and mobile in water. Forms of N fertilizer other than nitrate are transformed readily into nitrate and, thus, become subject to leaching to groundwater. Other forms of nitrogen fertilizers are seldom found in aquifers. Studies indicate that such conversion can take place within 30 days in the warm, moist soils. Soluble nutrients are carried with the water through soils. Excessive rainfall and/or irrigation will tend to leach N below the root zone, and ultimately to groundwater. This results in both an economic loss of N and deterioration of water quality in drinking water supplies. For these reasons N and water management practices must be jointly considered. Soil testing for residual soil nitrogen, crop nutrient requirement, realistic yield goals, and irrigation efficiency are concepts that must be integrated to develop a crop production system that avoids excessive N leaching.

EFFECT OF IRRIGATION APPLICATION RATE

Leaching of pesticides and nitrogen fertilizers due to irrigation can be controlled by proper matching of application rate and duration to soil water-holding properties. The water-holding capacity of soil is determined by the pore-size distribution of soil particles. The United States Department of Agriculture/Soil Conservation Service has developed information for all of the soils in Florida and published it in their Florida Irrigation Guide. This manual lists the available water capacity by depth for soils listed in county soil surveys.

The available water capacity is the amount of water held in soil between "field capacity water content" and "permanent wilting percent water content". Following a rain or an irrigation event, plants transpire water that they remove from the soil root zone. As plants transpire, a "soil-water deficit" occurs in the root zone. When the deficit approaches 60-80 percent it is necessary to irrigate to avoid plant water stress. If irrigation amount is matched to the soil moisture deficit, leaching of pesticides and nutrients below the root zone is avoided. If excess irrigation amounts are applied then they are leached below the rootzone and are lost from the production system and may contribute to groundwater contamination.

The effect of irrigation application rate and duration on pesticide leaching in ridge and flatwoods soils can be illustrated using a software package entitled "Chemical Movement in Layered Soil". The water-holding capacity for a Astatula fine sand is 1.95 inches per 48 inch depth, or 0.04"/", and for a Chobee fine sandy loam it is 11.26 inches per 30 inches, or .38"/". The Chobee soil has 9.5 times greater water holding capacity than the Astatula soil in the top 30 inches of soil.

Figure 1A shows the leaching of Direx and Solicam (registered products) in the Astatula soil under normal rainfall. Figure 1B shows the effect of irrigation application of 1.2 inches weekly when less than one inch of rainfall was received. Under the 1984 rainfall conditions, Direx leached to only 11 inches in that season, whereas Solicam leached to about 30 inches. With supplemental irrigation, these products leached four times deeper in this soil. Using supplemental irrigation only when 60 percent of available soil water was depleted to replenish the deficit (1.17") results in more leaching than by rainfall alone but much less than weekly irrigation at 1.2" without regard to soil moisture deficit status (Figure 1C).

Figure 2 shows the depths of leaching of Direx and Solicam in a Chobee soil for two irrigation application rates. The greater water-holding capacity and organic matter content greatly reduces pesticide leaching in this soil. Figure 2A shows that neither product leaches deeper than about 3 inches. With 1.2 inches of supplemental irrigation applied weekly (Figure 2B) some additional leaching occurred, however neither leached below about 5 inches over the season.

These figures illustrate the extremes among soils in Florida that are used for citrus production. Most citrus soils would lie between these extremes. Particular care should be taken when irrigating the deep sandy ridge soils to avoid excessive leaching of nutrients and pesticides. This can only be done by matching application amount to soil-water deficit.

Table 1. Sorption Coefficients, K_{oc} , and Degradation Half-lives, $T_{1/2}$, of Pesticides used in Citrus Production. Data from the SCS/ARS Pesticide Database 1/.

Trade Name	Common Name	K_{oc}	$T_{1/2}$
Herbicides			
Caliber 90	simazine	130	60
Casoron	dichlobenil	224	60
Devrinol	napropamide	700	70
Direx	diuron	480	90
Dual	metolachlor	200	20
Eptam	EPTC	200	6
Evik	ametryn	300	60
Fusilade 2000	fluazifop-P-butyl	5,700	15
Goal	oxyfluorfen	100,000	35
Gramozone	paraquat	100,000	1000
Hyvar X	bromacil	32	60
Karmex	diuron	480	90
Krovar II(M)*	diuron	480	90
Krovar II(M)	bromacil	32	60
Krovar I(M)	diuron	480	90
Krovar I(M)	bromacil	32	60
Poast	sethoxydim	50f(pH)**	20
Roundup	glyphosate	24,000	47
Sinbar	terbacil	55	120
Soilcam	norflurazon	248	90
Surflan	trifluralin	8,000	60
Weedone MCPA	MCPA	20f(pH)	14
Insecticides and Miticides			
Acraben	chlorobenzilate	17,000	20
Carzol SP	formetanate HCl	100,000	100
Comite	propargite	8,000	56
Cygon, Dimethoate	dimethoate	20	7
Cythion	malathion	1,800	1
Diazinon	diazinon	500	40
Dicofol, Kelthane	dicofol	8,000,000	60
Ethion	ethion	8,900	90
Guthion	azinophos methyl	1,000	40
Lannate, Nudrin	methomyl	72	33
Logic	fenoxycarb	1,000	1
Lorsban	chlorpyrifos	6,070	30
Malathion	malathion	1,800	1
Metasystox-R	oxydemeton-methyl	1	10
Morestan	oxythioquinox	5,000	20
Orthene	acephate	2	3
Parathion	parathion	5,000	14
Plictran	cyhexatin	1,380	180
Rotate	bendiocarb	400	7
Sevin	carbaryl	200	10
Supracide	methidathion	400	21
Systox	demeton	460	30

Continued ---

Table 1 Continued.

Trade Name	Common Name	K _{oc}	T _{1/2}
<u>Nematicides</u>			
Brom-O-Gas	methyl bromide	22	55
Dowfume MC2	methyl bromide	22	55
Methyl Bromide	methyl bromide	22	55
Nemacur	fenamiphos	200	20
Mocap	ethoprop	70	25
Telone II	1,3-dichloropropene	32	10
Telone C-17(M)	1,3-dichloropropene	32	10
Telone C-17(M)	chloropicrin	82	2
Temik	aldicarb	30	30
Terr-O-Gas(M)	methyl bromide	22	55
Terr-O-Gas(M)	chloropicrin	82	2
Vapam	metham-sodium	100	3
Vorlex(M)	M.I.T.	10	7
Vorlex(M)	1,3-dichloropropene	32	10
Vorlex 201(M)	M.I.T.	10	7
Vorlex 201(M)	chloropicrin	82	2
Vorlex 201(M)	chlorinated C ₃ compounds	nd***	nd
Vydate	oxamyl	25	4
<u>Fungicides</u>			
Aliette	fosetyl-Al	20	1
Benlate	benomyl	1900	240
Captan	captan	100	2.5
Difolatan, Sanspor	captafol	3,600	20
Ferbam	carbamate	300	17
Orthocide	captan	100	2.5
Phaltan, Thiophal	folpet	5,000	20
Ridomil	metalaxyl	100	70
TZB	thiabendazole	nd	nd

1/ SCS/ARS Pesticide Database, version 2.0 (D. Wauchope, USDA/ARS Tifton, Ga. personal communication).

* (M) indicates that the product is a mixture and that each active ingredient must be considered.

** f(pH) indicates that the K_{oc} value varies with pH.

*** nd indicates that no data are available for this active ingredient

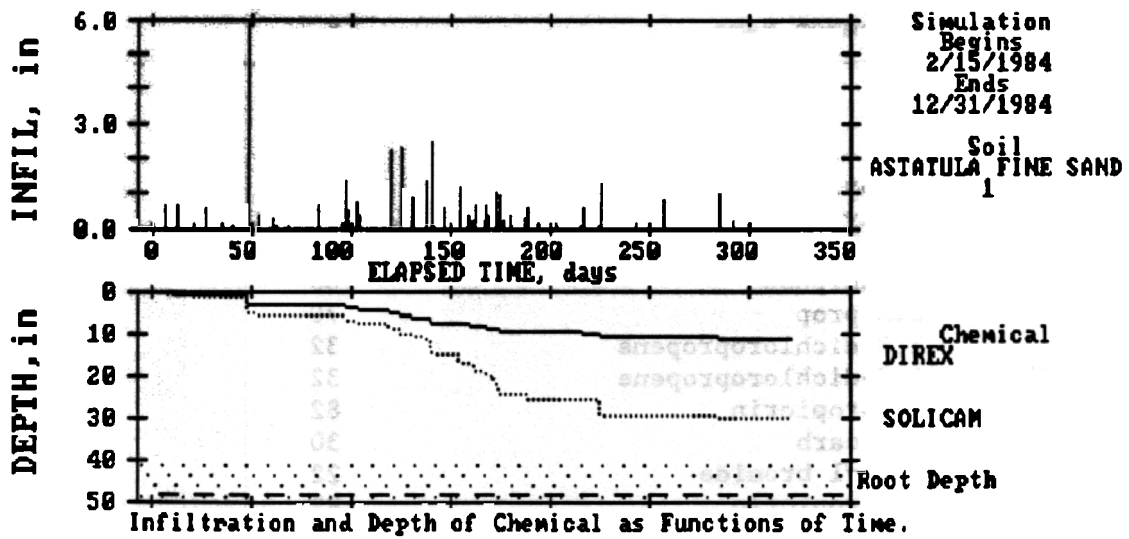


Figure 1A Leaching of Direx and Solicam in an Astatula soil under 1984 rainfall conditions.

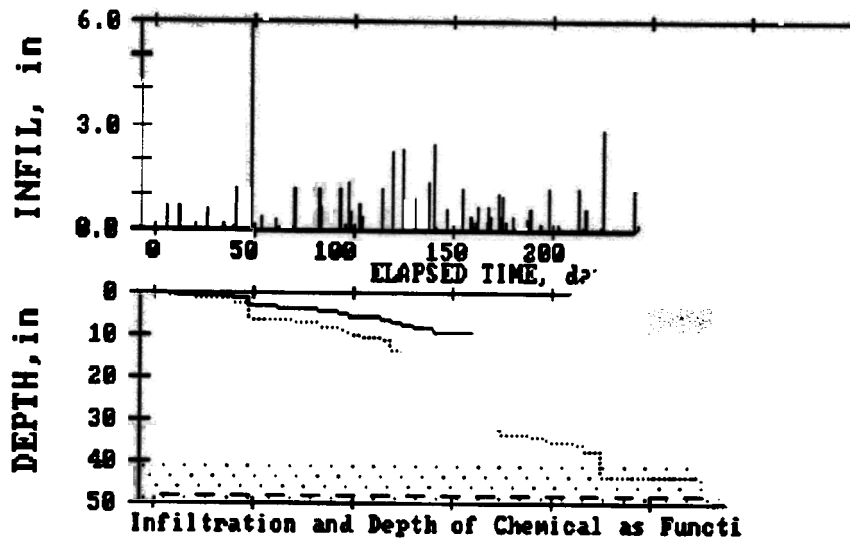


Figure 1B. Leaching of Direx and Solicam in an Astatula soil under 1984 rainfall conditions and 1.2 inches per week supplemental irrigation except when rainfall amount was greater than or equal to 1.0 inch.

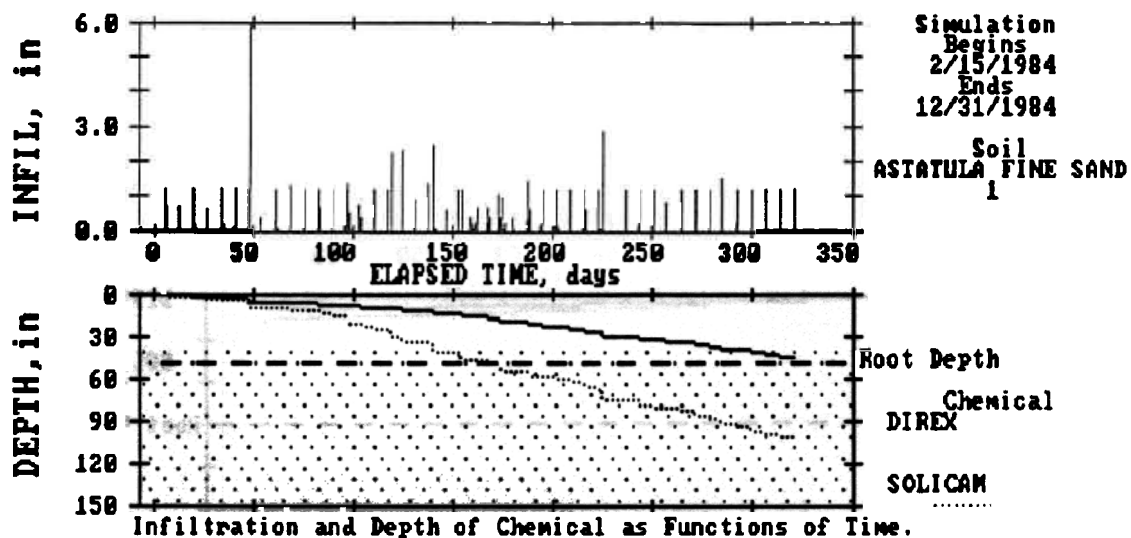


Figure 1C. Leaching of Direx and Solicam in an Astatula soil under 1984 rainfall conditions and 1.17 inches supplemental irrigation applied each day that the soil-water deficit equaled or exceeded 60 percent of the available water capacity.

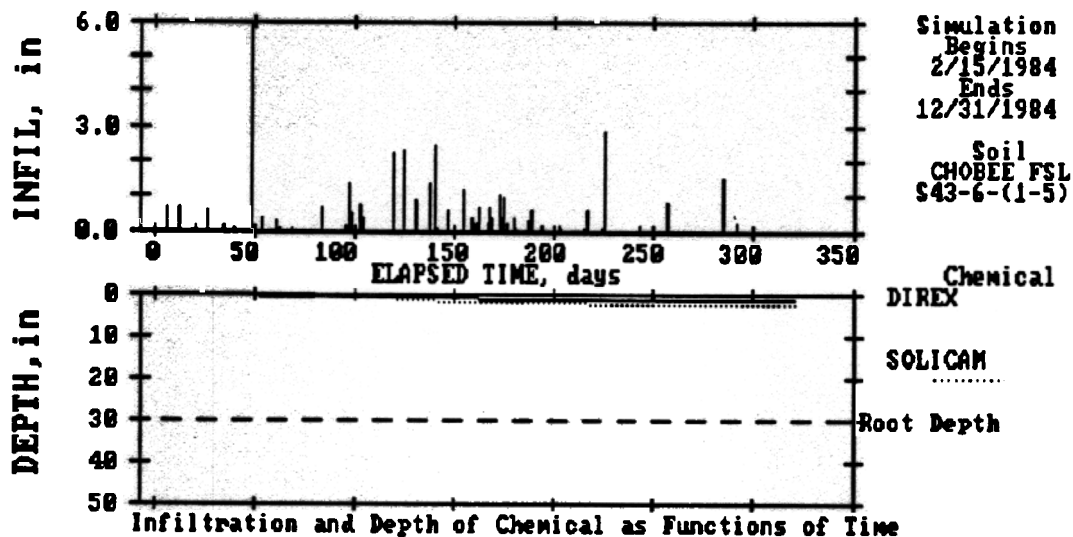


Figure 2A. Leaching of Direx and Solicam in a Chobee soil under 1984 rainfall conditions.

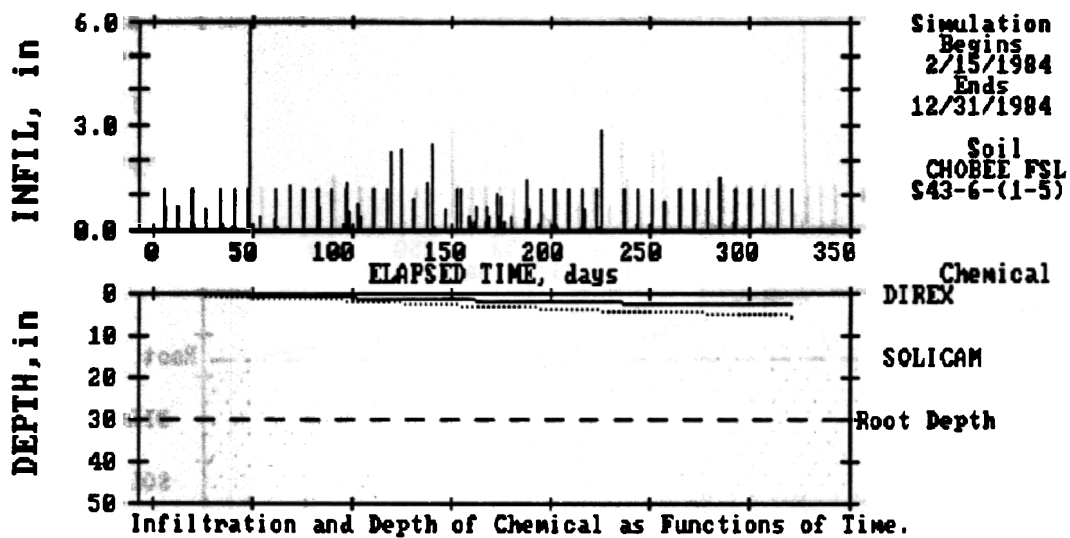


Figure 2B. Leaching of Direx and Solicam in a Chobee soil under 1984 rainfall conditions and 1.2 inches per week supplemental irrigation except when rainfall amount was greater than or equal to 1.0 inch.