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To the Graduate Council:

I am submitting herewith a thesis written by Shahiedy Ibrahim Shahied entitled "Leaching of Trifluralin, Linuron, Prometryne, and Cotoran in Soil Columns." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

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LEACHING OF TRIFLURALIN, LINURON, PROMETRYNE,
AND COTORAN IN SOIL COLUMNS

A Thesis
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

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CHAPTER I

INTRODUCTION

An understanding of the persistence of herbicides in soils is necessary in order to prevent possible injury both to crop plants being treated and to succeeding crops in the rotation.

In order to be acceptable for use, a preemergence herbicide must insure that the crop will obtain a good competitive position and must therefore remain in an active condition in the zone of weed seed germination until the crop has attained such a position. The active condition is dependent upon many variables--the herbicide's chemical stability and solubility, temperature, soil type, rainfall, and microorganism activity.

One of the major factors in herbicide inactivation is leaching. Therefore, a study was made of the leachability of N,N-di-n-propyl-2, 6-dinitro-4-trifluoromethylaniline (trifluralin); 3(3,4-dichlorophenyl)-1-methoxy-1-methyl urea

(linuron); 2,4-bis(isopropylamino)-6-methylmercapto-s-triazine (prometryne); and 3-(m-trifluoromethylphenyl)-1,1-dimethylurea (cotoran) in four agriculturally important soils.

CHAPTER II

REVIEW OF LITERATURE

I. FACTORS AFFECTING PERSISTENCE OF HERBICIDES

Aldrich (1) stated that although there is little implication of hazard associated with residues of herbicides, there is evidence of a need for detailed research of such compounds in soils.

Crafts and Drever (14) stated that the testing of persistence of herbicides in soil is essential in that all chemicals, whether applied to a plant or directly upon the soil, do reach the soil.

Although non-professional people tend to view the persistence of herbicides in soil as something undesirable, Zweep (86) directs the attention of professionals toward the benefits of this phenomenon and the problems which result from attempts to take advantage of the properties of herbicide chemicals which allow them to remain in soil.

Some herbicides remain in the soil for prolonged periods and, if susceptible crops are planted in the area,

these crops may be harmed. There is considerable variation in the persistence of herbicides in soil. There are some herbicides which, when used in quantities recommended for weed control in crops, normally disappear within a period of a month or six weeks. According to Behrens (5) these include 2-methyl-4-chlorophenoxy-acetic acid (MCPA); 2,4-dichlorophenoxyacetic acid (2,4-D); trichloroacetic acid (TCA); 2,2-dichloropropionic acid (dalapon); 3-amino-2,5-dichlorobenzoic acid (amiben); 2-chloro-N,N-diallylacetamide (CDAA); and ethyl N,N-di-n-propylthiolcarbamate (EPTC). Herbicides such as 3-(p-chlorophenyl)-1,1-dimethylurea (monuron); 2-chloro-4-ethylamino-6-isopropylamino-s-triazine (atrazine); 2-chloro-4,6-bis(ethyl-amino)-s-triazine (simazine); and 3-chloro-N,N-diallylacetamide (CDAA-T) may be found in toxic concentration for periods extending into the following growing season.

Burschel and Freed (11) described the limited persistence of some herbicides as a complex phenomenon. This phenomenon is affected by the nature of the chemical, the quantity employed, and adsorption by the soil as well as by the properties of the soil, precipitation, leaching velocity and temperature.

The rate of breakdown of herbicides in soils behaves as a first order reaction. This means, according to Burschel (12), that under comparable conditions the same percentage of the original dose will be found in the soil at a given time regardless of whether the dose was a high or a low one.

Possible factors in the loss of toxicity of a herbicide from a soil include microbiological decomposition, leaching, adsorption, vaporization, chemical decomposition, photo-chemical-decomposition, removal by plants, and tillage (1, 5, 11, 14, 32, 68).

Microbiological Decomposition

According to Behrens (5) most herbicides are deactivated by organisms in the soil. Microorganisms are important to soil fertility because they transfer into active or available forms potential plant nutrients. It is important in the use of any herbicide that there is no detrimental effect on soil microorganisms or soil microbial processes.

Influence of microbial action on the persistence of herbicides in soils has been subjected to many studies

because in the detoxification of organic herbicides micro-organisms are a prominent factor (1, 18, 49, 76).

Alexander and Aleem (2) reported that the resistance of some aromatic herbicides or their derivatives to microbial degradation is governed by the position of the halogen on the aromatic nucleus and by the linkage and type of aliphatic side chain. For example, Klingman (41) reported that 2,4-D and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) are identical except that 2,4,5,-T has an additional chlorine atom on the number 5 carbon.

Reid (55) determined that the heavy removal of such compounds from soils is accomplished by the soil pseudomonads (pseudomonas species) and the soil diptheroids (coryne bacteria ceae)--the important groups of soil bacteria. None of the compounds have been found useless as energy sources. None can persist over long periods of time with proper temperature, moisture, and aeration.

Most organic herbicides are inactivated more rapidly in soil which has not been autoclaved or otherwise altered in some manner intended to eliminate soil microorganisms. Talbert and Fletchell (74) found that deactivation occurred

only under conditions conducive to the growth of microorganisms and little or none occurred in frozen or sterile soil.

Duke (17) proposed that addition of a herbicide to soil may result in increased numbers in the species populations which are active in the utilization of the compound.

In the decomposition of urea herbicides in soils, a definite factor is soil microorganisms (31, 32, 68). Soil conditions which are favorable for growth of microorganisms are also favorable for inactivation of the phenylurea herbicides, but activity occurs slowly--or fails to occur--in dry soil or in autoclaved soil. Monuron was utilized as a sole carbon source by a species of *Pseudomonas* while another *Pseudomonas* isolate's utilization of monuron was greatly accelerated by the addition of yeast extract to the culture medium in experiments by Sheets (68).

Hill et al. (32) in 1955, reported that in a clay loam soil, 10 per cent monuron in a two-part-per-million concentration was lost in 90 days, as measured by CO_2^{14} evolution. Microbiological decomposition was determined to be a primary factor in the loss of the chemical as a result

of the demonstration that certain microorganisms could utilize 3-(P-chlorophenyl)-1,1-dimethylurea (CMU) as the only carbon source.

Sheets and Crafts (61) reached the same conclusion in their studies of four different urea herbicides--monuron; 3-(3,4-dichlorophenyl)-1,1-dimethylurea (diuron); 3-phenyl-1,1-dimethylurea (fenuron); and 3-(3,4-dichlorophenyl)-1-methylurea (DMU). All four compounds detoxified much more rapidly in non-autoclaved soil than in soil which was initially autoclaved. Fenuron, which had the shortest length of soil activity in the non-autoclaved soils, persisted nearly as long as did the more stable compounds in autoclaved soils.

Treatment which inhibits the growth of soil microbes enhances the soil persistence of the phenylureas. Proliferation of microorganisms--or so-called enrichment of the soil--does not occur under most favorable conditions for growth, according to Sheets (64). That certain microorganisms may utilize the phenylureas but not preferentially or selectively to other energy sources and that the adsorption-desorption equilibria of these herbicides in soil

systems may lie toward the adsorbed state are two possible explanations for this pattern of breakdown (68).

In 1955 studies Hill and McGahen (31) reported:

(1) Treated sample of a cecil loamy sand which was sterilized and stored for six weeks at 80° F and 65 per cent relative humidity retained the initial phytotoxic effects of both herbicides 1-3-(p-chloro-phenyl)-1,1 dimethyl urea and 3-(3,4-dichlorophenyl)-1,1 dimethyl-urea.

(2) In Warburg studies it was found that a soil bacterium of the Pseudomonas group could oxidize 3-(p-chlorophenyl)-1,1-dimethyl and use this compound as a sole source of carbon. Other related studies have indicated that bacteria such as Xanthomonas, Sarcina, and Bacillus and fungi such as Penicillium and Aspergillus can use 3-(p-chlorophenyl)-1,1-dimethylurea as a sole source of carbon in agar medium. Those soil organisms and many other probably are active in the decomposition of the substituted urea herbicides under field conditions.

Results from sterile and non-sterile soils treated with 10 u C of simazine-C¹⁴ indicate that microorganisms play an important role in the decomposition of simazine in soils (12, 17, 52, 73).

Simazine is deactivated by soil microorganisms; however, such activity is relatively slow and simazine is less available as a substrate in soil than are many herbicides, according to Burnside et al. (9). Compounds which demonstrate high persistence are likely to be resistant to

microbial destruction. Thus, the finding by Sheets regarding toxicity tends to support the observations of MacRae and Alexander (46) who stated that the s-triazine herbicides are not readily susceptible to microbial action.

In Columbia, Missouri, in studies by Talbert (73) only limited inactivation of simazine and atrazine occurred between September, 1960, and June, 1961, following a May, 1960, application.

Differences noted in the persistence of various s-triazines in different soil types could be the result of variations in microbial populations. Sheets and Shaw (66) stated that a primary relationship exists between variations in physiochemical properties of soils and microbial variations.

Pure cultures of A-fumigatus produced degradation of chain- and ring-labeled simazine in studies reported by Kearney et al. (39). Duke (17) reported that chain-labeled simazine showed greater radioactivity loss than did the ring labeled compound.

Agricultural application rates of triazine herbicides probably do not exert any profound or enduring effects on the microorganisms in the soil, stated Ercegovich (19).

Five microorganisms capable of growing on agar containing simazine as a carbon source and ammonium sulfate as a nitrogen source were isolated by Burnside et al. (9).

These were: Penicillium purpurogenum (Series) Stoll., Aspergillus utstus (Bainier), Thom and Church and three actinomycetes, all identified as Streptomyces species.

Guillemat et al. (25) isolated from the soil several fungi capable of growing on Czapeko agar with simazine as the sole carbon source. The isolated fungi were Fusarium Oxysoprum, Penicillium cyclopium, F. auenaceum, p. lanosococraleum, Cylindrocarpon radicolis, and Stachybotrys sp.

Bryant (7) conducted examinations utilizing ipazine, atratone, ametryne, atrazine, prometone, prometryne, and propazine as energy sources for two types of soil bacteria.

Activity of soil microorganisms seems to be associated with the process of inactivation of 2,4-D in soils since toxic effects remained at a high level for a period of two weeks in autoclaved soil (6).

Changes in ultraviolet absorption of herbicide solutions incubated with soil were measured by Whiteside and Alexander (82), who learned that soil microflora metabolize 4-(2,4-dichlorophenoxy) butyric acid and 2,4-dichlorophenoxy acetic acid.

The persistence of 2,4-D is greater in autoclaved soils than in non-autoclaved soils, according to the studies of Brown and Mitchell (6). It was suggested that micro-organisms active in the decomposition of 2,4-D are destroyed by autoclaving. These investigators found, too, that decomposition was apparently accelerated by the addition of manure or leafmold. This apparent acceleration was seen by Kries (42) in 1947 studies.

Hill (30) isolated from soils an organism of the Bacterium globiforme group capable of decomposing 2,4-D.

Capacity of the soil to deactivate applications of 2,4-D is far greater once bacteria capable of producing such activity have multiplied in the soil than was true preceding the initial application of the compound. With other important groups of herbicides, proliferation of effective micro-organisms did not seem to occur in studies by Sheets and Danielson (63).

Leaching

The presence of some herbicides in the surface areas of the soil could result in injury to crops, and their down-

ward movement with percolating water is an important factor in their removal from such locations, according to Behrens (5).

Weise and Davis (83) found that the herbicide, the method of application, and the amount of water were factors in variations noted in herbicide leaching. Amine salts of 2,3,6-trichlorobenzoic acid (2,3,6,-TBA) and polychlorobenzoic acid (PBA) and other herbicides which tended to leach easily were unaffected by method of application and were found to leach as deeply as water penetrated into soil.

Water solubility of the herbicide, permeability of the soil, soil texture, and amount and intensity of rainfall, along with the degree and tenacity of soil adsorption were found to be factors in the leaching and persistence of herbicides (1, 5, 13, 57, 64).

In reviewing literature, Gantz and Slife (24) noted that Aldrich and Watten found chemical formulation an important factor in the movement of herbicides in soils. These investigators found the esters of 2,4-D to be more resistant to leaching than were the amine formulations. Aldrich (1) stated that an important influence may be exerted by the carrier used. Aldrich (1) and Behrens (5), in independent

studies, found leaching greater in sandy soils due to better water percolation and less soil adsorption of the herbicide. This relation is a function of the adsorptive capacity of soils, and herbicide inactivation is promoted by dilution and adsorption as herbicide molecules are moved into untreated soils, according to Sheets (64).

Entrance of the herbicide into solution and adsorption of the herbicide to soil particles, according to Upchurch and Pierce (77), may be at least two steps involved in a herbicide's downward movement in soil.

Sheets et al. (65) stated that the entrance of the herbicide into solution could result from solid particles of the herbicide or from colloidal particles with adsorbed herbicide molecules. The adsorption of the herbicide to soil particles is influenced by such variables as soil temperature, organic matter content, and concentration of the percolating solution, according to Upchurch and Pierce (77), and soil texture; added Behrens (5).

Upchurch and Pierce (77) found that soil temperatures of 5° to 45° C. produced little influence on the monuron leached from the upper two-inch layer of soil columns. At temperatures of 25°, 35°, and 45° C. greater amounts of

monuron were retained by the two-to-eight inch layer than were retained at 5° and 15° C. in studies by Sheets and Danielson (63).

The greater solubility of monuron, when compared with that of diuron, resulted in relatively faster movement of the monuron in soils. Diuron, however, adsorbed more strongly than did monuron and differential leaching of these two compounds is probably influenced by difference in adsorption (63).

In greenhouse studies by these same investigators the low solubility of monuron was felt to be the essential factor in the increasing per cent retention when the rate of application was increased from 32 to 256 pounds per acre equivalents in soil columns which measured 3 inches in diameter.

Penetration and persistence of diuron was tested in an experiment by Weldon and Timmons (80) in an established field of alfalfa growing on a sandy clay loam soil in Wyoming in 1957. It was found that diuron was most heavily localized in the 0-to-1/2-inch layer of soil with less in the 1/2-to-2-inch depth.

Adsorption of monuron and diuron by Hawaiian sugar cane (Saccharum officinarum L.) soils was investigated by Yuen and Hilton (85), who stated that monuron showed greater tendency toward leaching to the depth of the cane root.

Sheets (62) reported that diuron moved only about half as far as did monuron in both sandy loam and clay loam soils.

The leaching of monuron was found by Upchurch and Pierce (77) to be greatly affected by soil organic matter.

In an experiment on four triazines in three soils which had different frequencies rates of rainfall, Rodgers (57) reported that atratone and simazine were intermediate in leaching while ipazine was seldom seen at depths of more than two inches and atrazine was most commonly toxic in all depths and leached most readily.

Ashton (4), studying the movement of three of the same triazine herbicides, reported that "the extent of the lateral movement of these three herbicides was in order of their solubilities." Atratone was seen to move to the greatest depths and simazine moved least deep, while atrazine's movement was to an intermediate depth. The

compounds were applied as a band to the surface of the soil and subjected to furrow irrigation.

Talbert and Fletchell (74) were in agreement with other investigators in simazine studies. Most of the surface-applied simazine has remained in the upper inch of the soil profile in the many studies which have indicated relative resistance of the compound to leaching in many agricultural soils. Atrazine has been found to leach more rapidly than has simazine.

On loam and silty loam clay soils in Nebraska, field results obtained by Burnside et al. (10) indicated that although they are resistant to leaching, simazine and atrazine could be moved through a 24-inch soil profile.

Ivey and Andrews (34), using four soils from Tennessee, produced greenhouse results indicating that atrazine and simazine moved more deeply in the columns than did diuron, which was found to remain within the surface six inches. These investigators stated that although "diuron is several times more soluble than simazine," the diuron demonstrated far less leaching.

Ercegovich (19) reported that Gast found monuron to be generally less resistant to leaching than was simazine in a comparison of the two compounds.

It has been found that both CDEC and CDAA were leached down with the water front and that both produced inhibition at every depth reached by the water, although CDAA was more easily leached than was CDEC. Both compounds were leached out of the soil surface in studies by Otten et al. (50), and in wet soils, movement of the herbicide is along a concentration gradient (24, 70).

The pH appeared to affect the leachability of DNBP, and Dowler et al. (15) concluded that in the movement of this compound the soil type and soil reaction are factors which merit consideration equal to that afforded the amount of rainfall.

Rauser and Switzer (53, 54) reported that in removing amiben from the surface layers of sandy soils, leaching appeared to be a major factor.

Adsorption

Basic to any understanding of the behavior of herbicides in soil is the process of adsorption by the colloidal

constituents in soil, thus reducing the phytotoxicity of herbicides. In this case, adsorption is the process in which a net decrease occurs in the concentration of the herbicide in the solution phase as a result of the herbicide's becoming physically or chemically bonded to the colloidal surfaces, according to Talbert (73). Behrens (5) stated that most herbicides are adsorbed to some extent.

There is a correlation between adsorption and organic matter content, clay content, and cation exchange capacity of the soil (5, 29, 35, 70). The pH and electrolyte concentration of the system are the main variables of concern, according to Frissel and Bolt (23).

Enhancing the adsorption properties, according to Leopold et al. (44) are molecular changes which reduce the water solubility of the growth regulator.

With 17 of the chlorinated derivatives of phenoxyacetic acid the adsorption onto carbon was measured by two groups of investigators--Leopold et al. (44) and Sheets et al. (65). The adsorption properties of the molecule were increased, it was learned, with 1, 2, and 3 chlorine substitutions in the phenyl ring.

Between the extent of adsorption and water solubility neither Hance (27) nor Harris (28) could discover a relationship.

Phosphate and certain other anions are adsorbed--this is generally accepted. Aldrich (1) postulated that some of the hydroxyl groups in the hydrated clay mineral can be exchanged with phosphate ions.

To some extent amiben is adsorbed by soil colloids. However, the strength of adsorption is far less than for many other herbicides, according to Warren (79). The retention in the soil of this herbicide, Sweet et al. (72) felt, would be directly related to adsorption.

Ashton and Sheets (3) found that in those soils in which it was most phytotoxic, EPTC was adsorbed least.

Hance (27), using a slurry-type procedure, studied the adsorption of substituted ureas and a number of derivatives by different soils and learned that increased adsorption is produced by increasing chain length in aryl substituents on chloro and chlorophenoxy substitution in aryl substituents. Available for adsorption is only a part of the total soil surface.

Sheets (68) stated that the results obtained by several investigators would apparently suggest that the concentration of substituted urea herbicide in the soil solution may influence or partially determine the rate of decomposition but not the rate of inactivation.

The results of a study by Sherburne and Freed (69) of the rate of adsorption of CMU in different soil types indicates a high adsorption of CMU on organic matter and a significant rate in inorganic clay particles.

For diuron, all soils demonstrate greater adsorptive capacity than do they for monuron; normal isothermal adsorption equilibria is shown by both chemicals.

Yuen and Hilton (85) found that adsorption of the hydrolytic degradation product from monuron, P-chloraniline, exhibited approximately the same relative order and degree as did monuron in a group of eight soils.

Burnside et al. (10) stated that in the dissipation of monuron, adsorption has been shown to be important.

In working with simazine and diuron, Upchurch and Mason (78) concluded that organic matter greatly influenced their toxicity.

Considerable variation in soil adsorption of the s-triazines was suggested in soil toxicity tests conducted by Sheets and Danielson (63).

Burnside and Behrens (8) found that simazine phytotoxicity was reduced in soils high in organic matter or in clay content or in both when such soils were compared to soils low in these compounds. Talbert (73) found organic matter content of soils is usually much lower than clay, but organic matter is much more adsorptive. Also important in determining the adsorptive capacity for these herbicides is the type of clay or organic matter in a soil. In the presence of kaolinite, clay, illite, and montmorillonite, Talbert (73) could detect no adsorption of simazine or atrazine.

Talbert (73) investigated the adsorption of five triazine herbicides from aqueous solutions by a number of Missouri soils. He found that initial adsorption reactions were rapid and established the order of increasing adsorption of his five test compounds to be propazine, atrazine, simazine, prometone, and prometryne.

Considerable amounts of EPTC, atrazine, and simazine may be adsorbed in soils. However, for most soils, this is not to be regarded as an important factor in reducing soil residues, according to Behrens (5).

Chemical Decomposition

Evaluation of chemical decomposition is difficult because there is a problem in isolating specific chemical reactions in soils. Jones (36) stated that photodecomposition is the most extensively discussed example of chemical decomposition.

Sheets (64) stated that from the standpoint of weed control the important consideration is that the activity of some herbicides suffers reduction with exposure to light.

However, Jordan et al. (37) postulated that photodecomposition is of minor importance in the loss of the herbicide once the compound is absorbed or incorporated into the soil.

Behrens (5) found deactivation by sunlight in monuron and 2,4-D. He felt that although most herbicides are light stable, this finding did not alter the idea that the reduction of soil residues by this means is negligible.

Chemical decomposition studies in vitro by Hill et al. (32) and by Sheets (68) have produced preliminary results suggesting that hydrolysis or oxidation of the substituted ureas is slow at ordinary temperature. Photodecomposition can occur and may be a positive factor in the disappearance of the compounds from soil when there is minimal rainfall after application of the compound and it remains on the soil surface.

Jordan et al. (37) found monuron, diuron, neburon, and fenuron--all four of the phenylurea herbicides--were degraded by light. After a period of two hours of exposure to sunlight, there was a visible change. The differences in spectral changes, it was felt, could be due to the different energy levels and to the different irradiation spectra.

There was an 83 per cent loss of monuron when a solution containing 88.3 p.p.m. of monuron sealed in quartz tubes was exposed for 48 hours to sunlight. Hill et al. (32) concluded that in dry areas ultraviolet irradiation may inactivate monuron.

Soil exposed to sun exhibited faster disappearance of monuron and diuron activity than did shaded soil. Moist soil produced more rapid loss of activity in monuron and in

simazine than did dry soil. Sheets and Danielson (63) found monuron, diuron, and simazine were affected in differing degrees by these variables.

Weldon and Timmons (80) used chemically pure samples of diuron and monuron which were irradiated with an 85-watt mercury vapor ultraviolet lamp for 0, 2, 8, and 28 hours. They concluded that "diuron appeared to break down more rapidly than did monuron."

An investigation of the effects of ultraviolet light on decomposition of three triazines at four different concentrations showed that these triazine compounds are subject to photodecomposition which is less rapid than is that with the phenylurea herbicides, according to Jordan et al. (38).

Talbert and Fletchell (74) stated that in the loss of simazine from the soil, photochemical decomposition did not appear to be a factor.

Photochemical reactions in water result in at least two major changes in the amiben molecule, according to Sheets (67)--one which destroys the diazotization and coupling capacity of one amino group and one which does not.

Vaporization

Hollingsworth (33) stated that to some degree, all compounds are volatile. With some herbicides, volatility is low and of little significance, while with others there is measurable loss from soil surfaces as a result of vaporization.

Wilson (84) stated that if applied as a surface spray, a herbicide with a high vapor pressure may be lost from the soil. Incorporation of the chemical into the soil by mechanical cultivation may result in increased persistence.

A number of herbicides show significant loss from the soil as vapors. In this manner are lost EPTC, CDAA, and volatile esters of 2,4-D, of which EPTC is most volatile. With an increase in moisture content, according to Ebeling (18), and in temperature, according to Behrens (5), the amount of vapor loss increases.

The volatilities of formulations of the same basic herbicide structure may be quite different. The isopropyl ester of 2,4-D is more volatile than is the octyl ester, which, in turn, is more volatile than is the sodium salt.

Many salts and esters of 2,4-D demonstrate a variety of rates of vaporization, according to Sheets and Danielson (63).

Volatilization of the carbamates has been related to their effectiveness as preemergence herbicides. At temperatures of 60° to 85° F., Sheets and Danielson (63) found that isopropyl N-phenylcarbamate (IPC) volatilized more rapidly than did isopropyl N-(3-chlorophenyl)-carbamate (CIPC). The most volatile carbamates were found to be most phytotoxic; however, loss by volatility following preemergence application reduced the concentration of the more volatile compounds to nonherbicidal levels more rapidly than did the less phytotoxic, less volatile compounds.

Effective preemergence herbicides include several s-triazines, some of which are extremely active as postemergence herbicides. In temperate climates soil surfaces often reach 50° C. and sometimes even 65° C. At these temperatures significant amounts of moderately volatile or low volatile herbicides might be lost by evaporation or sublimation. On wet soil the relative order of volatility of the herbicides with the most volatile one listed first

was established by Kearney et al. (39) as follows:

trietazine > atrazine > ametryne $\approx$ propazine $\approx$ prometryne $\approx$
prometone > simazine.

The percentage of sand seemed to be directly related to losses while per cent clays and organic matter appeared to be inversely related in studies by Ercegovich (19).

According to Kearney et al. (39), and Jordan et al. (38), greatest losses in radioactivity occur from planchets containing prometone. Slightly less volatile were trietazine, atrazine, ametryne, and prometryne. The loss of atrazine from the planchets was essentially doubled with increases of temperature by 10° C. increments.

A determination was made by Foy (21) of the relative volatility of several radiolabeled triazines from nickel-plated planchets at 25° and 60° C. Only trietazine and ipazine showed significant loss after 12 hours at 25°. At the end of 48 hours, 99 per cent of the trietazine and 94 per cent of the ipazine had disappeared as compared with the earlier losses of 85 and 60 per cent, respectively. After 15 hours, 95 per cent of the applied atrazine and propazine disappeared while only 35 per cent of the simazine was lost at the end of 24 hours.

Plant Uptake

Another means of removing residues from soil is provided by the uptake of herbicides by growing plants, according to Behrens (5).

When an organic chemical is introduced into a plant it is subject to possible degradation, alteration of structure, or conjugation with natural plant constituents. Shaw et al. (60) report that differences exist in the capacity of various species of plants to metabolize any individual herbicide.

Behrens (5) stated that the herbicide may be deactivated by tolerant plants or these plants could accumulate considerable quantities, thus removing the herbicide from the area when the crop is harvested. It would appear possible that substantial quantities of the compounds might be removed from a soil in this fashion.

Zweep (86) suggested that if the herbicide reacts with some chemical already present in the soil, the herbicide may be lost to the plant; the compounds are lost, too, when the herbicide is removed and degraded by plants as simazine is degraded by the maize plants.

Fang et al. (20) have suggested that CMU is absorbed through the root system, translocated upward to the leaves, and absorbed by the foliage.

Sheets (68) stated that hydrolysis of the phenylureas to the respective nonphytotoxic aniline derivatives might account for some disappearance of these herbicides from soil.

Fang et al. (20), investigating absorption and metabolism of monuron by bean plants, found that a small percentage of the chemical taken up is tied up by the plant in the form of a complex or conjugate.

A study by Burnside et al. (9), utilizing radioisotope techniques obtained evidence of plant uptake of simazine which continued for a considerable period of time.

According to Gysin (26), an old plant takes up less simazine than does a young plant. Repeated croppings by Burnside et al. (9) of soybeans in simazine-treated soil resulted in reduced phytotoxicity.

The metabolism of the triazine herbicides by plants appears to be a general phenomenon (19, 47). Although a good correlation exists between resistance and extent of metabolism, even the highly susceptible plants have a

limited capacity for degrading these chemicals, according to Montgomery and Freed (47), who also studied propazine and found it to be metabolized more rapidly by corn than is prometryne. Wheat, too, showed limited capacity to metabolize prometryne. Carrot appeared to degrade prometryne in a manner analogous to that in which corn degrades propazine.

Whitenberg (81) stated that cotton plants are unable to degrade completely the triazine ring of prometryne as indicated by the fact that no C^{14} carbon dioxide was evolved by plants treated with C^{14} prometryne. Prometryne, like any other s-triazine, is accumulated by the lysigenous glands.

Freed and Montgomery (22) found that essentially all simazine was metabolized in strawberry plants treated with labelled simazine.

Rate of Application

Since most microbiological processes follow first order kinetics, the deduction may be made that the decomposition of herbicides in the soil should likewise follow first order kinetics, according to Burschel and Freed (11).

Sheets (64) stated that inactivation rates of diuron and simazine as well as of several other herbicides are related to the initial concentrations of the chemicals in soils. It is understood from the concept of the relationship between rates of inactivation and application why massive doses of organic soil sterilants will not control weeds for several years.

When Chandra et al. (13) applied herbicides at higher rates, inhibitions were not in proportion to the concentrations applied to various soils.

Hollingsworth's (33) broadcast application of 2.0 to 4.0 pounds per acre of diuron and monuron to cotton resulted in jeopardy to oats planted for winter grazing. However, the application of these two compounds at 1.0 to 1.5 pounds per acre, providing the herbicides were mixed thoroughly in the soil, would prove of no hazard to oats.

The climatic difference is of greater influence on persistence than is the rate of application, as seen in the study by Lillie and Aldrich (45) wherein monuron was applied at the rate of 10 pounds per acre to the same plots in two successive years. These investigators found greater residue

in the fourth year from these applications than from a 50 pound per acre administration during the first year.

Herbicidal properties of simazine, an effective soil sterilant, will persist over the entire year of application. Depending upon rate, soil, and climate, the properties will persist, according to Richards (56), in varying lengths into the second year.

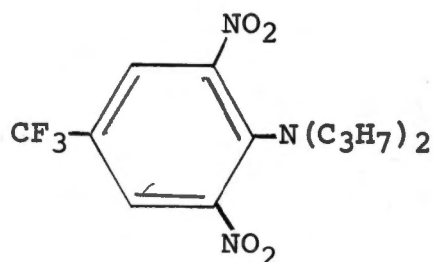
Simazine, atrazine, diuron, and dacthal have proven to be the most persistent materials in soils. However, no injury has occurred at the recommended rates. Jones and Andrews (35) found there was slight stunting of corn with application of 2.5 times the recommended rates; at 5 times the recommended rates, corn was severely stunted, but no injury occurred when treatment was at the recommended rates.

In a study by Newman et al. (48), the rate of addition to the soil influenced the persistence of IPC. At rates of 2, 10, 50, and 250 mmg. per pound of soil (9, 44, 220, and 1,102 pounds per acre), the compound disappeared in 15, 19, 39, and 39 weeks, respectively. In field experiments it appeared that the 10 pound rate persisted for a shorter period of time than did the 50 pound rate.

II. PERSISTENCE OF SPECIFIC HERBICIDES

Trifluralin

N,N-di-n-propyl-2,6-dinitro-4-trifluoromethylaniline
(trifluralin):



Numerous studies conducted on a variety of soils demonstrate little leaching of trifluralin. In studies of degradation by Parka and Worth (51) using carbon-14 labeled trifluralin, more than 90 per cent of the radioactivity which remained at the end of a period of three months was trifluralin. Potentially hazardous degradation product accumulation in soil is negligible.

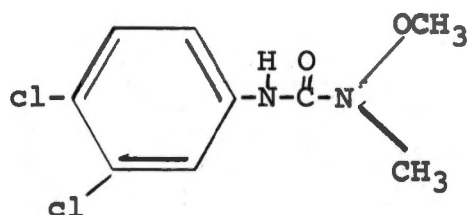
Trifluralin when applied pre-plant demonstrated soil persistence which varied according to rate and other undetermined factors in a 1964 California study by Kempen et al. (40). When the compound was applied at the rate of 1/2 pound per acre, pigweed control was not maintained for the entire season. At rates of 1 and 2 pounds per acre there

was noted some injury to sugar beets and to annual rye grass. Provided the compound is not placed below seed depth, Standifer et al. (71) found the cotton root system shows no gross effect to trifluralin applied at the rate of 4 pounds per acre at planting time.

Even at the lower rate trifluralin remained at a toxic level for post-application periods up to three months in Tifton soils in bioassay with oats. At the higher rates Bosket and Yahola soils showed toxicity three months after application by Scheizer (59).

Linuron

3(3,4-dichlorophenyl)-1-methoxy-1-methylurea:



Possible factors in the disappearance of this methoxy derivative include biological degradation, volatilization, chemical decomposition, and leaching (32, 61).

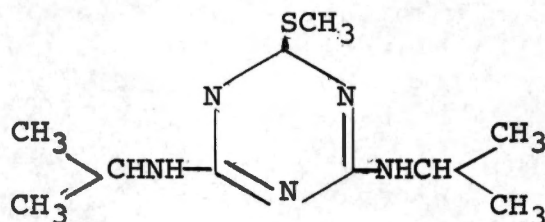
In field experiments by Sheets (68) it was seen that when the compound was applied at rates used for selective weed control, phytotoxicity from linuron disappeared from a wide variety of soils within three to four months. In four Maryland soils used in a greenhouse study, the persistence of linuron was of shorter duration than was that of monuron. According to these results there is less soil residue hazard with linuron than with monuron and diuron. Crop plants which follow a treated crop in a rotation system incur little or no danger of linuron phytotoxicity.

The order in which phytotoxicity increases is: fenuron < linuron <= monuron < diuron; while for water solubility it is: diuron < linuron <= monuron < fenuron. Harris (28) stated that with soils of high adsorptivity relatively little was released on dilution while the adsorption of linuron on a soil of low adsorptivity was released with comparative ease.

When linuron was applied to carrots post-emergence at the rate recommended--0.75 kg. per acre--Talbert (75) found no risk of residual injury to crops sown four months after treatment with the compound.

Prometryne

2,4-bis(isopropylamino)-6-methylmercapto-s-triazine
(prometryne):



Included in those crops on which the methyl-mercapto triazines show much promise is that of cotton. In a comparison of mercapto- and chloro-triazines by Gysin (26), the significantly shorter persistence of the former represented a remarkable difference. An intermediate rate of inactivation is found by Sheets and Shaw (66) in the methyl-mercapto derivatives.

According to Talbert (73) there is a carry-over problem associated with colder, dryer climates which effects a reduction in dissipation processes. This problem is acute in the Dakotas and present to a lesser degree in the more northern and western areas.

Investigations of volatility of the seven s-triazine herbicides on wet soils established the following order:

trietazine > atrazine > ametryne $\approx$ propazine $\approx$ prometryne $\approx$ prometone > simazine. This order was determined by Kearney et al. (39) and Ercegovich (19) in non-related studies.

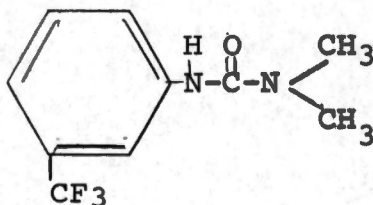
Using Lakeland fine sandy soil and different amounts and frequencies of simulated rainfall, studies were made by Rodgers (58) in columns 6 inches in diameter and 23 inches deep. Two wettable powder formulations containing 50 per cent and 80 per cent active ingredient of prometryne were applied at 2 or 4 pounds per acre. Only in soil from the top inch was prometryne lethal to oat seedlings; however, oats often survived in soil from this zone. Concentrations sufficient to cause serious stunting were not found below the top inch of soil.

Prometryne was shown on bioassay with oats to effect an initial reduction of growth and at the higher rate, to persist for a period of three months in Bosket soil tests by Scheizer (59).

Montgomery and Freed (47) found that propazine is metabolized more rapidly by corn than is prometryne. Because corn cannot detoxify prometryne the crop should be more sensitive to this compound than it is to propazine. Evidence indicates that carrots degrade prometryne.

Cotoran3-(m-trifluoromethylphenyl)-1,1-dimethylurea

(cotoran):



A search of the available literature failed to reveal a study with the persistence of this compound.

CHAPTER III

MATERIALS AND PROCEDURES

In order to determine the effects of leaching on the movement of herbicides in soil columns, a greenhouse study was carried out using four preemergence herbicides, four soils, and three leaching treatments.

To the surfaces of soil columns measured amounts of water were applied. At the end of the leaching period, in each column two pre-formed slots were exposed and planted to German Millet (Setaria italica L.). Twenty-four days after planting, the aerial portions of the plants were measured.

A randomized complete block design was used in the experiment, which was carried out in triplicate. Leaching, planting, and measuring times were staggered.

The four herbicides used in the experiment were trifluralin, linuron, prometryne, and cotoran. Each of the herbicides was applied at the rate recommended (1X) and at a rate two and one-half times that recommended (2.5X) (Table I).

TABLE I
HERBICIDES AND RATES OF APPLICATION
USED IN LEACHING STUDIES

Herbicide	Rates in pounds of active ingredient or acid equivalent per acre	
	1X*	2.5X
Check	-	----
Trifluralin	1	2.5
Linuron	1	2.5
Prometryne	2	5.0
Cotoran	1	2.5

*X represents the recommended rate of application.

Four agriculturally important soils with varying chemical and physical properties were selected from several locations within the state (Table II) (Table III). Approximately one-half ton of each of the four soils was taken from the Ap horizon. The soil was mixed, run through a 5.5 mm. sieve, and air dried.

Black plastic sewer pipe, measuring 3 inches in diameter, was cut into 30-inch sections. Into each section of pipe, 2 inches from each end, were cut slots, each of which was 1/2 inch wide and 12 inches long, thus producing an unbroken 2-inch center section. A pressure-sensitive plastic-backed tape was applied inside the pipe to cover the slots, as was suggested by the investigators responsible for the development of the slotted tube (43). One end of each pipe section was closed with cheesecloth applied in three thicknesses and secured with rubber bands. The pipe sections were placed in a vertical position and uniformly packed with soil. Subirrigation with demineralized water saturated the columns, which were then allowed to drain for a period of four days.

TABLE II
SOILS USED IN LEACHING STUDY OF
HERBICIDES IN SOIL COLUMNS

Soil	Location	Grams of Soil/Column
Bowdre Clay Loam	Mississippi River Bottom State Prison Farm Ft. Pillow, Tennessee	4100
Sequatchie Fine Sandy Loam	U.T. Plant Science Farm Knox County	4500
Cumberland Loam	U.T. Blount County Farm	4200
Collins Silt Loam	West Tennessee Experiment Station Jackson, Tennessee	4200

TABLE III
SELECTED PROPERTIES OF SOILS USED
IN HERBICIDE LEACHING STUDY*

Soil	Organic Matter Per Cent	pH	C.E.C. me/100 gms.	Per Cent		
				Sand	Silt	Clay
Cumberland Loam	2.2	7.1	7.9	32.0	43.0	25.0
Sequatchie Fine Sandy Loam	1.6	5.6	4.0	80.0	14.9	5.1
Collins Silt Loam	1.1	6.3	4.7	23.3	68.6	8.1
Bowdre Clay Loam	3.0	5.3	20.9	38.6	21.2	40.2

*Table presented by Ivey and Andrews (34).

Immediately preceding use, aqueous suspensions of the herbicides were made up. These suspensions were applied to the surfaces of the columns with a pipette. One hundred grams of sand was then applied to the surface of the soil, producing a layer approximately one inch thick. It was seen in preliminary studies that such a layer was necessary both to prevent puddling of the soil surface and to aid infiltration during the leaching phase. To insure that all water treatments would contribute to leaching, the sand was saturated with 25 ml. of water. To produce leaching of the herbicides, water equivalent to 3, 9, and 18 inches was applied to the columns. The equivalent of 3 inches of demineralized water was applied daily during the leaching periods. Eighty-seven ml. of water (equivalent to $3/4$ inch) was applied at three hour intervals, four times a day.

Columns which received an equivalent of 3 inches of water were leached one day, those which received an equivalent of 9 inches of water were leached for three days, and columns which received an equivalent of 18 inches of water were leached six days. To minimize evaporation, the columns were covered with inverted petri dishes for 14 days--from the beginning of the leaching period until the planting date.

After leaching, the soil-filled pipe sections were placed in a horizontal position and the previously-applied tape was removed with a razor blade, exposing the slots. German Millet seeds were uniformly distributed in the slots. The seeds were covered with vermiculite and watered once daily with demineralized water.

On the 24th day following planting, the average heights of living aerial portions of several plants in each two-inch section of the slots were measured. Averages were computed and all figures presented in the findings were thus determined.

For purposes of description, any difference between control (check) and treated plants equal to less than .50 inch was not considered stunting; thus, lightly stunted plants are at least .51 inch shorter than are the plants in the control.

CHAPTER IV

RESULTS AND DISCUSSION

I. TRIFLURALIN

General Observations

Trifluralin was clearly the least susceptible to leaching of the four herbicides tested. Generally, the compound applied at 2.5 times the recommended rate (2.5 pounds per acre) was leached two inches deeper than was that applied at the recommended rate (1 pound per acre). Results of this study of trifluralin, indicating little leaching (Figure 1), coincide with those of Parka and Worth (51).

Specific Soils

Bowdre clay loam soil. Bowdre clay loam soil is high in organic matter content, cation exchange capacity, and percent clay content (Table III, page 44). Trifluralin applied to this soil (Table IV) at the recommended rate and leached with 3 inches of water produced no stunting of plants, while the application of the compound at 2.5 times

Depth--Inches	Bowdre Clay			Sequatchie			Cumberland			Collins Silt		
	Loam			Fine Sandy Loam			Loam			Loam		
	Inches of Water	Inches of Water	Inches of Water	Inches of Water	Inches of Water	Inches of Water	Inches of Water	Inches of Water	Inches of Water	Inches of Water	Inches of Water	Inches of Water
2---4	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18
4---6	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18
6---8	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18
8--10	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18
10--12	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18
12--14	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18
16--18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18
18--20	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18
20--22	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18
22--24	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18
24--26	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18
26--28	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18	3 3 9 9 18 18

*First figure is LX; second is 2.5X.

Figure 1. Depth of penetration of trifluralin in soil columns leached with three rates of water.

TABLE IV

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS
IN BOWDRE CLAY LOAM SOIL WITH TRIFLURALIN APPLIED AT TWO RATES
AND LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil Column Section Inches	Three Inches Applied Water		Nine Inches Applied Water		Eighteen Inches Applied Water	
	Rate*		Rate*		Rate*	
	0.00	1.00	2.50	0.00	1.00	2.50
2---4	3.00	3.00	2.75	3.08	.75	.83
4---6	3.41	3.41	3.00	3.41	2.33	1.92
6---8	3.75	3.58	3.41	3.50	3.41	3.33
8---10	3.67	3.50	3.50	3.58	3.58	3.41
10---12	3.83	3.58	2.70	3.75	3.58	3.58
12---14	3.83	3.58	3.17	3.58	3.41	3.41
16---18	3.50	3.58	3.50	3.67	3.41	3.50
18---20	3.58	3.58	3.66	3.83	3.33	3.67
20---22	3.83	3.70	3.41	3.75	3.41	3.41
22---24	3.66	3.50	3.33	3.58	3.41	3.33
24---26	3.33	3.42	3.25	3.67	3.33	3.00
26---28	3.25	3.00	2.58	3.50	3.33	2.58

*Rate is expressed as active ingredient, pounds per acre.

the recommended rate caused slight stunting of plants in the upper 2 inches of the column. When applied water was increased to 9 inches severe stunting resulted at the low rate to the 4 inch depth and, at the higher rate, to the 6 inch depth. The same pattern of stunting was seen when water equivalent to 18 inches was applied.

Sequatchie fine sandy loam. Sequatchie fine sandy loam soil is low in organic matter, in cation exchange capacity, and in clay, and high in per cent sand content. Trifluralin applied at both the recommended rate and at 2.5 times that recommended and leached in this soil (Table V) with 3 inches of water produced slight stunting of plants to the 4 inch depth. Applied water equivalent to 9 inches produced only slight stunting to the 6 inch depth when the compound was applied at the higher rate. Eighteen inches of water resulted in stunted plants to the 4 inch depth at the recommended rate and to the 6 inch depth at the higher rate. Severe stunting was seen in plants at the 4 inch level in soil treated at the higher rate.

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS IN SEQUATCHIE FINE SANDY LOAM SOIL WITH TRIFLURALIN APPLIED AT TWO RATES AND LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

*Rate is expressed as active ingredient, pounds per acre.

Cumberland loam soil. Cumberland loam soil has low organic matter content and high pH, while percentage of clay content is average, as is cation exchange capacity (Table III, page 44). Plants in this soil (Table VI) were slightly stunted at the 4 inch depth when the herbicide was applied at a rate 2.5 times that recommended and treated with water equivalent to 3 inches. Moderate stunting was seen at the 4 inch level and slightly stunted plants were in evidence at the 6 inch position in Cumberland loam treated at the higher rate when water equivalent to 9 inches was applied. Water equivalent to 18 inches produced similar results at the higher rate and mild-to-moderate stunting to the 6 inch depth at the recommended rate.

Collins silt loam soil. Collins silt loam is a soil which is low in per cent organic matter content, in cation exchange capacity, and in per cent clay content, but which is high in per cent silt content (Table III, page 44). This soil treated with trifluralin (Table VII) at the recommended rate and at 2.5 times that recommended produced unstunted plants when the compound was leached by either 3 inches or

TABLE VI

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS
IN CUMBERLAND LOAM SOIL WITH TRIFLURALIN APPLIED AT TWO RATES
AND LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil Column Section Inches	Three Inches		Nine Inches		Eighteen Inches	
	Applied Water		Applied Water		Applied Water	
	Rate*		Rate*		Rate*	
	0.00	1.00	2.50	0.00	1.00	2.50
2---4	3.17	3.83	2.17	3.08	3.17	2.67
4---6	3.58	3.00	2.83	3.33	3.17	2.83
6---8	3.50	3.25	2.92	3.41	3.33	3.41
8---10	3.58	3.08	2.83	3.58	3.50	3.33
10---12	3.91	3.50	3.17	3.91	3.50	3.41
12---14	3.67	3.25	3.25	3.83	3.50	3.17
16---18	3.67	3.50	3.17	3.83	3.83	3.41
18---20	3.41	3.25	3.17	3.67	3.67	3.41
20---22	3.67	3.33	3.08	3.50	3.67	3.50
22---24	3.41	3.08	3.17	3.67	3.41	3.50
24---26	3.75	3.33	3.33	3.41	3.41	3.41
26---28	3.33	2.83	2.83	3.50	3.25	3.25

*Rate is expressed as active ingredient, pounds per acre.

TABLE VII

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS
IN COLLINS SILT LOAM SOIL WITH TRIFLURALIN APPLIED AT TWO RATES
AND LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil Column Section Inches	Three Inches		Nine Inches		Eighteen Inches	
	Applied	Rate*	Applied	Rate*	Applied	Rate*
	0.00	1.00	2.50	0.00	1.00	2.50
2---4	2.08	2.17	2.08	2.17	2.08	2.08
4---6	2.20	2.25	2.08	2.50	2.50	2.25
6---8	2.33	2.33	2.33	2.83	2.58	2.41
8---10	2.41	2.41	2.50	2.67	2.58	2.50
10---12	2.67	2.58	2.41	2.83	2.00	2.41
12---14	2.58	2.75	2.67	2.67	2.75	2.25
16---18	2.75	2.75	2.50	2.67	2.91	2.58
18---20	3.00	2.75	2.67	2.67	2.75	2.41
20---22	2.58	2.33	2.41	2.67	2.41	2.25
22---24	2.67	2.41	2.41	2.67	2.41	2.17
24---26	2.50	2.41	2.50	2.41	2.25	2.33
26---28	2.33	2.25	1.67	2.17	2.00	1.75

*Rate is expressed as active ingredient, pounds per acre.

9 inches of water. The compound applied at 2.5 times the recommended rate and leached with 18 inches of water showed slight stunting to the 6 inch position.

II. LINURON

General Observations

Increasing linuron's recommended rate by 2.5 times enabled the herbicide to move downward. An increase in the amount of applied water caused linuron to move to greater depths in the soil columns (Figure 2).

The results of this experiment agree quite closely with those of other studies (10, 16, 62, 68, 77) in that, in light soil there was marked mobility of the herbicide, while in heavy soil, although the applied water was equivalent to 18 inches, linuron moved only a few inches from the surface and remained in a highly phytotoxic concentration at the surface.

Specific Soils

Bowdre clay loam soil. In Bowdre clay loam soil (Table VIII) linuron applied at the recommended rate of 1 pound per acre and leached with 3 inches of water produced

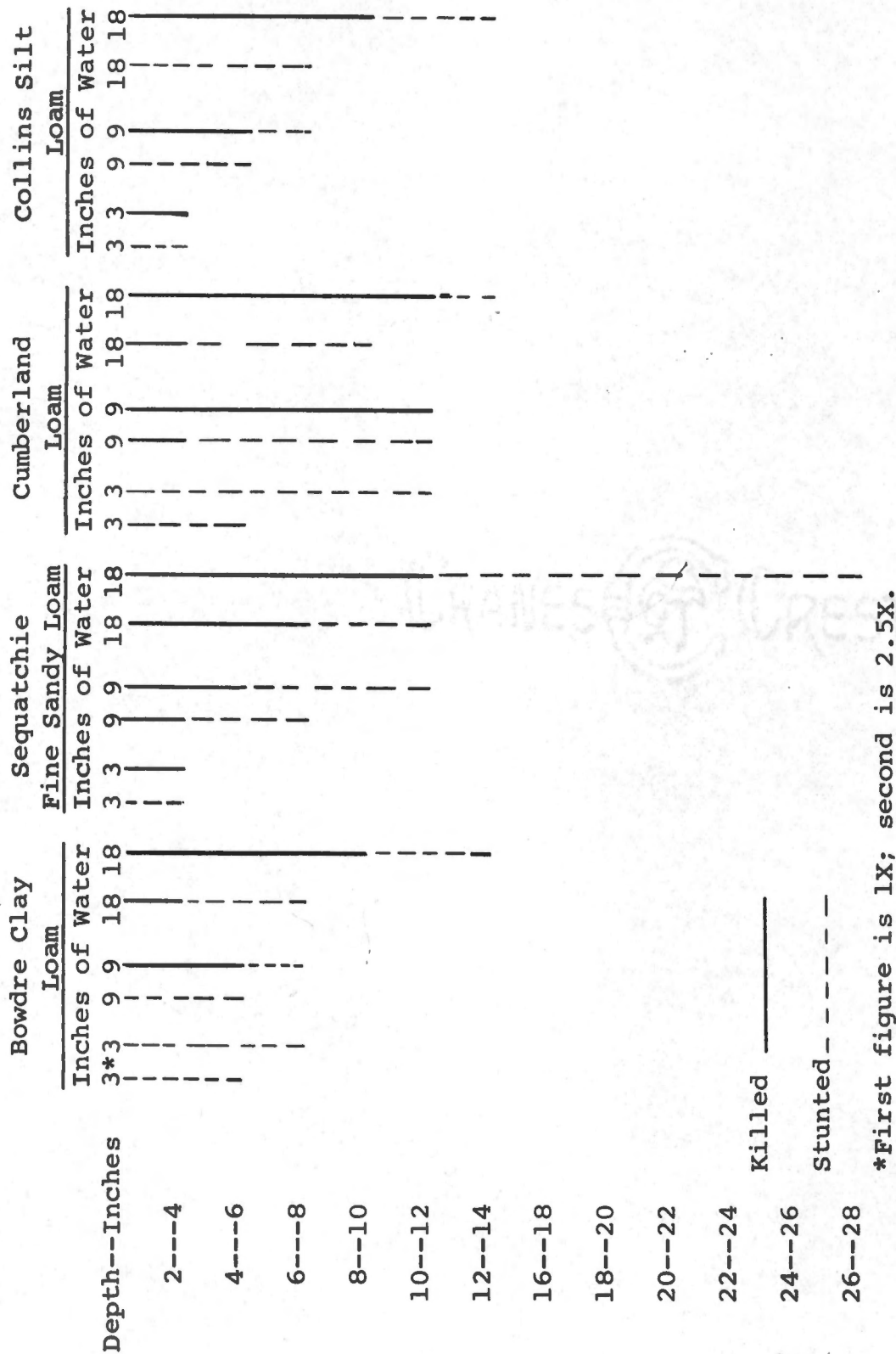


Figure 2. Depth of penetration of linuron in soil columns leached with three rates of water.

TABLE VIII

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS
IN BOWDRE CLAY LOAM SOIL WITH LINURON APPLIED AT TWO RATES AND
LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil Column Section Inches	Three Inches			Nine Inches			Eighteen Inches		
	Applied Water			Applied Water			Applied Water		
	Rate*			Rate*			Rate*		
	0.00	1.00	2.50	0.00	1.00	2.50	0.00	1.00	2.50
2---4	3.00	1.58	1.08	3.08	.58	----	3.08	----	----
4---6	3.41	2.67	2.83	3.41	2.25	----	3.33	.50	----
6---8	3.75	3.00	2.83	3.50	3.08	2.08	3.50	2.83	----
8--10	3.67	3.33	3.00	3.58	3.17	3.08	3.41	2.91	----
10--12	3.83	3.25	3.17	3.75	3.33	3.33	3.67	3.00	.67
12--14	3.83	3.08	3.33	3.58	3.50	3.33	3.50	3.25	.75
16--18	3.50	3.25	3.33	3.67	3.00	3.41	3.58	3.17	3.17
18--20	3.58	3.58	3.25	3.83	3.50	3.50	3.75	3.25	3.58
20--22	3.83	3.33	3.25	3.75	3.58	3.58	3.67	3.50	3.41
22--24	3.66	3.25	3.25	3.58	3.50	3.50	3.50	3.67	3.58
24--26	3.33	3.00	3.08	3.67	3.33	3.50	3.75	3.08	3.50
26--28	3.25	2.75	2.50	3.50	3.00	3.00	3.58	3.33	3.50

*Rate is expressed as active ingredient, pounds per acre.

moderately stunted plants at the 4 inch depth and light stunting of plants at the 6 inch depth. When the herbicide was applied at a rate 2.5 times that recommended, that is at 2.5 pounds per acre and leached by 3 inches of water, severe stunting resulted at the 4 inch depth while light stunting was seen to the 8 inch position. When applied water was equivalent to 9 inches, severe stunting of plants at the 4 inch depth and moderately stunted plants at the 6 inch depth resulted in that soil treated at the lower rate. Nine inches of water leaching the herbicide applied at the rate of 2.5 pounds per acre produced killing of plants to the 6 inch depth and moderately stunted plants in the 6-to-8 inch section. Leaching of linuron applied at 1 pound per acre through 18 inches of water killed plants in the surface 2 inches, severely stunted plants in the 4-to-6 inch position, and lightly stunted plants to the 8 inch position, and lightly stunted plants to the 8 inch depth. This leaching treatment with linuron applied at the rate of 2.5 pounds per acre resulted in kills to the 10 inch depth and severely stunted plants to a depth of 14 inches.

Sequatchie fine sandy loam soil. When linuron was applied to Sequatchie fine sandy loam soil (Table IX) and leached by 3 inches of water, those columns treated with 1 pound per acre showed severely stunted plants, and the treatment with 2.5 pounds per acre produced killed plants in the surface 2 inches. When water equivalent to 9 inches was applied to columns treated with the compound at a rate of 1 pound per acre the 4 inch depth contained only killed plants, the 6 inch depth resulted in severely stunted plants, and in the 8 inch depth there was moderate stunting. Application of 2.5 pounds per acre linuron leached by 9 inches of water killed plants to the 6 inch position, moderately stunted plants to the 8 inch depth, and resulted in lightly stunted plants to the 12 inch depth. Application of the herbicide at 1 pound per acre and 18 inches of water applied produced killing to the 8 inch depth, stunted plants to the 10 inch depth, and light stunting was seen in plants to the 12 inch depth. When the compound's application was increased to a rate of 2.5 pounds per acre there were killed plants to the 12 inch depth, while plants in the remaining seven 2-inch sections were stunted.

TABLE IX

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS IN
 SEQUATCHIE FINE SANDY LOAM SOIL WITH LINURON APPLIED AT TWO RATES
 AND LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil Column Section Inches	Three Inches		Nine Inches		Eighteen Inches	
	Applied Water		Applied Water		Applied Water	
	Rate*		Rate*		Rate*	
	0.00	1.00	2.50	0.00	1.00	2.50
2---4	2.50	.91	----	2.58	----	----
4---6	2.91	2.58	2.58	3.00	.83	----
6---8	3.33	2.75	2.75	3.41	2.08	1.75
8---10	3.50	3.00	3.33	3.33	2.41	2.00
10---12	3.41	3.00	3.17	3.50	2.67	2.50
12---14	3.25	3.08	3.00	3.25	3.00	2.75
16---18	3.50	2.58	3.25	3.25	2.50	2.41
18---20	3.33	2.91	3.08	3.41	2.83	3.17
20---22	3.25	2.75	3.17	3.33	2.75	3.00
22---24	3.25	2.83	3.08	3.41	3.00	3.00
24---26	3.33	2.91	2.83	3.08	2.75	2.83
26---28	3.25	2.67	2.41	3.00	2.58	2.17

*Rate is expressed as active ingredient, pounds per acre.

Cumberland loam soil. Cumberland loam soil (Table X) which received 1 pound per acre linuron and 3 inches of water showed severely stunted plants in the surface 2 inches and moderately stunted plants to the 6 inch depth. When the rate was increased to 2.5 pounds per acre, the soil to the 6 inch depth contained severely stunted plants; there was moderate stunting to 10 inches and lightly stunted plants were seen to the 12 inch depth. With applied water increased to an equivalent of 9 inches, in soil treated with the compound applied at 1 pound per acre, plants to the 4 inch depth were killed, those to 8 inches were moderately stunted, and plants to the 12 inch depth were lightly stunted. An increase in the application rate of the herbicide to 2.5 pounds per acre resulted in killed plants to the 12 inch depth. Eighteen applied inches of water and 1 pound per acre linuron killed plants to a depth of 4 inches, severely stunted those growing in the 4-to-6 inch section, and lightly stunted plants as deep as 10 inches in the column. Linuron applied at 2.5 pound per acre with the same leaching treatment (18 inches of water) killed plants to the 12 inch depth and lightly stunted those to 14 inches.

TABLE X

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS
IN CUMBERLAND LOAM SOIL WITH LINURON APPLIED AT TWO RATES AND
LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil Column Section Inches	Three Inches			Nine Inches			Eighteen Inches		
	Applied Water			Applied Water			Applied Water		
	Rate*			Rate*			Rate*		
	0.00	1.00	2.50	0.00	1.00	2.50	0.00	1.00	2.50
2---4	3.17	.58	.41	3.08	----	----	3.17	----	----
4---6	3.58	1.41	.50	3.33	1.08	----	3.17	1.08	----
6---8	3.50	3.08	1.33	3.41	1.83	----	3.33	2.58	----
8--10	3.58	3.08	1.75	3.58	2.75	----	3.50	2.83	----
10--12	3.91	3.17	2.33	3.91	2.83	----	3.50	3.25	----
12--14	3.67	3.08	3.00	3.83	2.91	3.17	3.50	3.17	2.75
16--18	3.67	3.25	3.25	3.83	3.25	3.17	3.83	3.33	3.41
18--20	3.41	3.17	3.50	3.67	3.17	3.25	3.67	3.50	3.33
20--22	3.67	3.33	3.25	3.50	3.17	3.17	3.67	3.41	3.50
22--24	3.41	3.25	3.17	3.67	3.25	3.33	3.41	3.33	3.41
24--26	3.75	3.08	3.25	3.41	3.00	3.50	3.41	3.08	3.17
26--28	3.33	2.41	3.08	3.50	2.75	3.27	3.25	3.08	3.08

*Rate is expressed as active ingredient, pounds per acre.

Collins silt loam soil. Linuron applied to Collins silt loam soil (Table XI) at a rate of 1 pound per acre and leached with 3 inches of water resulted in lightly stunted plants to the 4 inch depth, while the compound applied at 2.5 pounds per acre killed plants in the same area. Leaching treatment of water equivalent to 9 inches produced moderately stunted plants to the 4 inch depth and light stunting to the 6 inch position when the herbicide was applied at 1 pound per acre, while an increase in the application rate to 2.5 pounds per acre killed plants to the 6 inch depth and severely stunted those growing to the 8 inch depth. Applying 18 inches of water and 1 pound per acre linuron severely stunted growth to the 4 inch depth, moderately stunted plants to the 6 inch section, and produced light stunting to the 8 inch depth. The compound used at 2.5 pounds per acre killed the plant to the 10 inch depth and severely stunted plants in the 10-to-12 inch section while those to the 14 inch depth were lightly stunted.

TABLE XI

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS
IN COLLINS SILT LOAM SOIL WITH LINURON APPLIED AT TWO RATES AND
LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil Column Section Inches	Three Inches		Nine Inches		Eighteen Inches	
	Applied	Water	Applied	Water	Applied	Water
	Rate*		Rate*		Rate*	
	0.00	1.00	2.50	0.00	1.00	2.50
2---4	2.08	1.21	----	2.17	1.00	----
4---6	2.20	2.12	1.83	2.50	1.83	----
6---8	2.33	2.20	2.25	2.83	2.17	.41
8---10	2.41	2.33	2.63	2.67	2.33	2.25
10---12	2.67	2.54	2.33	2.83	2.25	2.41
12---14	2.58	2.56	2.33	2.67	2.08	2.33
16---18	2.75	2.25	2.50	2.67	2.33	2.25
18---20	3.00	2.91	2.73	2.67	2.41	2.54
20---22	2.58	2.25	2.00	2.67	2.67	2.33
22---24	2.67	2.08	2.17	2.67	2.22	2.63
24---26	2.50	2.00	2.25	2.41	2.41	2.25
26---28	2.33	2.25	1.91	2.17	2.00	2.25
	2.08	.83	2.08	2.58	2.00	2.25
	2.50	1.21	2.50	2.58	2.75	2.22
	2.58	2.00	2.58	2.58	2.91	2.25
	2.58	2.17	2.58	2.00	2.75	2.73
	2.00	2.25	2.00	2.41	2.41	2.08
	2.75	2.22	2.75	2.41	2.91	2.50
	2.91	2.25	2.91	2.25	2.25	2.25
	2.75	2.73	2.75	2.00	2.41	2.41
	2.41	2.08	2.41	2.00	2.41	2.08
	2.41	2.91	2.41	2.00	2.41	2.50
	2.25	2.25	2.25	2.00	2.41	2.25
	2.00	2.41	2.00	2.00	2.41	2.41

*Rate is expressed as active ingredient, pounds per acre.

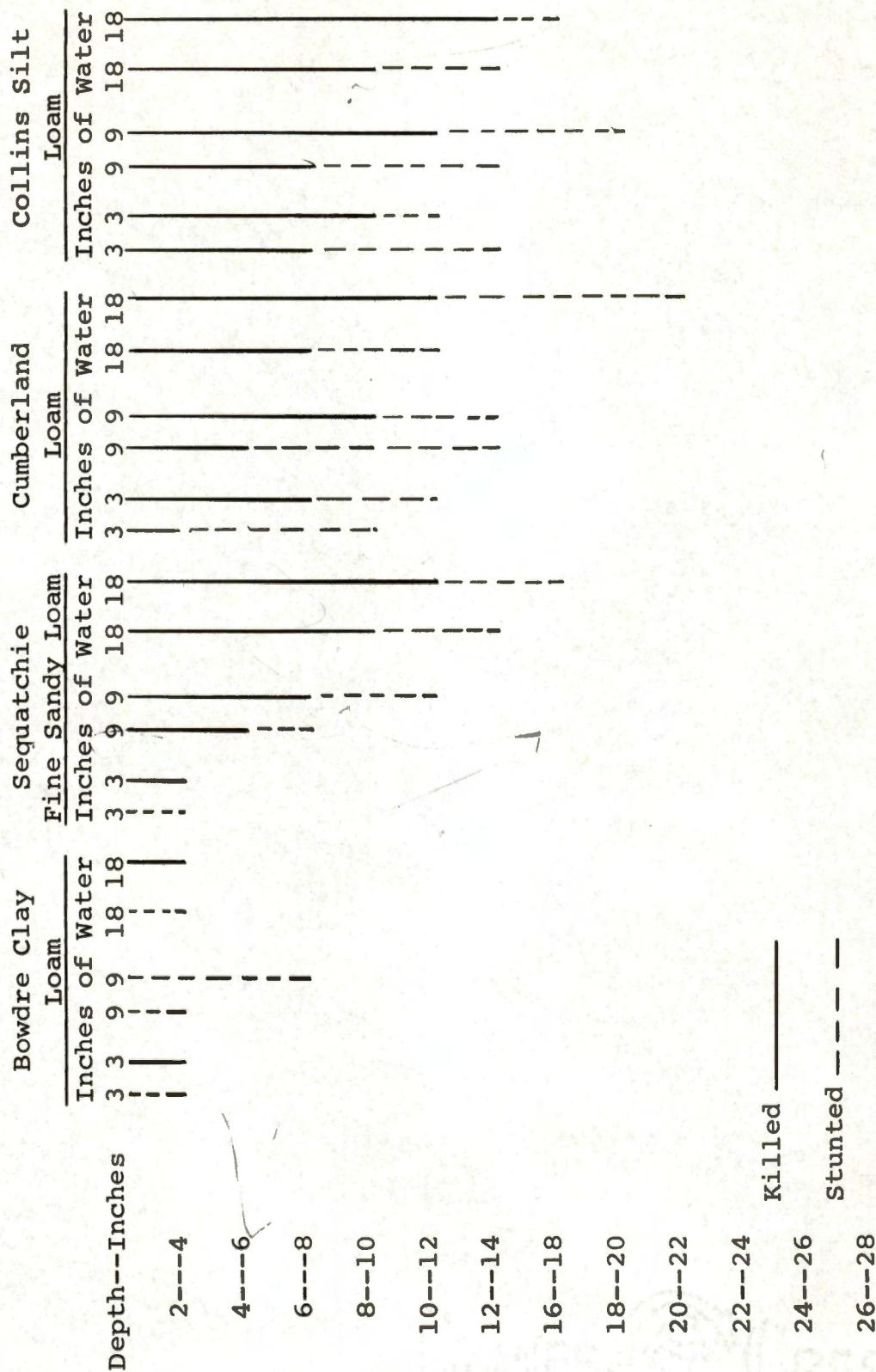
III. PROMETRYNE

General Observations

In heavier soils (e.g., Bowdre) concentrations of prometryne sufficient for phytotoxicity or serious stunting were not carried below the top inch of soil although application rates of water were increased to 9 inches and 18 inches (Figure 3). In light soil, however, the herbicide moved to the 12 inch depth when leached through 18 inches of water, a finding in direct opposition to that of Rodgers (58), who found no increase in downward movement in sandy soil when applied water was increased.

Specific Soils

Bowdre clay loam soil. Bowdre clay loam soil (Table XII) treated with the recommended rate of 2 pounds per acre of prometryne, when leached by 3 inches of water, produced moderately stunted plants in the surface 2 inches, while application of the herbicide at a rate 2.5 times that recommended (5 pounds per acre) killed plants in the same area. When the water applied was equivalent to 9 inches on soil treated with 2 pounds per acre prometryne, moderate stunting resulted to the 4 inch depth; however, an increase



*First figure is 1X; second is 2.5X.

Figure 3. Depth of penetration of prometryne in soil columns leached with three rates of water.

TABLE XII

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS
IN BOWDRE CLAY LOAM SOIL WITH PROMETRYNE APPLIED AT TWO RATES
AND LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil Column Section Inches	Three Inches			Nine Inches			Eighteen Inches		
	Applied Water			Applied Water			Applied Water		
	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*
	0.00	2.00	5.00	0.00	2.00	5.00	0.00	2.00	5.00
2---4	3.00	2.17	----	3.08	2.00	.75	3.08	2.17	----
4---6	3.41	3.00	2.91	3.41	2.75	2.25	3.33	3.08	2.91
6---8	3.75	3.25	3.17	3.50	3.08	2.91	2.50	3.17	3.08
8--10	3.67	3.08	3.41	3.58	3.41	3.33	3.41	3.00	3.17
10--12	3.83	3.08	3.41	3.75	3.58	3.50	3.67	3.33	3.33
12--14	3.83	3.08	3.33	3.58	3.50	3.41	3.50	3.33	3.50
16--18	3.50	3.33	3.17	3.67	3.33	3.41	3.58	3.33	3.41
18--20	3.58	3.41	2.83	3.83	3.50	3.33	3.75	3.17	3.33
20--22	3.83	3.50	3.33	3.75	3.41	3.50	3.67	3.33	3.17
22--24	3.66	3.17	3.25	3.58	3.50	3.33	3.50	3.33	3.25
24--26	3.33	2.83	3.08	3.67	3.08	3.33	3.75	3.17	3.08
26--28	3.25	2.25	2.58	3.50	3.00	3.08	3.58	3.00	2.91

*Rate is expressed as active ingredient, pounds per acre.

in the application rate of the herbicide to 5 pounds per acre killed no growth, severely stunted plants in the first 2-inch section, moderately stunted those plants in the 4-to-6 inch position, and produced lightly stunted plants to the 8 inch depth. Plants to the 4 inch depth were moderately stunted in soil treated with 2 pounds per acre and killed in that treated with 5 pounds per acre when the water for leaching was equivalent to 18 inches, exactly duplicating results obtained with the 3-inch leaching treatment.

Sequatchie fine sandy loam soil. When prometryne was applied to Sequatchie fine sandy loam soil (Table XIII) at rates of 2 pounds per acre and 5 pounds per acre with 3 inches of water applied, the results were similar to those obtained with Bowdre, i.e. moderate stunting and killing, respectively in the surface 2 inches. Nine equivalent inches of water produced killing of plants to the 6 inch depth with slight stunting to 8 inches in soil treated with 2 pounds per acre prometryne, while application of the compound at 5 pound per acre rates killed all growth to the 8 inch depth and moderately stunted plants to the 12 inch position in the column. Two pounds per acre of prometryne

TABLE XIII

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS IN SEQUATCHIE FINE SANDY LOAM SOIL WITH PROMETRYNE APPLIED AT TWO RATES AND LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil Column Section Inches	Three Inches			Nine Inches			Eighteen Inches		
	Applied Water			Applied Water			Applied Water		
	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*
	0.00	2.00	5.00	0.00	2.00	5.00	0.00	2.00	5.00
2---4	2.50	1.25	----	2.58	----	----	3.00	----	----
4---6	2.91	3.00	3.00	3.00	----	----	3.25	----	----
6---8	3.33	3.08	3.08	3.41	1.75	----	3.00	----	----
8---10	3.50	3.08	2.91	3.33	3.08	2.33	3.50	----	----
10---12	3.41	3.00	3.08	3.50	3.00	2.58	3.25	.41	----
12---14	3.25	3.25	3.17	3.25	3.17	3.25	3.25	1.33	1.08
16---18	3.50	3.17	3.00	3.25	3.33	3.25	3.25	2.91	2.67
18---20	3.33	2.91	3.17	3.41	3.33	3.25	3.33	2.75	3.08
20---22	3.25	2.83	2.83	3.33	3.00	2.92	3.33	3.17	3.00
22---24	3.25	3.00	2.67	3.41	3.25	2.33	3.17	3.17	3.00
24---26	3.33	3.00	2.83	3.08	3.25	2.75	3.00	2.75	2.50
26---28	3.25	2.67	2.83	3.00	3.83	3.00	3.08	2.58	2.50

*Rate is expressed as active ingredient, pounds per acre.

leached through 18 inches of water killed plants to the 10 inch depth and severely stunted those growing to the 14 inch depth. Columns subjected to application of the herbicide at the higher rate--5 pounds per acre--had all plants killed to the 12 inch depth, while plants in the 12-to-14 inch position were severely stunted and those to the 18 inch depth were moderately stunted.

Cumberland loam soil. Of the four soils involved in this study, Cumberland loam (Table XIV) proved most conducive to the leaching of prometryne (Figure 4). With a leaching treatment of 3 inches of water when the herbicide was applied at 2 pounds per acre, growth to the depth of 4 inches was killed, that to 8 inches severely stunted, and plants to the ten inch position were moderately stunted; while an increase in the application rate of the herbicide to 5 pounds per acre (Figure 5) increased the leaching depth by two inches--to the 12 inch position--with phytotoxic concentrations seen to 8 inches, severe stunting to 10 inches, and light stunting to the 12 inch depth. When leached by 9 inches of water, both rates moved downward to the same depth, although plant damage was greater at the

TABLE XIV

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS
IN CUMBERLAND LOAM SOIL, WITH PROMETRYNE APPLIED AT TWO RATES AND
LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil Column Section Inches	Three Inches			Nine Inches			Eighteen Inches		
	Applied Water			Applied Water			Applied Water		
	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*
	0.00	2.00	5.00	0.00	2.00	5.00	0.00	2.00	5.00
2---4	3.17	-----	-----	3.08	-----	-----	3.17	-----	-----
4---6	3.58	1.33	-----	3.33	-----	-----	3.17	-----	-----
6---8	3.50	2.25	-----	3.41	1.83	-----	3.33	-----	-----
8--10	3.58	2.58	2.00	3.58	2.67	-----	3.50	1.50	-----
10--12	3.91	3.25	3.17	3.91	3.17	1.58	3.50	2.83	-----
12--14	3.67	3.41	3.41	3.83	2.91	2.91	3.50	3.17	.92
16--18	3.67	3.41	3.41	3.83	3.50	3.08	3.83	3.08	2.41
18--20	3.41	2.91	3.17	3.67	3.33	3.00	3.67	3.51	2.67
20--22	3.67	3.17	3.17	3.50	3.17	3.08	3.67	3.33	2.83
22--24	3.41	3.00	3.17	3.67	3.33	3.17	3.41	3.41	3.00
24--26	3.75	3.08	3.17	3.41	3.00	3.33	3.41	3.33	3.17
26--28	3.33	2.71	2.58	3.50	2.50	2.58	3.25	3.25	3.33

*Rate is expressed as active ingredient, pounds per acre.



Figure 4. Plants growing in Cumberland loam soil which was untreated and treated with prometryne applied at two rates and leached by 3, 9, and 18 inches of water (first replication).

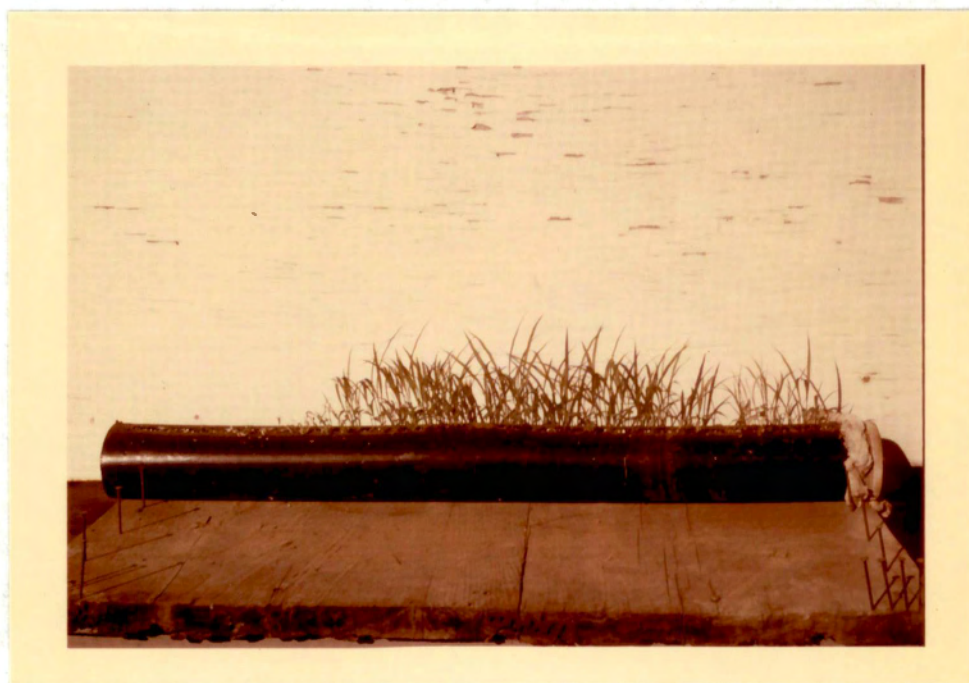


Figure 5. Plants growing in Cumberland loam soil which was treated with five pounds per acre of prometryne leached by three inches of water (first replication).

higher rate in that prometryne killed plants to 6 inches, severely stunted those to 8 inches, and lightly stunted growth to 14 inches when applied at the recommended rate of 2 pounds per acre. Application at 2.5 times the recommended rate--5 pounds per acre--killed plants to the 10 inch depth, severely stunted those to 12 inches, and lightly stunted plants to the 14 inch position. In soil treated with 2 pounds of prometryne per acre, and leached with 18 inches of water there were phytotoxic concentrations to the 8 inch depth, while in the section from 8-to-10 inches plants were severely stunted, and to the 12 inch depth were lightly stunted. Leaching was seen through the 22 inch depth in soil treated with 5 pounds per acre prometryne and water equivalent to 18 inches, with killing concentrations apparent to 12 inches. Plants were severely stunted to the 14 inch position, moderately stunted to 20 inches, and lightly stunted to the 22 inch depth.

Collins silt loam soil. Prometryne applied to Collins silt loam soil (Table XV) at the rate of 2 pounds per acre killed plants to the 8 inch position, moderately stunted those to 12 inches, and lightly stunted growth to

TABLE XV

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS
IN COLLINS SILT LOAM SOIL WITH PROMETRYNE APPLIED AT TWO RATES
AND LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil Column Section Inches	Three Inches			Nine Inches			Eighteen Inches		
	Applied Water			Applied Water			Applied Water		
	Rate*			Rate*			Rate*		
	0.00	2.00	5.00	0.00	2.00	5.00	0.00	2.00	5.00
2---4	2.08	----	----	2.17	----	----	2.08	----	----
4---6	2.20	----	----	2.50	----	----	2.50	----	----
6---8	2.33	----	----	2.83	----	----	2.58	----	----
8---10	2.41	1.58	----	2.67	.75	----	2.58	----	----
10---12	2.67	1.75	1.91	2.83	1.17	----	2.00	1.00	----
12---14	2.58	2.00	2.33	2.67	2.00	1.08	2.75	2.08	----
16---18	2.75	2.25	2.00	2.67	2.50	1.83	2.91	2.41	2.17
18---20	3.00	2.25	2.58	2.67	2.33	2.08	2.75	2.25	2.41
20---22	2.58	2.50	2.33	2.67	2.41	2.50	2.41	2.41	2.50
22---24	2.67	2.50	2.25	2.67	2.41	2.33	2.41	2.33	2.33
24---26	2.50	1.91	2.17	2.41	2.33	2.00	2.25	2.25	2.58
26---28	2.33	1.72	2.33	2.17	1.91	1.91	2.00	1.92	2.17

*Rate is expressed as active ingredient, pounds per acre.

the 14 inch depth when water equivalent to 3 inches was applied. When 5 pounds per acre was applied and leached with 3 inches of water, plants were killed to the 10 inch depth and lightly stunted to the 12 inch position. Leaching treatment of 9 inches of water moved phytotoxic concentrations to the 8 inch depth, producing severe stunting to 10 inches, moderate stunting to 12 inches, and light stunting to the 14 inch depth in columns treated with 2 pounds per acre prometryne. Application of 5 pounds per acre killed plants to the 12 inch depth and severely, moderately, and lightly stunted plants growing to depths of 14, 18, and 20 inches respectively. Application of the compound at the rate of 2 pounds per acre leached by 18 inches of water killed plants to the 10 inch position, moderately stunted those to 12 inches, and lightly stunted plants to the 14 inch depth. Increased rate of application of the herbicide killed all growth to the 14 inch depth and produced lightly stunted plants at the 18 inch depth.

IV. COTORAN

General Observations

Cotoran was the most highly leached of the four herbicides tested (Figure 6). Even in heavy soil there was downward movement to 20 inches as application rates of both the compound and the water were increased. With applied water at 3 inches and at 9 inches, and the compound applied at the rate of 1 pound per acre, downward movement was minimal with toxic concentrations in only the surface two inches. In moderate and light soils, cotoran moved further and it was evident that mobility increased with increases in the rates of water application.

Specific Soils

Bowdre clay loam soil. Bowdre clay loam soil which was treated with cotoran (Table XVI) applied at a rate of 1 pound per acre, as recommended, produced severely stunted plants to the 6 inch depth when the leaching treatment was 3 inches; while the herbicide applied at a rate of 2.5 times that recommended (2.5 pounds per acre) severely stunted growth to 6 inches and lightly stunted plants were seen to the 10 inch depth. With water application increased to an

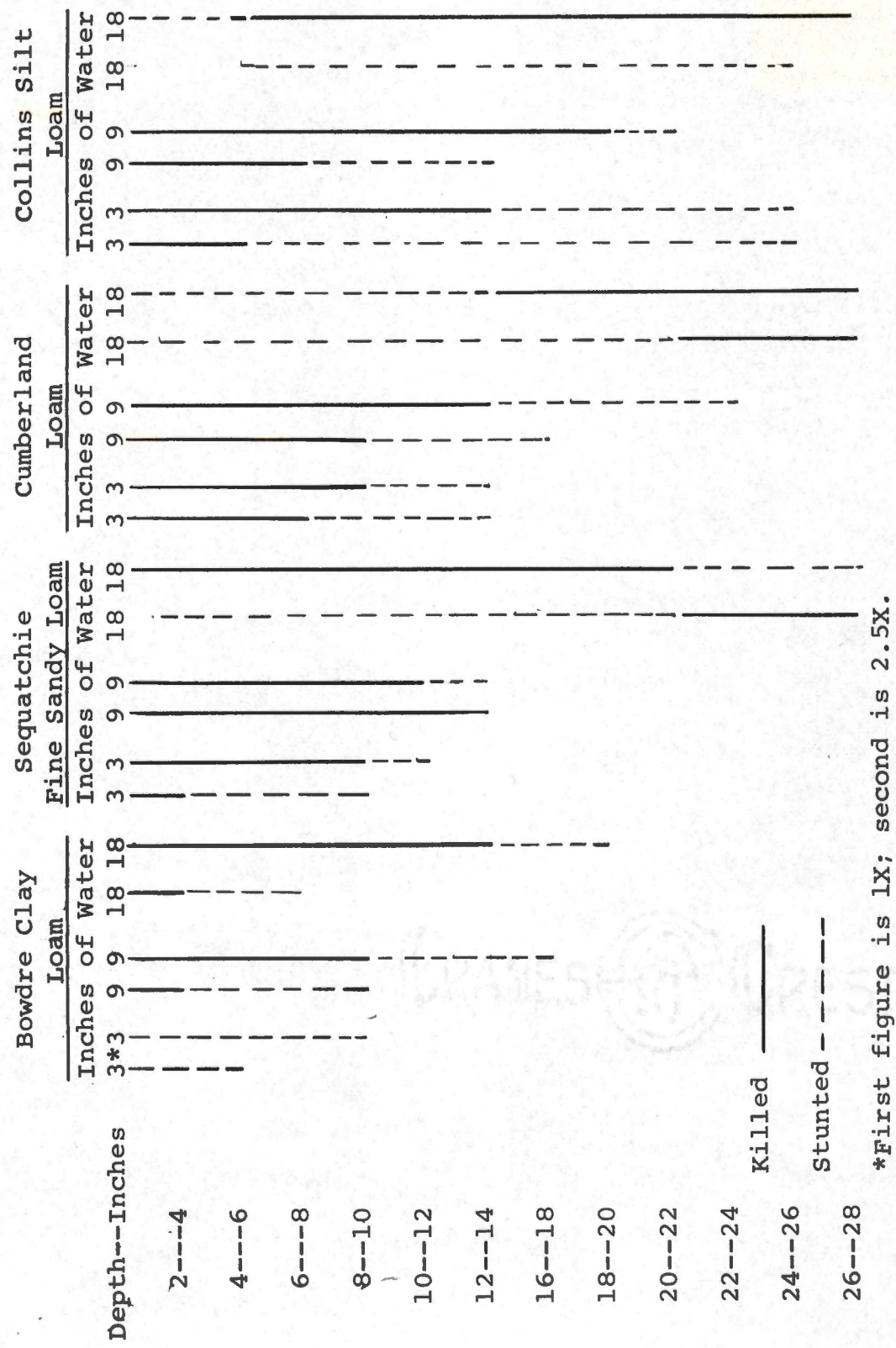


Figure 6. Depth of penetration of cotoran in soil columns leached with three rates of water.

IN BOWDRE CLAY LOAM SOIL WITH COTORAN APPLIED AT TWO RATES AND LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

*Rate is expressed as active ingredient, pounds per acre.

an equivalent of 9 inches, soil which received the compound at the rate of 1 pound per acre contained plants which were affected to the 4, 8, and 10 inch depths, showing, respectively, killing, severe stunting, and moderate stunting. Soil which was treated with 2.5 pounds per acre application of the herbicide produced killed plants to the 10 inch depth and severe stunting of plants to 14 inches, with those plants growing to the 18 inch depth lightly stunted. Eighteen inches of water carried 1 pound per acre applications of the herbicide to the 8 inch depth where plants were moderately stunted; plants growing in the 4-to-6 inch section were severely stunted and, in the first 2 inches, growth was killed. Application of the herbicide at the higher rate (2.5 pounds per acre) killed plants to 14 inches, caused severe stunting to 18 inches, and light stunting to the 20 inch depth was seen.

Sequatchie fine sandy loam soil. Columns of Sequatchie fine sandy loam soil which received cotoran (Table XVII) applications of 1 pound per acre leached with 3 inches of water contained, in the initial two 2-inch sections, killed plants, followed by severely stunted plants

TABLE XVII

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS IN
 SEQUATCHIE FINE SANDY LOAM SOIL, WITH COTORAN APPLIED AT TWO RATES
 AND LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil Column Section Inches	Three Inches			Nine Inches			Eighteen Inches		
	Applied Water			Applied Water			Applied Water		
	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*
	0.00	1.00	2.50	0.00	1.00	2.50	0.00	1.00	2.50
2---4	2.50	----	----	2.58	1.33	----	3.00	2.75	----
4---6	2.91	----	----	3.00	1.50	----	3.25	2.67	----
6---8	3.33	1.17	----	3.41	----	----	3.00	1.00	----
8---10	3.50	2.75	----	3.33	----	----	3.50	.91	----
10---12	3.41	3.08	2.67	3.50	----	----	3.25	.91	----
12---14	3.25	3.33	2.83	3.25	----	.25	3.25	1.00	----
16---18	3.50	3.25	2.67	3.25	2.75	1.58	3.25	.75	----
18---20	3.33	2.91	3.00	3.41	3.25	3.17	3.33	.75	----
20---22	3.25	3.17	2.83	3.33	3.33	3.25	3.33	.91	----
22---24	3.25	3.33	3.33	3.41	3.08	2.83	3.17	----	1.25
24---26	3.33	3.08	2.58	3.08	3.00	3.25	3.00	----	2.00
26---28	3.25	2.58	2.08	3.00	3.00	2.91	3.08	----	2.08

*Rate is expressed as active ingredient, pounds per acre.

to 8 inches and lightly stunted plants to the 10 inch depth. When the applied rate of the herbicide was 2.5 pounds per acre, growth was killed to the 10 inch position and lightly stunted to the 12 inch depth. The plants in soil which received 1 pound per acre cotoran leached through 9 inches of water contained phytotoxic concentrations to the 14 inch depth, preceded by severely stunted plants to the 4 inch depth. When the water treatment remained equivalent to 9 inches and the application rate of the herbicide was increased to 2.5 pounds per acre, the compound was carried 4 inches deeper; however, phytotoxic concentrations ceased at the 12 inch depth, with plants in the zone to 14 inches severely stunted. Plants growing in the initial two-inch sections of columns treated with the herbicide at 1 pound per acre leached through 18 inches of water were not affected although there was moderate stunting of plants to the 6 inch depth and severe stunting to 22 inches, with phytotoxicity evident in the remaining sections of the column. Increased application rate of the herbicide killed growth to the 22 inch depth. Plants in the 22-to-24 inch section were severely stunted and those in the two remaining sections were moderately stunted.

Cumberland loam soil. Cumberland loam soil treated with cotoran (Table XVIII) at 1 pound per acre demonstrated phytotoxic concentrations to the 8 inch depth with severe, moderate, and light stunting of plants to, respectively, 10, 12, and 14 inch depths, with a 3 inch leaching treatment; while with application of the herbicide at a rate of 2.5 pounds per acre, light and moderate stuntings were identical with those of the lower rate, but all growth to the 10 inch depth was killed. Cotoran at 1 pound per acre leached with 9 inches of water killed plants to the 10 inch depth, severely stunted those to 14 inches, and lightly stunted plants to the 18 inch depth. With the same amount of water for leaching, the herbicide, when applied at the rate of 2.5 pounds per acre, moved to the 24 inch depth with only killed plants seen at the 14 inch depth and above, and severe stunting produced to 22 inches. Termination of leaching was seen at the 24 inch depth, where the plants were lightly stunted.

In columns which received 18 inches of water, leaching of cotoran was evident throughout the column. When the rate of application of the herbicide was at the recommended 1 pound per acre, all plants to the 22 inch position were

TABLE XVIII

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS
IN CUMBERLAND LOAM SOIL, WITH COTORAN APPLIED AT TWO RATES AND
LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil' Column Section Inches	Three Inches			Nine Inches			Eighteen Inches		
	Applied Water			Applied Water			Applied Water		
	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*
	0.00	1.00	2.50	0.00	1.00	2.50	0.00	1.00	2.50
2---4	3.17	-----	-----	3.08	-----	-----	3.17	1.08	1.17
4---6	3.58	-----	-----	3.33	-----	-----	3.17	1.17	1.41
6---8	3.58	-----	-----	3.41	-----	-----	3.33	1.25	1.08
8---10	3.58	1.25	-----	3.58	-----	-----	3.50	1.25	1.33
10---12	3.91	3.00	2.58	3.91	.91	-----	3.50	.67	1.08
12---14	3.67	2.91	3.00	3.83	1.08	-----	3.50	.75	1.17
16---18	3.67	3.33	3.50	3.83	3.25	1.08	3.83	.83	-----
18---20	3.41	3.50	3.25	3.67	3.17	1.33	3.67	.67	-----
20---22	3.67	3.33	3.58	3.50	3.25	1.41	3.67	.91	-----
22---24	3.41	3.50	3.41	3.67	3.17	3.00	3.41	-----	-----
24---26	3.75	3.33	3.17	3.41	3.33	3.08	3.41	-----	-----
26---28	3.33	3.25	3.17	3.50	3.08	3.00	3.25	-----	-----

*Rate is expressed as active ingredient, pounds per acre.

severely stunted while killed plants occupied the remaining sections. Severe stunting was seen to the 14 inch depth and killed plants throughout the rest of the column when the compound was applied at the rate of 2.5 pounds per acre.

Collins silt loam soil. Cotoran applied to Collins silt loam soil (Table XIX) at both the recommended rate of 1 pound per acre and at 2.5 times that rate, was leached throughout the columns with those which received the lower rate having only killed plants to 6 inches, severely stunted plants to the 10 inch depth, and moderately stunted plants in the rest of the column, while application at the higher rate produced killing to 14 inches, severe stunting to 22 inches, and, in the rest of the column, moderate stunting.

Varying water treatment to 9 inches in soil treated at 1 pound per acre affected the plants to the 14 inch depth with those to 8 inches killed. Moderate stunting resulted to the 12 inch depth with light stunting to the 14 inch position. Plants were killed to the 20 inch depth and moderately stunted plants were found to 22 inches when the herbicide was applied at the higher rate. Water equivalent to 18 inches carried cotoran applied at 1 pound per acre to

TABLE XIX

AVERAGE LENGTH IN INCHES OF GERMAN MILLET PLANTS IN THREE REPLICATIONS
IN COLLINS SILT LOAM SOIL WITH COTORAN APPLIED AT TWO RATES AND
LEACHED BY THREE, NINE, AND EIGHTEEN INCHES OF WATER

Soil Column Section Inches	Three Inches			Nine Inches			Eighteen Inches		
	Applied Water			Applied Water			Applied Water		
	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*	Rate*
	0.00	1.00	2.50	0.00	1.00	2.50	0.00	1.00	2.50
2---4	2.08	----	----	2.17	----	----	2.08	2.75	1.50
4---6	2.20	----	----	2.50	----	----	2.50	3.00	1.75
6---8	2.33	.67	----	2.83	----	----	2.58	.91	----
8--10	2.41	.67	----	2.67	1.08	----	2.58	.67	----
10--12	2.67	1.08	----	2.83	1.25	----	2.00	.91	----
12--14	2.58	1.50	----	2.67	1.75	----	2.75	.91	----
16--18	2.75	1.25	.67	2.67	2.50	----	2.91	.71	----
18--20	3.00	1.33	.75	2.67	2.75	----	2.75	.67	----
20--22	2.58	1.50	.75	2.67	2.17	1.58	2.41	.17	----
22--24	2.67	1.25	1.25	2.67	2.17	2.33	2.41	.50	----
24--26	2.50	1.17	.83	2.41	1.83	2.17	2.25	2.50	----
26--28	2.33	1.17	.91	2.17	2.17	2.17	2.00	2.50	----

*Rate is expressed as active ingredient, pounds per acre.

the 24 inch depth although no phytotoxicity was observed, in that plants above the 6 inch position were unaffected, those to the depth of 10 inches were moderately stunted, and to 12 inches were lightly stunted. Moderate stunting was observed in plants growing in the 12-to-14 inch position, while only severely stunted plants were found in depths of from 16 to 24 inches. Application of the herbicide at 2.5 pounds per acre noticeably affected the entire columns so treated. There was mild stunting to the 6 inch depth with phytotoxic concentrations evident throughout the rest of the column.

CHAPTER V

SUMMARY AND CONCLUSIONS

In order to study the leaching of trifluralin, linuron, prometryne, and cotoran; 30-inch lengths of black plastic sewer pipe 3 inches in diameter were filled with soil. After presaturation of the vertically-placed columns herbicide treatments of 1 and 2.5 times the recommended rates of application and leaching treatments of 3, 9, and 18 inches of water were replicated three times on Bowdre clay loam soil, Sequatchie fine sandy loam soil, Cumberland loam soil, and Collins silt loam soil.

In pre-formed slots, which were exposed after the leaching period, German Millet was planted. Bioassays were used to evaluate the effects of the herbicides in the columns, with aerial growth measured 24 days after planting.

There was little leaching of trifluralin even when the rate of application was increased to 2.5 times that recommended and the amount of applied water was increased to an equivalent of 18 inches. The results of this study agree quite closely with those of Parka and Worth (51). It can

be said that trifluralin will persist in soil over a prolonged period of time, with determination of the exact length of persistence dependent upon many factors including the rate of application.

Results of the linuron leaching study agree quite closely with those of other studies (10, 16, 62, 68, 77) in that, in coarse textured soils there was marked mobility of the herbicide while in fine textured soil, although the applied water was equivalent to 18 inches, linuron moved only a few inches from the surface, remaining in a highly phytotoxic concentration at the surface. Linuron might persist in soil for a period of from three to four months, although there does appear to be only a minimal residue hazard.

Although application rates of water were increased from 3 inches to 9 inches and 18 inches, in fine textured soil, concentrations of prometryne sufficient for phytotoxicity or serious stunting were not carried below the top inch of soil. However, in coarse textured soil, prometryne moved to a 12 inch depth when the water was applied at the highest rate, a finding not in agreement with that of Rodgers (58) who found no increase in downward movement when

applied water to a sandy soil was increased. There is definite indication of a possibility that prometryne could persist in soil for extended periods of time. This possibility becomes more probable in a cold, dry climate because such a climate is known to effect a reduction in this process of dissipation.

from this study

Cotoran was the most highly leached of the four herbicides tested. Even in fine textured soil there was downward movement to 20 inches when application rates of both the compound and the water were increased. This herbicide leached through the entire depth of the tube in coarse textured soil. causing death to all growth above the 22 inch depth while stunting all plants in the remaining 4 inches of the column. It appears that persistence in soil of cotoran is nonexistent.



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