THE EFFECTS OF ISOPROPYL N- (3-CHLOROPHENYL) CARBAMATE ON VARIOUS CROPS AND THE RESIDUAL ACTION OF THE CHEMICAL WHEN APPLIED TO VARIOUS SOILS

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By

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INTRODUCTION

The chemical isopropyl N-phenyl carbamate is rapidly becoming an important compound for weed control. This compound, better known simply as IPC, has been shown to be promising as a selective herbicide for controlling some grasses among broadleaved crops. The limited solubility and the rapid decomposition of IPC in the soil have led to increased interest in one of its derivatives, isopropyl N-(3-chlorophenyl) carbamate. The chlorinated IPC is of special interest because it remains in a liquid state at ordinary temperatures; is readily soluble with a wide variety of organic solvents; has shown indications of lasting for a longer period of time in the soil than does IPC; and, most important of all, the introduction of a chlorine atom to the IPC molecule has caused increased phytotoxicity.

It is the purpose of this study to determine the effects of 3-chloro IPC on such crops as alfalfa, clover, oats, wheat, rye, sorghum, soybeans, and corn; and also to determine its rate of decomposition in light, heavy, and organic soils under various environmental conditions.

REVIEW OF LITERATURE

Isopropyl N-phenyl carbamate was first shown to be important as a selective plant growth regulator when Templeman and Sexton (33), in a comparison of fifty arylcarbamic esters and related compounds, found that concentrations which arrested the growth of cereals did not affect mangolds, sugar beet, flax, rape, or yellow charlock.

Allard *et al* (2) found that concentrations of from 1 1/2 to 6 milligrams per four inch pot of soil either stunted or killed seedlings of oats, wheat, corn, barley, and non-flooded rice; was less injurious to soybeans, kidney beans, cowpeas, sunflowers, radishes, turnips, and sugar beets; and actually showed a possible stimulatory effect on tomatoes. This tolerance of dicotyledonous plants to the compound was not entirely consistent since applications to potatoes caused a reduction in growth, and the germination of buckwheat was completely prevented. The evidence was sufficient, however, to warrant recommendation that the compound be tested for use as a herbicide on weedy grasses. Allard, De Rose, and Swanson (1) also showed mixtures of the chlorophenoxyacetic acids with IPC would inhibit seedling development of both dicotyledonous and monocotyledonous species indicating that these mixtures had promise as general herbicides.

It was not until August of 1947 that 3-chloro IPC was synthesized at Oregon State College, and to this date very little information on this compound exists in published form. Freed (16) in his work with the chlorinated derivative has found it similar to IPC in effectiveness to various species, but under conditions of high moisture and high temperature it may persist in the soil from two to three times longer than IPC. De Rose (11) also suggested its value as an herbicide after comparative studies of carbamates under greenhouse conditions in which he found that crabgrass seed germinated and developed in all pots except those which had been treated with this compound.

To present a discussion of the growth regulating abilities of 3-chloro IPC it becomes necessary to assume the compound to be much like IPC. Therefore, the review which follows will be the results of investigations made, for the most part, with IPC.

Ennis (14) and Doxey (12) have shown that treatment of oat, rye, and onion roots with IPC resulted in cells with polyploid nuclei, due to impaired action of the spindle fibers. Ennis also describes certain histological changes which occur due to treatment. In general, he found that the increase in chromosome number resulted in increased cell volume of the cortical cells of the primary root, adventitious root initials, and cells of the apical meristem. This increase in cell volume was not observed in some stelar cells, although the chromosome number did increase, presumably due to their lack of capacity to enlarge. He suggested the use of IPC to induce chromosome changes in cereals and grasses. These facts give insight to the mode of action which this chemical and its derivatives have on plant growth. However, Mitchell, Burris, and Riker (23) have observed that IPC, applied to tomato slices at a concentration of 0.002 M, reduced respiration below that of the controls, although it was less effective, in this respect, than other plant growth regulators having a free carboxyl group on an aromatic ring. This may indicate that there is a combination of factors involved in the ability of IPC to induce growth responses.

Thompson, Swanson, and Norman (36), in an attempt to compare the growth regulating activities of many different organic compounds, found that IPC showed 46 percent of the activity of 2,4-dichlorophenoxyacetic acid as determined by the response of germinating corn seedlings, 16 percent with the "kidney bean single droplet water test", and 90 percent with the "kidney bean single droplet oil test". This illustrates the low solubility of IPC in water.

For maximum effectiveness IPC should be applied to the soil rather than to the plant itself. This fact was illustrated by Ennis (13), who found that oats and barley, sprayed with IPC when the soil was not exposed, did not show the characteristic injury which was reported by Templeman and Sexton (33). However, when the soil was exposed, injury occurred and grain yield was reduced.

It was established by Allard, Ennis, and De Rose (2) that young cereal plants were more susceptible to applications of IPC than were older plants. It has, therefore, been considered that the most efficient applications are those made when plants are in a young stage of development, or those made before seedling emergence.

The herbicidal properties of IPC have been demonstrated by several research workers (4, 5, 22, 34, 39). Carlson (4) found that IPC was inhibitory to the growth of rhizomes of quackgrass (*Agropyron repens* L.) in greenhouse tests. Concentrations of 100 parts per million caused rhizomes to develop but few leaves, and concentrations above 500 parts per million completely stopped the development of new shoots. Weeds which he cited as resistant to treatment are lamb's quarters (*Chenopodium album* L.), thistle (*Cirsium arvense* (L.) Scop.), ragweed (*Ambrosia elatior* L.), and clover (*Trifolium repens* L.). In a later report, Wolcott and Carlson (39) stated that field applications of 30 pounds of IPC per acre were effective in delaying bud development of quackgrass rhizomes for 30 to 60 days, but that such treatments did not kill rhizomes, and inhibition was not permanent. Lachman (22) delayed the growth of chickweed in onions for a period of three weeks by the use of 5 pounds per acre, while Carlson and Moulton (5) obtained satisfactory control of chickweed in strawberries with concentrations as low as 5 pounds per acre. Applications were made in September, October, and November with successful control at all times. Templeman and Wright (34) obtained good control of grasses and Polygonum species with 2 1/2 and with 5 pounds of IPC per acre, and mixtures of 5 pounds of IPC with 1 pound of 2,4-dichlorophenoxyacetic acid or 2-methyl-4-chlorophenoxyacetic acid gave good results on weed species which were not susceptible to one of the other of the compounds used in the mixture. The mixtures were superior to IPC alone when applied to chickweed and Gallium aparine.

That 3-chloro IPC appears effective on many grass species not effectively controlled by IPC, has been stated by Freed (16). Among these are the Panicoideal group, which includes water grass (Echinichola crus-galli (L.) Beauv.), and barnyard millet (Setaria spp.). Both IPC and 3-chloro IPC appear to be equal in action on chickweed and purslane, while 3-chloro IPC is more effective on species of Polygonum. Danielson (8) has had successful control of chickweed in spinach with 2 pounds of 3-chloro IPC per acre. A comparison of 2,4-dichlorophenoxyacetic acid, IPC, and 3-chloro IPC by De Rose (11), has shown that 2 and 5 milligrams of 3-chloro IPC per pound of soil prevented the development of crabgrass seedlings beyond the height of 5 millimeters after emergence, while no apparent effect was noted on crabgrass with treatments of IPC below 5 milligrams per pound of soil, and 2,4-dichlorophenoxyacetic acid was found to be intermediate in its action on crabgrass. Crabgrass seedlings, in pots treated with 0.5 milligram of 3-chloro IPC per pound of soil, made only slight recovery.

The importance of the type and degree of injury to crops due to herbicidal applications can not be over emphasized, hence an abundant amount of literature exists which describes the effect of IPC on various species of economic importance (5, 15, 21, 25, 29, 31, 34, 35).

Taylor (31) observed that cereals grown in nutrient solutions, containing as low as 0.25 parts per million of IPC, responded abnormally. Growth was inhibited and changes occurred in the root system, one of the most common of which was a swelling of the root tips. Low concentrations encouraged the development of an increased amount of shoots. Treated plants remained alive, but the leaves became dark green and highly cutinized or leathery. The compound stimulated small tillers on wheat plants and adventitious roots on older rice plants.

Millet, Indian grass, Amber sorghum, and Bermuda grass were not affected by applications of 5 pounds of IPC per acre, in an experiment carried on by Mitchell and Marth (25). Fesque, Ryegrass, Redtop, Timothy, Orchard grass, Quackgrass, and Barley failed to emerge after the above treatment, while Bluegrass emerged only slightly. At much higher concentrations (30 to 60 pounds per acre) the less sensitive grasses, such as sorghum and Sudan grass, grew to a height of 1 to 3 centimeters but failed to develop further. These stunted plants failed to produce seed. At concen-

trations of 50 to 100 pounds per acre, crabgrass extended only 1 to 2 centimeters above the level of the soil and eventually died. Two pound applications of IPC failed to reduce the growth of spinach, onions and table beets. Sugar beets were only temporarily checked, and radishes were affected slightly.

Ennis (15) reports that 13 monocotyledonous species treated with IPC showed a lack of root and shoot elongation with an accompanied swelling of these parts. The roots became stubby and bulbous, and the coleoptile region exhibited a definite dwarfing with the leaves becoming dark green. No epinasty occurred as it did in similar applications of 2,4-dichlorophenoxyacetic acid. Fifteen of 39 dicotyledonous plants tested gave some response to IPC. Nine of these were permanently inhibited: the hypocotyl became enlarged and failed to elongate; the root system remained stunted; the cotyledons did not fully expand; and the stem apex failed to grow. Applications of IPC to the tops of oat plants in the "boot" stage stopped the development of the panicle, while similar treatments in the seedling stage failed to give this response.

Lachman (21) reports that beans, spinach, beets, and onions survived treatments of IPC from 2.5 to 10 pounds per acre, although grasses were effectively controlled.

Five pounds of IPC per acre did not cause injury to kale, mangolds, lettuce, onions, beans, peas, lucerne, sugar beets, or swedes in the experiments of Templeman and Wright (34).

These treatments were applied at least 2 weeks before sowing, however.

Carlson (5) has shown that strawberry plants treated with applications as high as 25 pounds of IPC per acre had yields equal to those of plants in hand weeded rows. The roots of the treated plants appeared more vigorous than the check plants except when the 25 pound rate was used. This treatment caused a darkening of the roots and the formation of new roots at the crown.

The phenomenon of increased growth due to very low concentrations of IPC has been observed by several investigators on certain species, with various growth regulators. However, Thompson (35) used several growth regulators, including IPC, at very low concentrations to determine if these treatments would increase the yield of alfalfa. No increase in yield was obtained where the crop was not in competition with plants which would be killed by treatments.

The information available on 3-chloro IPC indicates that it is selective to the same crops as IPC, but more toxic at high concentrations. De Rose (11) found that rates of 0.5 and 1 milligram per pound of soil had no effect on germinating peas, soybeans, and cotton, but stunted growth of these plants occurred at a 2 milligram rate, and inhibited germination occurred at a 5 milligram rate. These higher concentrations also severely stunted strawberry transplants. When cotton was treated in pots which also contained crabgrass seedlings the crop appeared normal at the 5 milligram rate. All other plants were stunted by high concentrations of 3-chloro IPC when grown in pots which included crabgrass. Danielson (8) has observed that spinach plant stands were reduced from 12 to 14 percent after 2 pounds of 3-chloro IPC had been applied. He did not consider this to be particularly harmful since the plants usually need thinning anyway. Freed (16) relates that both IPC and 3-chloro IPC are being used to control annual grasses in perennial grass crops grown for seed, and in most of the legumes. The clovers of the red clover group are an exception -- they appear to be susceptible to both compounds. The use of these compounds on beets, strawberries, and certain ornamentals, as azalea, has shown IPC to be the least toxic of the two.

One very interesting point, which deserves mention, is the action of IPC in preventing the sprouting of potato tubers in storage. Rhodes et al (29) compared IPC with alpha-naphthylacetate and found it much superior in reducing sprouting.

The factors contributing to the degree of residual action of plant growth regulators when applied to the soil have been investigated to a limited extent. By far the largest amount of work has been done with 2,4-dichlorophenoxyacetic acid, and it has been assumed that these factors described for 2,4-D contribute to the persistence of most herbicides.

That different compounds vary in ability to last in the soil, has been well established (9, 10). De Rose and Newman (10) compared 2,4-dichlorophenoxyacetic acid with 2,4,5-trichlorophenoxyacetic acid and 2-methyl-4-chloroacetic acid, and found that 2,4,5-trichlorophenoxyacetic acid persisted for a longer period than did the other compounds, independent of concentration, temperature, or soil moisture. De Rose (9) also has shown that applications of 50 pounds of IPC per acre completely lost its inhibitory effect within 60 days while 50 pounds of 2,4-dichlorophenoxyacetic acid lasted nearly 80 days.

The influence of the soil on the breakdown of herbicides can be broken down into five main catagories: soil moisture; soil temperature; soil reaction; organic matter content; and microbial action.

De Rose (9) leached soils treated with IPC and 2,4-dichlorophenoxyacetic acid and found these compounds present in the leachate. Crafts (6) found that 2,4-dichlorophenoxyacetic acid does not move freely by percolation, and that excessive amounts of water are required to leach this compound downward, with leaching being more pronounced in sandy loam than in clay loam. Hanks (18), working with 2,4-dichlorophenoxyacetic acid and its calcium salt, observed that leachates of treated peat soils were non-toxic at the end of 2 weeks, and all other soils used except one, which was naturally alkaline, had leachates which were non-toxic after 6 weeks. Brown and Mitchell (3) have indicated that 2,4-dichlorophenoxyacetic acid was inactivated most rapidly

at a moisture content of 30 percent. Mitchell and Marth (24) found 2,4-dichlorophenoxyacetic acid to last as many as 18 months in air dried soil, while it is without toxic effects in about 28 days in warm moist soil. Hernandez and Warren (19) have made similar observations.

De Rose and Newman (10) state that persistance varies inversely with the soil temperature. Crafts (6) and Brown and Mitchell (3) also give support to this statement. Hernandez and Warren (19) stored soils treated with 2,4-dichlorophenoxyacetic acid at various temperatures and found that persistance was greatest at the minimum temperature of 40 degrees.

Kries (20) has shown inactivation to be less rapid in soils of high alkalinity, and Hanks (18) has indicated that limed soils do not effect persistance but that those soils which are naturally alkaline remain toxic for a longer period. Crafts (6), in observation of several California soils, has concluded that 2,4-dichlorophenoxyacetic acid is broken down more slowly in naturally alkaline and neutral soils than in acid soils. A very interesting point in this connection is that Weaver (37) has found that 2,4-dichlorophenoxyacetic acid is more strongly adsorbed by cation exchangers of the hydrogen form, while IPC is adsorbed equally by those of the hydrogen, calcium, and sodium form.

The addition of leaf mold to soils treated with 2,4-dichlorophenoxyacetic acid strikingly reduced the degree of persistance of toxicity in the experiments of Kries (20).

Brown and Mitchell (3) found that the addition of small amounts of manure increased the rapidity with which this compound disappeared, but that applications of 2,000 to 8,000 pounds of manure per acre retarded inactivation. Hernandez and Warren (19) have shown that 2,4-dichlorophenoxyacetic acid was leached more rapidly from soils low in organic matter than from soils high in organic matter.

Brown and Mitchell (3); De Rose and Newman (10); Hernandez and Warren (19); and Newman et al (27), have shown that herbicides last longer in soils which have been autoclaved in contrast to non-autoclaved soils. Compounds included in these various experiments include IPC, 2,4-dichlorophenoxyacetic acid, 2,4,5-trichlorophenoxyacetic acid, and 2-methyl-4-chlorophenoxyacetic acid. This has led to the belief that much of the disappearance of toxicity after application is due to the action of microorganisms.

The action of plant growth regulators on the soil population has not gone without investigation. Newman (26) found that as the acidity of the soil increased 2,4-dichlorophenoxyacetic acid, 2-methyl-4-chlorophenoxyacetic acid, and 2,4,5-trichlorophenoxyacetic acid, at 125 and 500 parts per million, showed increasing inhibitory effects on the soil population. However, IPC, ethyl-2,4-dichlorophenoxyacetic acid, and ethyl-2-methyl-4-chlorophenoxyacetic acid were equally inhibitory to organisms at all pH levels. The author proposed that growth regulators are inhibitory to soil life only in undissociated form. He also found that

2,4-dichlorophenoxyacetic acid, 2-methyl-4-chlorophenoxyacetic acid, 2,4,5-trichlorophenoxyacetic acid, and IPC inhibited nitrification of ammonium sulfate at high concentrations. Tests for carbon dioxide evolution showed that the above compounds were also inhibitory in this respect, with IPC being the least inhibitory. Smith et al (30) found 2,4-dichlorophenoxyacetic acid did not reduce the total count of microorganisms, but that nitrate and nitrite forming organisms were injured by 100 parts per million. The nitrite organisms were more sensitive than the former.

Newman and Thomas (28) applied 2,4-dichlorophenoxyacetic acid to soil which had been pretreated with the same compound and found the residual action much less after a second application, but when soils were pretreated with compounds related to 2,4-dichlorophenoxyacetic acid the persistance was not reduced. This suggests that the organisms responsible for the decomposition of 2,4-dichlorophenoxyacetic acid are quite specific.

The specific residual properties of IPC are of interest. Wolcott and Carlson (30) reported that IPC was inactivated under field conditions, within 30 to 60 days, depending on the concentration. Weaver (38) found IPC lasted only 12 days in a three-to-one mixture of silt loam and coarse sand, with a moisture content of 18.2 percent, and a pH of 8.1. He used concentrations as high as 220 parts per million based on the dry weight of the soil. Mitchell and Marth (25),

however, have shown that 2 pounds per acre lasted almost 2 months. Taylor (32) applied IPC at rates of from 1 to 4 pounds per acre on neutral and alkaline soils in the field and found that IPC lasted only 5 weeks. Newman _et al_ (27) have made an extensive study of the persistance of IPC in the soil. In their experiments oat seedlings emerged 0, 40, 50, 80, and 100 percent of controls after 8 days with treated soils incubated at 10, 15, 20, 25, and 30 degrees Centigrade. After 20 days there was only a slight stunting of seedlings at the 10 degree level, and after 36 days there was no visible toxic effects at any temperature level. After 19 days IPC had disappeared at all moisture levels except 100 percent water holding capacity and flooded soil. Silt loam, with a pH of 6.7, treated with 9, 44, 220, and 1,102 pounds per acre showed a loss of toxicity in 15, 19, 36, and 39 days. In still another experiment the compound was broken down in three weeks despite the concentration.

De Rose (11) has compared the residual action of IPC with 3-chloro IPC, and his results were quite significant. While IPC at the rate of 2 milligrams per pound of soil inhibited barley seeds for less than 24 days, the 3-chloro compound lasted from 48 to 56 days. His results indicated strongly the ability of 3-chloro IPC to last for a longer period than IPC.

METHODS AND MATERIALS

The chemical used in the following experiments has the name isopropyl N-(3-chlorophenyl) carbamate. The emperical formula of this compound is $C_6H_4ClNHCO_2C_3H_7$, and it was used exclusively in the following formulation:

Isopropyl N-(3-chlorophenyl) carbamate .	40.6%
Xylene	38.2%
Isopropyl alcohol.	3.1%
Atlas G1255.	18.1%

The concentrations used were based on the actual weight of 3-chloro IPC per unit weight of soil. In each case the chemical was suspended in enough water to insure adequate coverage of the soil or leaf surface, as the case demanded.

In the experiments to determine the residual action, the terms light, heavy, and organic soil will be used. These soils are mixtures described in Table 1. The reaction of these soils ranged from pH 6.0 to pH 6.5 where the reaction was not adjusted.

The terms pre-planting, pre-emergence, and post-emergence when used to describe the time of application, demand definition. Pre-planting treatments were applied to the soil before the crop was planted; pre-emergence treatments were applied to the soil after planting but before the crop seedlings emerged from the soil; and post-emergence treatments were applied after emergence of the crop seedlings.

For the convenience of the reader the description of the work done will be divided into four parts: (1) Laboratory technique used in determining the residual action of 3-chloro IPC in various soils; (2) Greenhouse experiments to determine the residual action of 3-chloro IPC in various soils; (3) A field experiment to compare the residual action of 3-chloro IPC with IPC; and (4) Field experiments to determine the toxicity of 3-chloro IPC to various crops.

TABLE 1

A DESCRIPTION OF HOW SOIL MIXTURES WERE PREPARED IN EXPERIMENTS INVOLVING THE RESIDUAL ACTION OF 3-CHLORO IPC

Soil mixture	Kind and amount of soil in mixture
Light soil	1/2 sand 1/2 garden soil
Heavy soil	1/4 clay 1/4 sand 1/2 garden soil
Organic soil	1/4 peat 1/4 sand 1/2 muck

Laboratory Experiment Involving A Technique Used In Determining The Residual Action of 3-Chloro IPC In Various Soils

Five gram samples of light, heavy, and organic soil mixtures, which had been air dried, were shaken with 25 milliliters of water containing 0, 1,000, 5,000, 10,000, 50,000, 100,000, and 200,000 parts per million of 3-chloro IPC based on 5 grams of soil. The shaking process lasted for 2 minutes to ensure contact of the chemical with the soil particles. The mixture of soil, chemical, and water was then filtered through a filter paper, and the leachate collected in a beaker. A 5 milliliter sample of the leachate from each treatment was added to a Petri dish containing 15 cucumber seeds (Marketer variety) placed on a filter paper. The Petri dishes were covered and the cucumber seeds were allowed to germinate for 4 days at room temperature, after which the root length of each seedling was measured and recorded.

Similarly, a 5 milliliter sample of 25 milliliters of water containing 0, 1,000, 5,000, 10,000, 50,000, 100,000, and 200,000 parts per million of 3-chloro IPC, which had not been mixed with the soil, was applied to 15 cucumber seeds in a Petri dish. These seeds were allowed to germinate along with the seeds treated with the soil leachates, to determine the sensitivity of cucumber seeds to the concentrations of 3-chloro IPC used.

Subsequent leachings of these soil samples were made at weekly intervals for 7 weeks. Leaching was accomplished with 25 milliliters of water, and, as before, a 5 milliliter sample of the leachate was applied to 15 cucumber seeds, which were allowed to germinate for 4 days. The color of the leachates and the length of the seedling roots were observed.

Greenhouse Experiments To Determine Residual Action Of 3-Chloro IPC In Various Soils

Experiment I. Portions of light, heavy, and organic soils were divided into thirds and the acid reaction of each third adjusted to pH 3, pH 7, and pH 8.5 respectively. The adjustment to an acid reaction was made with dilute sulfuric acid; the adjustment to a neutral reaction was made with calcium carbonate; and the high alkaline condition was accomplished by adding calcium carbonate until no further change in reaction occurred, and then raising it to pH 8.5 by the addition of sodium carbonate.

Samples of each soil and each reaction were placed in number 10 tin cans in such a way that there were 3 cans containing light soil with a pH 3, 3 cans containing light soil with a pH 7, and 3 cans containing light soil with a pH 8.5. A similar number of cans containing heavy and organic soils were prepared.

On April 17, 1951, 25 oat seeds were planted in the cans at a depth of about 1/2 inch, water was added to field capacity, and the soils were treated with 2 and 24 pounds per acre of 3-chloro IPC by pouring it over the surface of the soil. Each treatment included one can of each kind of soil and each reaction. Untreated controls of each kind of soil and of each reaction were also used as shown in Table 2.

The oat seeds were allowed to germinate and continue growth for approximately 10 days. The tops of the oat seedlings were cut off at the surface of the soil and the fresh

TABLE 2

DIAGRAM OF GREENHOUSE EXPERIMENT I SHOWING THE RATE OF APPLICATION OF 3-CHLORO IPC ON VARIOUS SOILD ADJUSTED TO DIFFERENT pH LEVELS

Treatment	Kind of soil and pH reaction								
	Organic soil			Light soil			Heavy soil		
Control	3	7	8.5	3	7	8.5	3	7	8.5
2 pounds/acre	3	7	8.5	3	7	8.5	3	7	8.5
24 pounds/acre	3	7	8.5	3	7	8.5	3	7	8.5

weights were recorded. Planting was repeated after weights were taken, and this continued approximately every 10 days until the treated soils produced seedlings of a weight equal to or above the weight of those grown in the control cans.

The cans were not allowed to drain and care was taken to keep the soil moisture at about field capacity. At each planting the soil in the top 3 inches was mixed to insure contact of the seed with the soil.

Experiment II. Three groups of fifteen number 10 tin cans were filled with light, heavy, and organic soils respectively. Before filling these cans, holes were punched in the bottom to allow drainage and a filter paper was laid inside to prevent the loss of soil particles. After filling, the cans were placed on two 2" x 4" boards in such a manner that beakers could be placed beneath the cans to catch the leachate.

Twenty-five oat seeds were planted in each can at a depth of about 1/2 inch. Each group of 15 cans was further divided into groups of five. One can of the 5 was saved as a control while the other 4 cans were treated with 2, 6, 12 and 24 pounds of 3-chloro IPC per acre based on the weight of the soil. The soil was then brought to field capacity and finally leached with 1, 1 1/2, and 2 surface inches of water. The treatment was applied on April 28, 1951.

The fresh weight of the tops of the seedlings was taken after about 10 days and the cans were replanted at the end of 2 weeks. The soils were leached every week after the initial leaching with the same amount of water. Replanting was continued until the growth of seedlings in the treated soils was equal to or greater than the seedlings grown as controls.

After each leaching a 5 milliliter sample of the leachate from each can was added to a Petri dish containing 10 cucumber seeds. The seeds were allowed to germinate at room temperature for 4 days at which time the lengths of the roots were measured and recorded.

After the toxic effects of the 3-chloro IPC had disappeared from the surface of the soil treated with the highest concentration (24 pounds per acre), as determined by the growth of the oat seedlings, the soil in the cans was divided into thirds to separate the upper 2 inches, the middle 2 inches, and the lower 2 inches. These individual soil layers were put into four inch pots and planted with oat seeds. After 10 days the fresh weight of the tops of the seedlings was recorded. Each kind of soil was treated individually in this respect, since the compound did not disappear as rapidly from the organic soil as it did from the light and heavy soil.

Table 3 illustrates the experimental set up for this leaching experiment.

Experiment III. One hundred and sixty-two four inch pots were divided into equal groups of three to be stored at temperatures of 35, 55, and 75 degrees Fahrenheit. Each

TABLE 3

DIAGRAM OF GREENHOUSE EXPERIMENT II SHOWING THE PLAN USED TO DETERMINE THE EFFECT OF LEACHING WITH VARIOUS AMOUNTS OF SURFACE WATER ON THE RESIDUAL ACTION OF 3-CHLORO IPC IN VARIOUS SOILS

Amount of surface water used in leaching	Pounds of 3-chloro IPC applied to three soil mixtures														
	Light					Heavy					Organic				
1 inch	C	2	6	12	24	C	2	6	12	24	C	2	6	12	24
1 1/2 inches	C	2	6	12	24	C	2	6	12	24	C	2	6	12	24
2 inches	C	2	6	12	24	C	2	6	12	24	C	2	6	12	24

group of 3 was again divided into thirds to be filled with light, heavy, and organic soils. Each kind of soil was treated with 2 and 24 pounds of 3-chloro IPC per acre based on the weight of the soil, and a number of pots were kept for controls. Addition of the compound to the soil occurred June 22, 1951.

The pots were then placed in sand filled flats so that it would not be necessary to water them from the top and thus keep leaching to a minimum. The respective groups were then stored: one in a cold storage room with a temperature of 35 degrees Fahrenheit; one in cold storage at 55 degrees Fahrenheit; and the other in the greenhouse, where temperatures averaged about 75 degrees Fahrenheit. The soil in the pots was kept moist at all times. Every 2 weeks for a period of 12 weeks a series of pots, of each treatment and kind of soil, and from each storage temperature, were removed. Twenty oat seeds were planted to a depth of 1/2 inch in each pot. These seeds were allowed to germinate and develop for a period of 2 weeks. The fresh weights of the tops of the seedlings were recorded.

A Field Experiment To Compare The Residual Action Of 3-Chloro IPC With IPC

A field plot 24 feet by 8 feet was further divided into lesser plots of 4 feet by 4 feet. On July 3, 1951, three of these plots were sprayed with IPC in concentrations of 2, 6, and 12 pounds per acre, and another 3 plots were sprayed with 3-chloro IPC in the same concentrations. Plots were spaced such that there were at least two controls on either side of a treatment, as shown in Table 4. The chemicals were added to one quart of water and applied with a compressed air sprayer. Isopropyl N-phenyl carbamate was applied as a 50 percent wettable powder.

Oat seeds were scattered over the plots by hand and each plot was raked to insure contact of the soil with the seeds. Two weeks after planting 10 seedlings were weighed and these fresh weights recorded. Replanting was continued in the same manner every 2 weeks until the weight of the seedlings grown on the treated plots was equal to or greater than those grown on the control plots.

This experiment was carried out on Hillsdale sandy loam soil graded into Grandy sandy loam. The reaction ranged from pH 6 to pH 6.5. This also describes the soil used in the next experiment on crop toxicity.

Field Experiments To Determine The Toxicity Of 3-Chloro IPC To Various Crops

A field plot, 75 feet by 300 feet, was divided into 270 smaller plots each 2 feet by 20 feet. The rows ran lengthwise with 15 plots to the row and 2 rows were allowed for each of 9 crops. A space 2 feet wide was allowed between each row of plots.

An equal number of plots were allowed for each of 3 treatments: (1) pre-planting; (2) pre-emergence; and (3) post-emergence. Each division of treatments included a control and 1, 3, 6, and 12 pounds of 3-chloro IPC per acre

TABLE 4

DIAGRAM OF THE FIELD EXPERIMENT SHOWING THE PLAN USED TO COMPARE THE RESIDUAL ACTION OF 3-CHLORO IPC WITH IPC WHEN APPLIED TO A SANDY LOAM SOIL

3-Chloro IPC 12 lbs./acre	Control	IPC 6 lbs./acre	Control	3-Chloro IPC 6 lbs./acre	Control
Control	IPC 2 lbs./acre	Control	3-Chloro IPC 2 lbs./acre	Control	IPC 12 lbs./acre

based on soil weight. All plots were assigned a treatment in a random fashion and each treatment was repeated twice.

On May 20, 1951 the pre-planting treatment was applied. The chemical was added to 3 gallons of water and applied with a compressed air sprayer to all plots designated to receive the particular concentration. Between May 21, 1951 and May 24, 1951 the crops were planted. The seeds were sowed by hand and the rows were raked by hand after sowing. The corn was planted in hills 1 1/2 feet apart and the soil was not raked after planting. The following crops were planted: alfalfa, red clover, ladino clover, rye, oats, wheat, soybeans, sorghum, and corn.

On May 26, 1951 the pre-emergence treatment was applied, and 1 month after the germination of all crops (June 29, 1951) the post-emergence treatment was applied. On June 15, 1951 the percentage of germination of seedlings developing from the pre-planting and pre-emergence treatments was recorded. These data were obtained by counting the number of crop plants found in 4 samples of 1 square foot each, from all treated plots. On June 22, 1951 the percentage of weeds killed in the pre-planting and pre-emergence treatments was recorded. The data were taken by counting the number of weeds per square foot in the manner mentioned above. Between July 15, 1951 and July 31, 1951 plants were dug from each control plot and from each treated plot and the fresh weights of the roots and shoots were recorded.

RESULTS

Results Of The Laboratory Experiment To Determine The Residual Action Of 3-Chloro IPC In Various Soils

Concentrations of 3-chloro IPC similar to those applied to the soils were also added to 25 milliliters of water so that a 5 milliliter sample could be used to test the sensitivity of the cucumber seeds when the concentration was at its maximum. Table 5 shows that the cucumber seed test was sensitive in the range of concentrations used.

Figure I indicates that 3-chloro IPC was leached from light, heavy, and organic soils by 25 milliliters of water, but that the amount leached from each soil was not related to the concentration, with the lowest concentration an exception. There is also shown some tendency for each leaching to remove less of the chemical from the soil, probably because there was progressively less of the chemical to be removed as the leaching proceeded from week to week.

No comparison can be made of the property of the individual soil mixtures to lose the chemical by leaching, since the leachate from the control sample of the organic soil stimulated the roots of the cucumber seedlings to grow to almost 5 times the length of roots of seedlings grown in

TABLE 5

INHIBITION OF THE PRIMARY ROOT OF GERMINATING CUCUMBER SEEDS TO VARIOUS CONCENTRATIONS OF 3-CHLORO IPC WHICH WERE ADDED TO TWENTY-FIVE MILLILITERS OF WATER TO BE COMPARED WITH TOXIC EFFECTS OF SIMILAR CONCENTRATIONS ADDED TO SOIL

Concentration of 3-chloro IPC in parts per million	Amount of inhibition of cucumber roots expressed as a percentage of the growth of normal roots
1,000	9
5,000	7
10,000	6
50,000	4
100,000	3
200,000	2

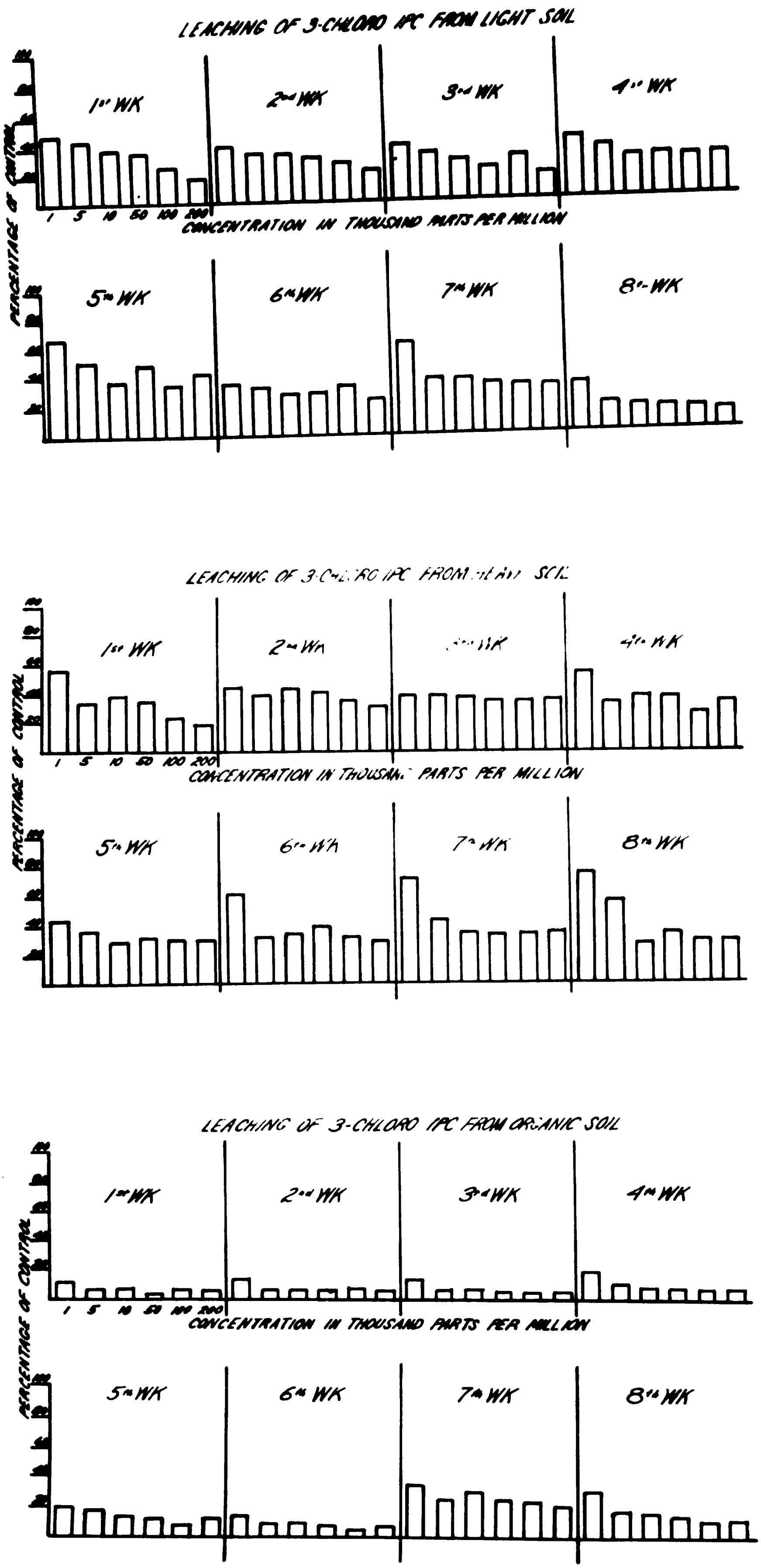


Figure I. Graphs showing the loss of 3-chloro IPC from 5 gram samples of 3 soils with 25 milliliters of water, as measured by the inhibition of germinating cucumber seed leachates of light and heavy soil. This was probably due to the extra nutritional value of the organic soil.

At the outset of this leaching experiment the leachates obtained from the soils treated with the highest concentrations were cloudy. This cloudy appearance was intensified as the concentration was increased. After the eighth week, however, the leachates from the organic soils, even at the highest concentration, were clear although the chemical contained in these leachates remained toxic to germinating cucumber seeds. This clearing of leachates, from week to week as the experiment continued, was not observed with the light and heavy soils.

The response of the cucumber seedlings to these concentrations of 3-chloro IPC was of interest. The most severe injury was expressed by an extreme swelling at the cotyledonary plate with the root failing to develop. Milder injury was expressed by the development of a swollen, club-like primary root from which no secondary roots developed. Seemingly less toxic concentrations caused growth that was more nearly normal but injury was shown by the shorter length of the primary root as compared to the roots produced by seedlings in the control cultures.

It was also observed that the soils treated with 50,000, 100,000, and 200,000 parts per million leached more slowly than those soils treated with the lower concentrations. The soils with the higher concentrations also failed to dry out from week to week, while the soils treated with the lower

concentrations became dry within 24 hours after leaching.

If the experiment could have been extended until all toxic effects were removed, the data would have been more complete, however due to an unforeseen accident the experiment was discontinued after eight weeks.

Results Of Greenhouse Experiments To Determine The Residual Action Of 3-Chloro IPC On Various Soils

Experiment I. Figure II is a graphical representation of experiments involving the effect of soil reaction on the persistance of 3-chloro IPC in light, heavy, and organic soil.

It can be clearly seen that the acid soils, when treated with 2 pounds per acre, lost their toxic effect on oat seedlings before those soils of pH 8.5. The heavy, organic, and light soils at pH 3 were completely free of inhibitory action due to 3-chloro IPC in 9, 18, and 37 days, while the alkaline heavy, organic, and light soils did not produce normal oat seedlings for 18, 37, and 47 days respectively. The loss of the chemical from neutral soils was somewhat more variable, with the light soil being non-toxic in 29 days, and the heavy and organic soils in 47 days.

The opposite relationship occurred when these soils of different reaction were treated with 24 pounds per acre. The alkaline soil was not toxic after 72 days in the case of the heavy soil, and 95 days in the case of the light and organic soils (Figures III and IV). In the acid, heavy soil the chemical remained active up to 108 days, and in the acid, light and organic soils the toxic effect was still present

Figure II. Graphs showing the loss of 3-chloro IPC from 3 soils adjusted to 3 pH levels, as measured by the inhibition of oat seedlings: (a) pH 3 - 2 lbs./acre, (b) pH 3 - 24 lbs./acre, (c) pH 7 - 2 lbs./acre, (d) pH 7 - 24 lbs./acre, (e) pH 8.5 - 2 lbs./acre, (f) pH 8.5 - 24 lbs./acre.

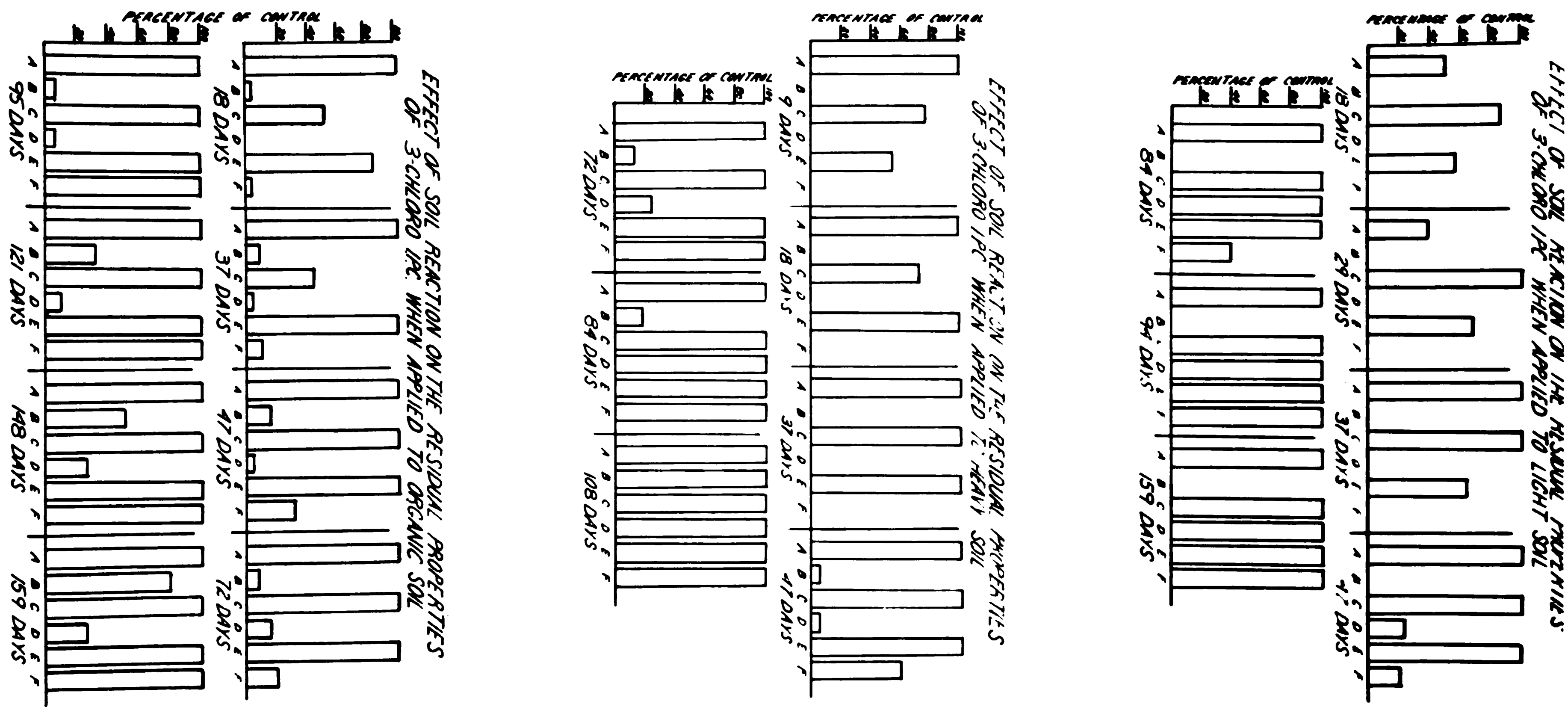


Figure III. Growth of oat seedlings in heavy soil adjusted to pH 8.5, 47 days after treatment with 3-chloro IPC: (1) control, (2) 2 lbs./acre, and (3) 24 lbs./acre.

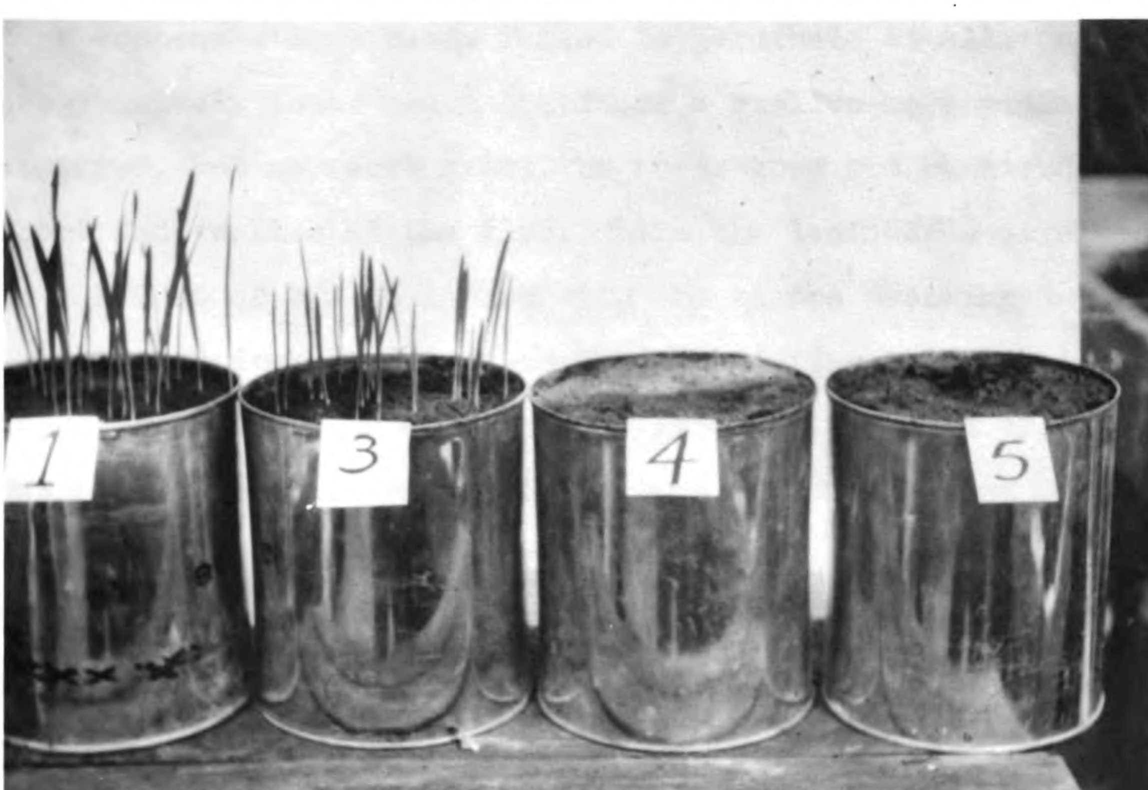


Figure IV. Growth of oat seedlings in soils adjusted to pH 8.5, 47 days after treatment of (1) heavy control soil, (2) heavy soil, (3) light soil, and (4) organic soil at the rate of

159 days after treatment. Again, the neutral soil varied from this relationship with the light and heavy soils becoming non-toxic in 84 days whereas the organic soil remained toxic more than 159 days.

During this experiment the highly alkaline soil formed a dark crust at the surface, and did not dry out as rapidly as did the neutral and acid soils. This was assumed to be a black alkali condition due to an abundance of sodium carbonate. Black alkali soils are known to result in a deflocculation of the soil colloids with the soil becoming puddled. The development of anaerobic conditions in the soil usually ensues.

In this experiment, and in all of the following experiments in which oats were used as a test crop, the seedlings showed a characteristic response to 3-chloro IPC. At very high concentrations seeds failed to germinate at all. At progressively lower concentrations: a swollen coleoptile appeared, but no roots grew; the roots grew but remained short and swollen at the tips, while the leaf blade developed to a height of 1/2 to 1 inch with the tissue becoming brittle and dark bluish-green in color (often these seedlings would die 2 or 3 days after germination); the growth was nearly normal, but the leaf blade showed signs of epinasty. Usually when a soil became completely free of toxic effects the oats grew at a much greater rate than the controls, with later plantings developing at the same rate as controls. This indicates that very light applications of

3-chloro IPC may be stimulating to the growth of oats.

Experiment II. The amount of surface water applied to light, heavy, and organic soils did not appear to influence the length of time required for the toxic effects of 3-chloro IPC to disappear, as is shown in Figure V. However, the type of soil to which the chemical was applied did influence the loss of toxicity (Figure VI). The light and heavy soils usually were completely free of toxic effects on the test crop in 30, 60, 76, and 104 days for rates of 2, 6, 12, and 24 pounds per acre respectively, while the toxic effect was lost from the organic soil in approximately 44, 76, 90, and 148 days depending on the rate of application.

The use of the cucumber seedling test to determine the relative amounts of 3-chloro IPC in the leachate from the light, heavy, and organic soils, proved to be unsatisfactory. No significant results were obtained, either because the chemical did not leach the full depth of the soil (6 inches), or because the cucumber seedlings did not respond at low concentrations of the compound.

One hundred and four days after treatment, the cans of light and heavy soils were dumped and soil from each can divided into 3 layers so that the toxicity remaining below the surface soil could be determined. The degree to which these three soil layers inhibited the growth of germinating oat seeds is illustrated in Figure VII. Apparently there are toxic effects remaining below the surface even after the

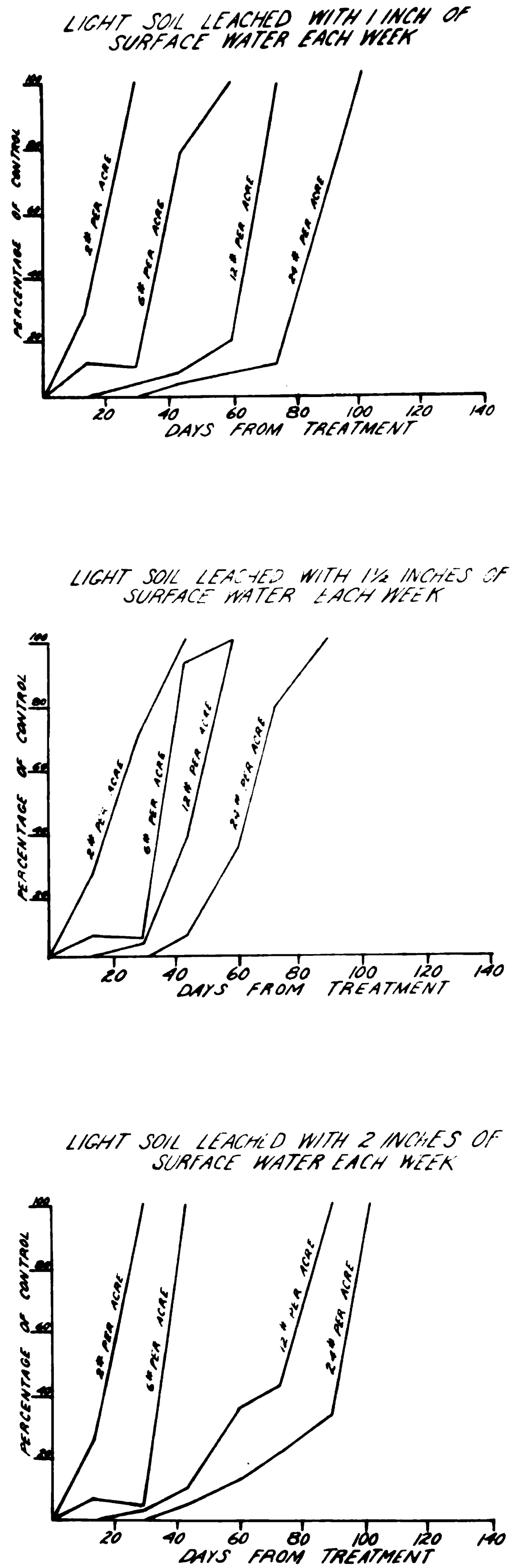


Figure Va. Graphs showing the loss of 3-chloro IPC from light soil after weekly leachings with various amounts of surface water, as measured by the inhibition of oat seedlings.

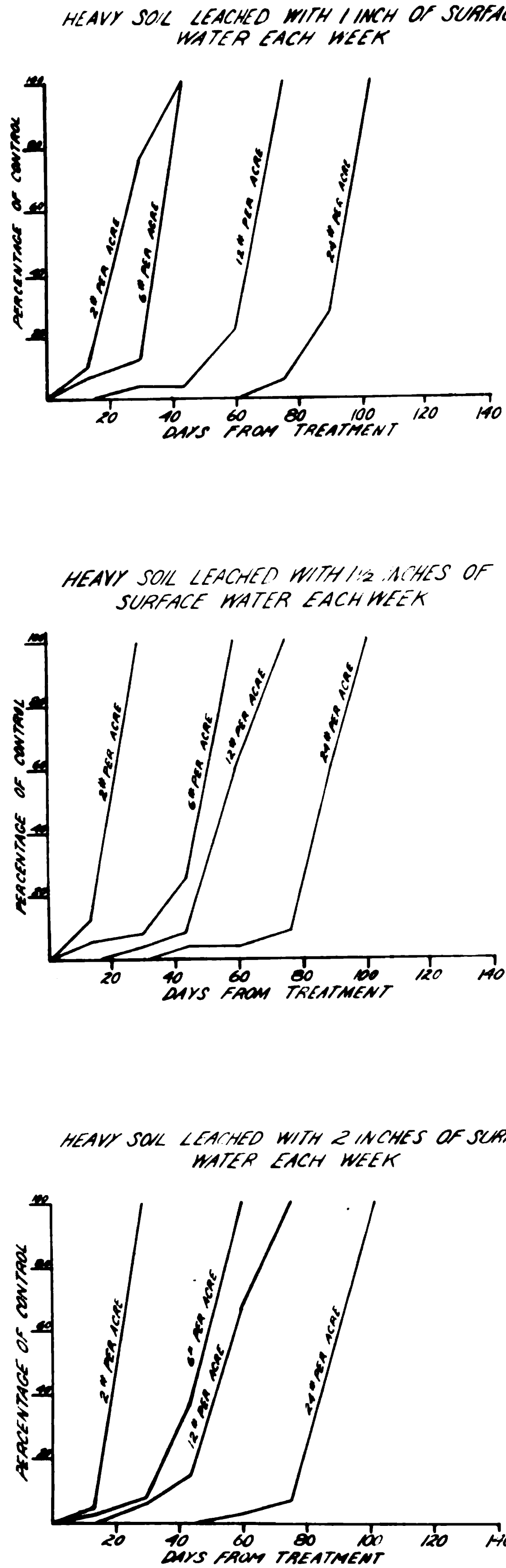


Figure Vb. Graphs showing the loss of 3-chloro IPC from heavy soil after weekly leachings with various amounts of surface water, as measured by the inhibition of oat seedlings.

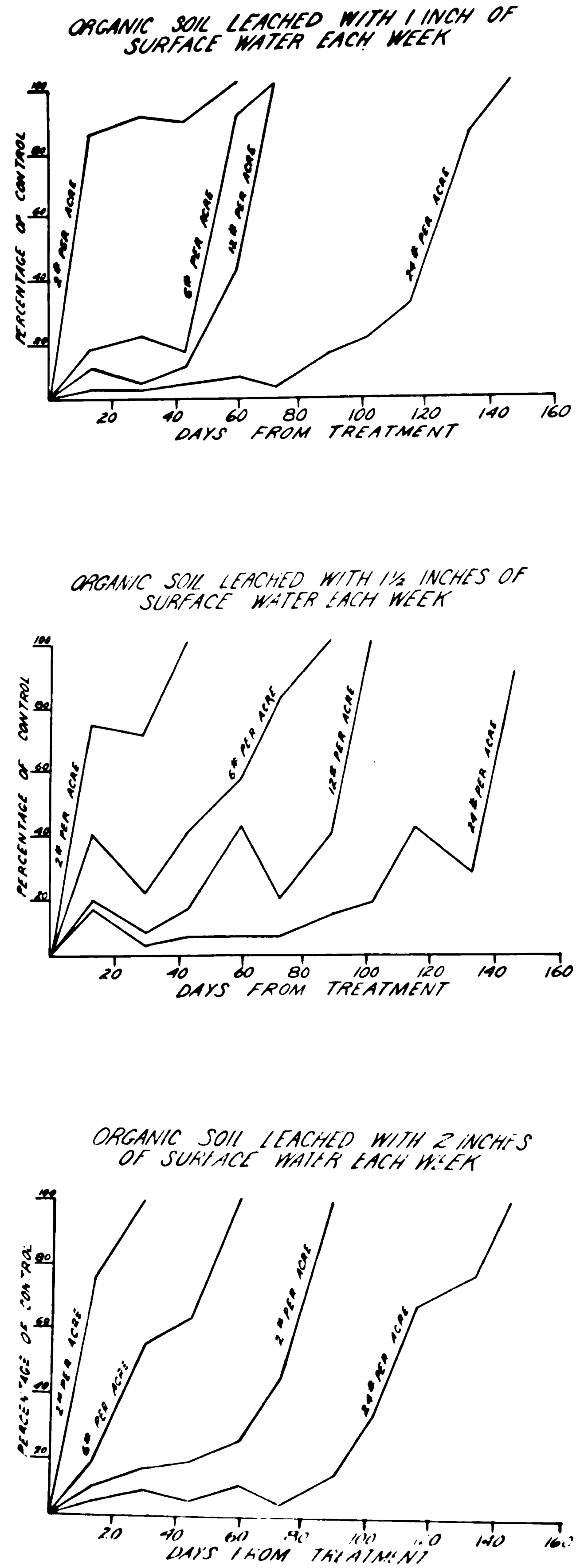


Figure Vc. Graphs showing the loss of 3-chloro IPC from organic soil after weekly leachings with various amounts of surface water, as measured by the inhibition of oat seedlings.

Figure VI. The growth of oat seedlings in light, heavy, and organic soils 102 days after treatment with 24 lbs./ acre of 3-chloro IPC and weekly leaching with one inch of surface water.

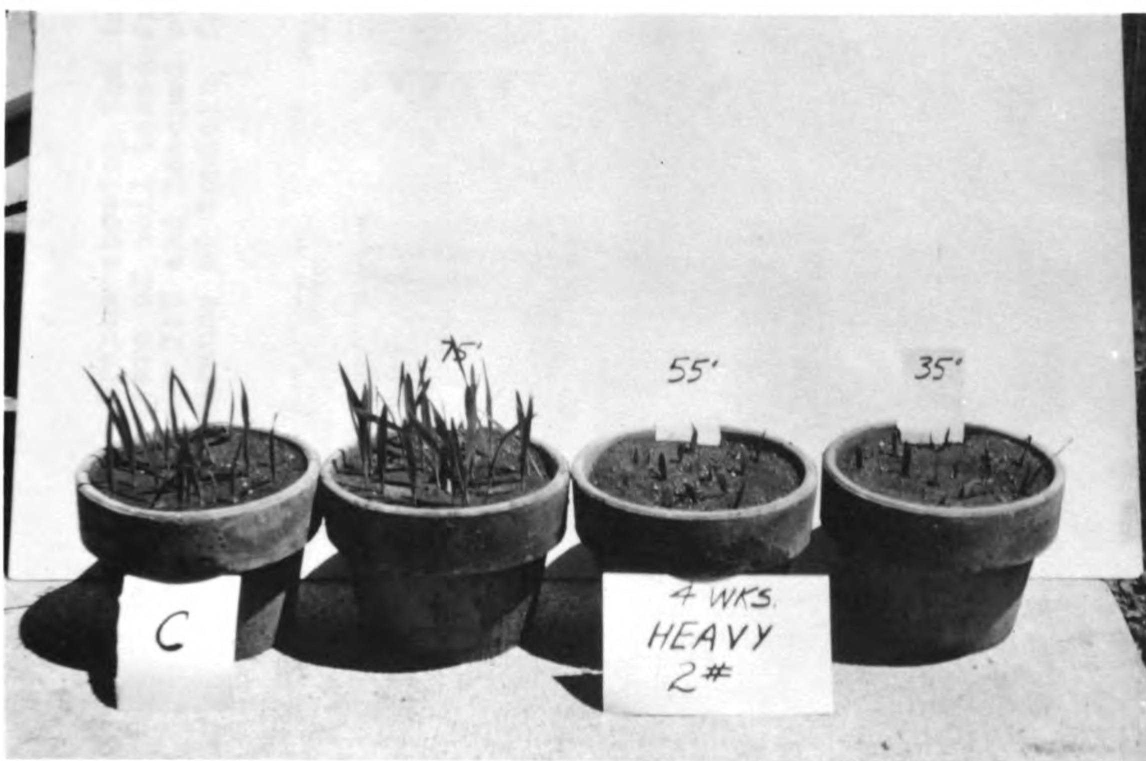
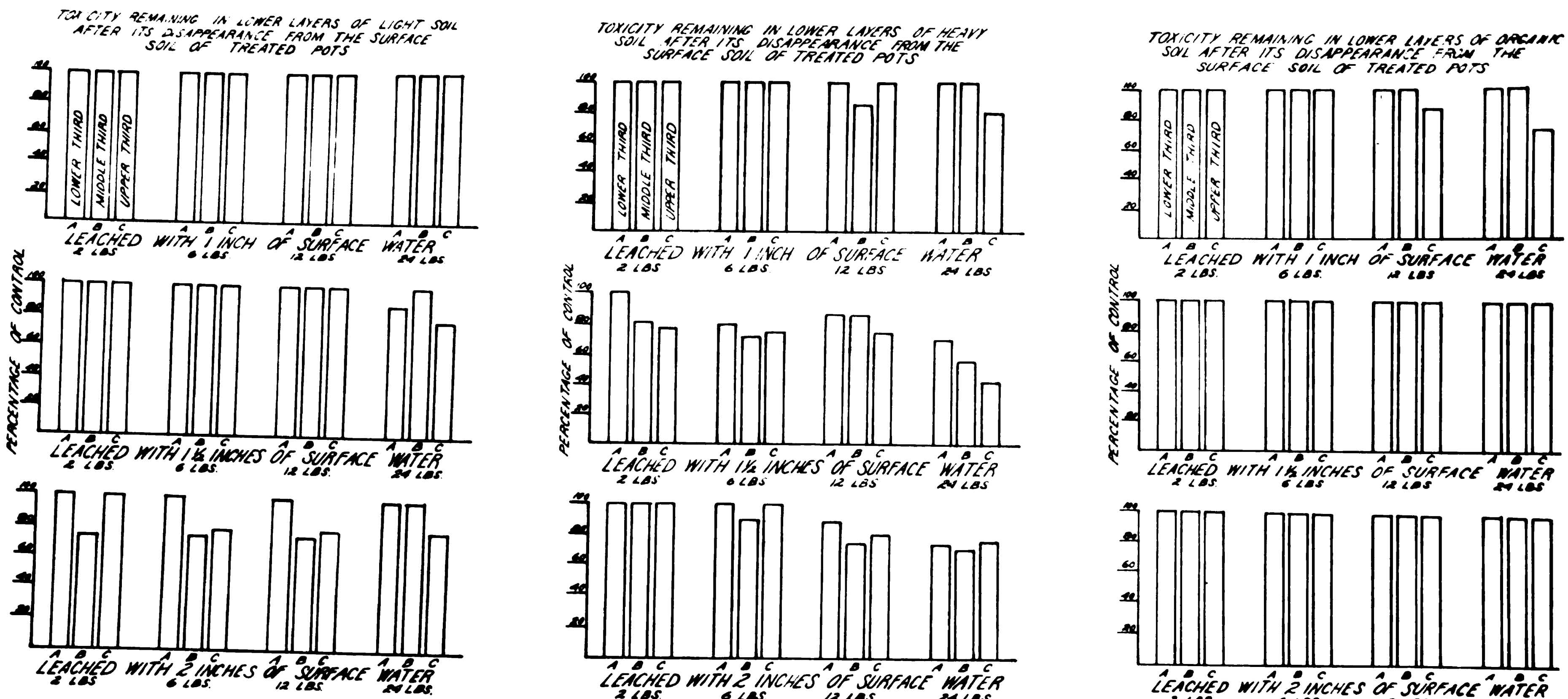


Figure IX. The growth of oat seedlings in heavy soil 4 weeks after treatment with 2 lbs./acre of 3-chloro IPC and storage at 75, 55, and 35° F.

Figure VII. Graphs showing the inhibition of oat seedlings grown in successive two inch layers of soil taken from cans containing soils, which were treated with 3-chloro IPC and leached with various amounts of surface water, after the disappearance of toxicity from the surface soil.

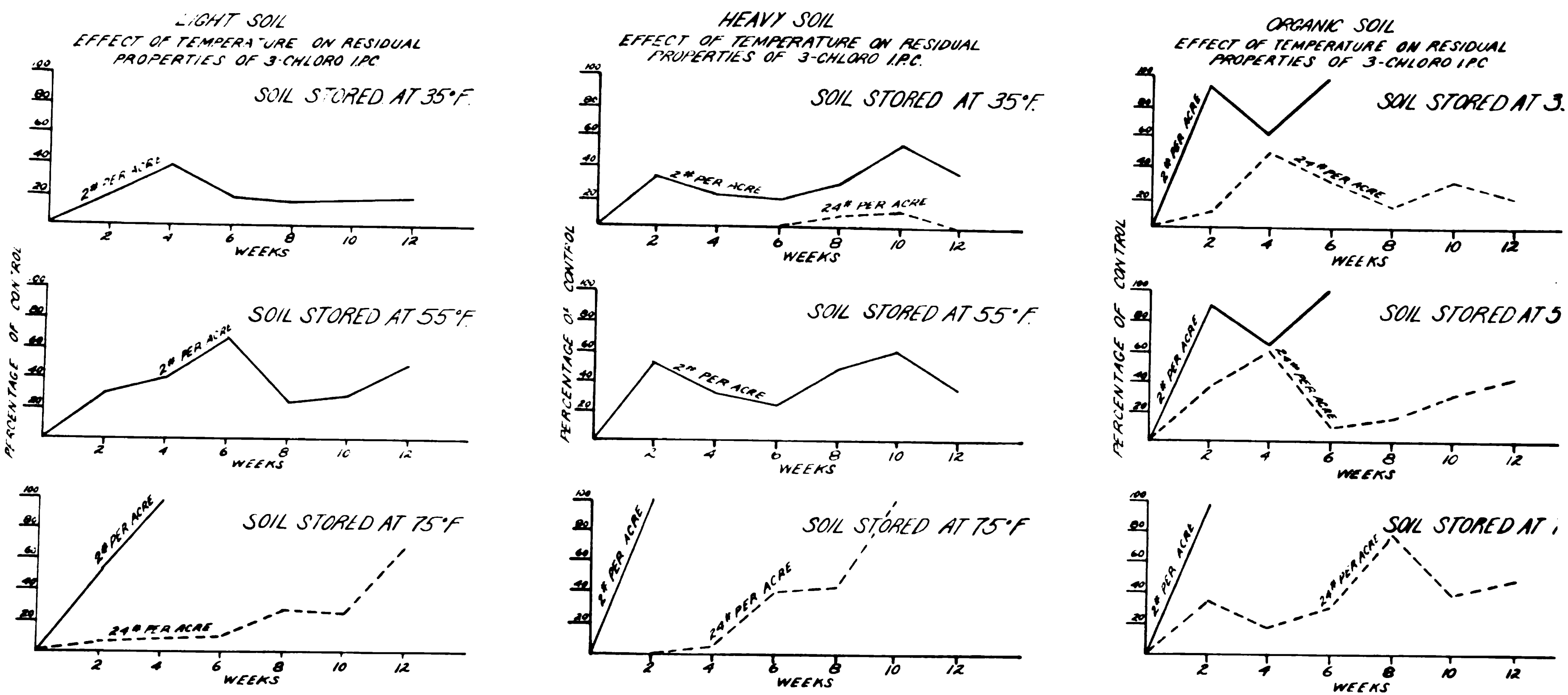


chemical has disappeared from the surface soil. Similar data for the organic soil are also shown in Figure VII. In this case, the soil was divided into layers 148 days after treatment. Only in the soil leached with 1 inch of surface water was there a trace of the chemical. In nearly all cases where there was a trace of 3-chloro IPC present, the amount in the lower 2-inch layer was less than that in the other layers.

Experiment III. Temperatures below 75 degrees Fahrenheit delayed the breakdown of 3-chloro IPC very markedly. Figure VIII shows the effects of temperatures of 35, 55, and 75 degrees Fahrenheit on loss of 3-chloro IPC applied to light, heavy, and organic soils. In light soil the toxic effects from the application of 2 pounds per acre, were lost in 4 weeks at a temperature of 75 degrees, while at temperatures of 55 and 35 degrees the soil was still toxic after 12 weeks when the experiment was terminated. When the light soil was treated with 24 pounds per acre and stored at 75 degrees the oat seeds germinated and the soil lost most of its toxicity after 12 weeks. This was not the case when the soil treated at the 24 pound rate was stored at the lower temperatures, since the oat seeds did not germinate over the 12 week period.

Similarly, heavy soil treated with 3-chloro IPC and stored at 75 degrees became non-toxic after 2 weeks, in the case of the 2 pound rate, and 10 weeks, in the case of the 24 pound rate. At the lower temperatures the 2 and 24

Figure VIII. Graphs showing the loss of 3-chloro IPC from 3 soils treated with 2 and 24 pounds per acre and stored at 3 temperatures, as measured by the inhibition of oat seedlings.



pound rate remained toxic for over 12 weeks. The effect of temperatures on the toxicity of heavy soils after 4 weeks is illustrated in Figure IX. (See page 40).

At a temperature of 75 degrees 3-chloro IPC persisted in the organic soil 2 weeks at the 2 pound rate and more than 12 weeks at the 24 pound rate. It is interesting to note that, at the lower temperatures, the toxic effects of 2 pounds per acre dissipated in 6 weeks in the organic soil and that the loss of 24 pounds of 3-chloro IPC closely correspond at all storage temperatures. This suggests that temperature is not as important a factor in delaying the breakdown in organic soil as are other variables.

Results Of The Field Experiment To Compare The Residual Action Of 3-Chloro IPC With IPC

This experiment was designed to compare the residual properties of 3-chloro IPC with those of IPC under field conditions. Figure X shows the degree of inhibition of germinating oat seedlings when seeds were planted at 2-week intervals in plots treated with 2, 6, and 12 pounds per acre of each of the previously mentioned compounds.

The 2 pound rate of IPC was toxic for only 4 weeks, while the 6 and 12 pound rate was toxic for 6 weeks. Plots treated with 2 pounds of 3-chloro IPC, on the other hand, did not produce normal seedlings until 8 weeks after treatment, and the higher concentrations were still toxic after 12 weeks. Figure XI shows the comparative growth of oat seedlings in plots treated with 2 and 6 pounds per acre after 6 weeks.

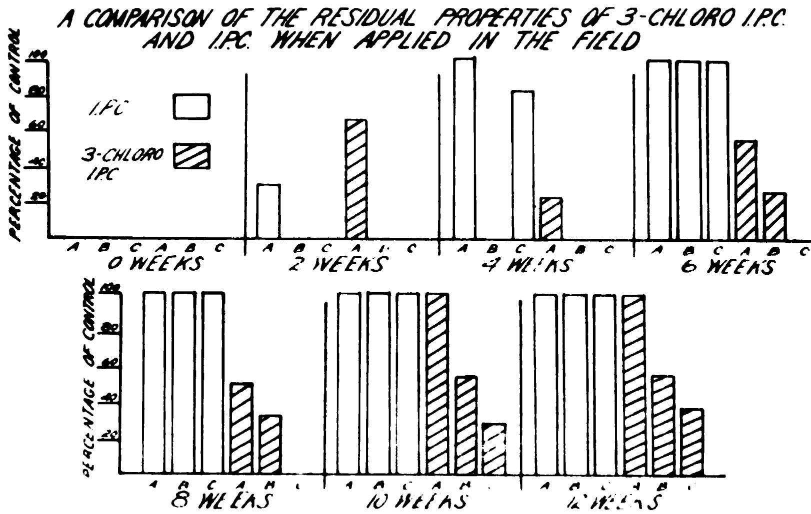


Figure X. A graph showing the inhibition of oat seedlings which were planted at 2-week intervals in field plots treated with (a) 2 lbs./acre, (b) 6 lbs./acre, and (c) 12 lbs./acre of 3-chloro IPC and IPC.

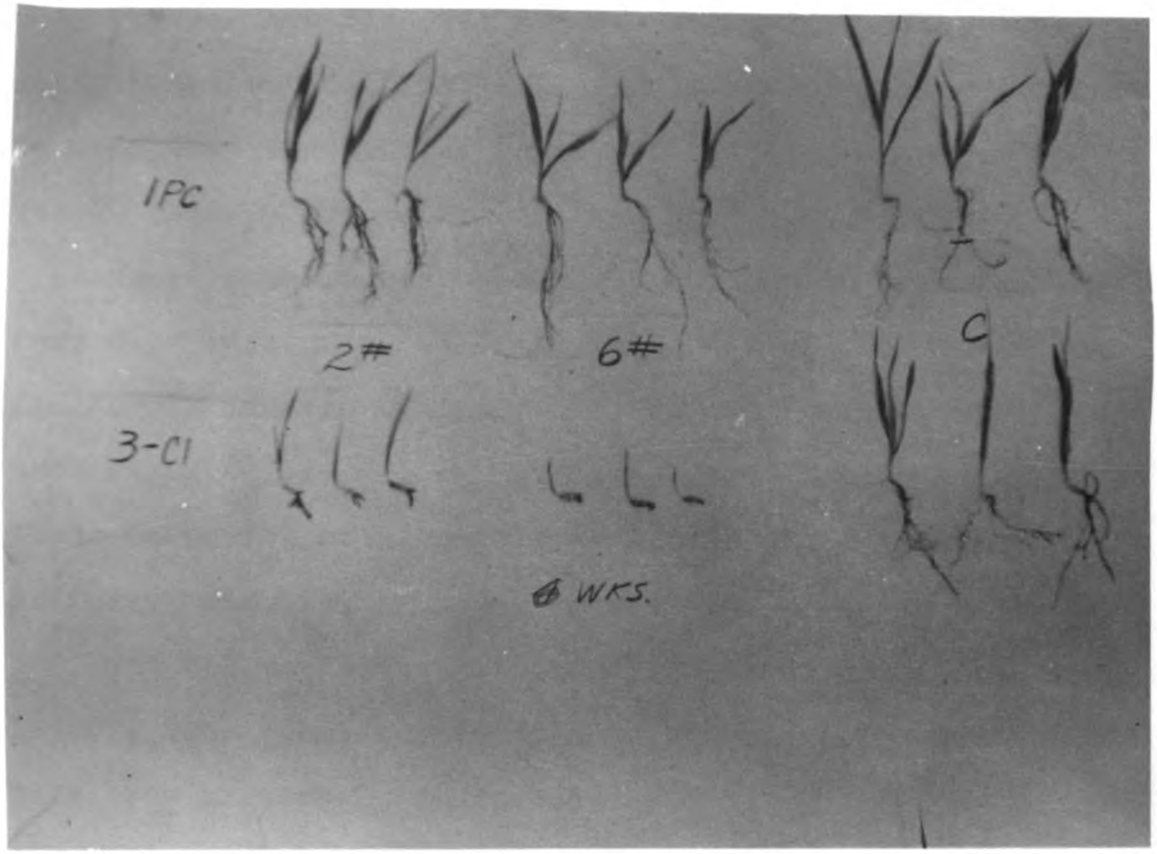


Figure XI. The growth of oat seedlings, in plots (from left to right) treated with 2 and 6 pounds per acre of 3-chloro IPC and IPC as compared to seedlings from controls, 6 weeks after treatment.

Figure XX. The effects of pre-planting treatments of 3-chloro IPC at the rate of 12 pounds per acre on corn are shown at the right. Seedlings from control plots are shown on the

The weather data for the 12-week period after treatment is presented in Table 6. It is of particular interest to note that the average temperature during this period was 10 degrees lower than the temperatures used in the greenhouse experiments, which may account in part for the very slow loss of the 2 pound rate of 3-chloro IPC in the field. It is also evident that the temperatures were somewhat higher while IPC was still active. A comparison of these compounds at higher temperatures might have given different results.

The oat seedlings responded, in terms of observable injury, very similarly to both treatments. These responses have been previously described.

This experiment was stopped at the end of 12 weeks because of a killing frost which occurred on September 28, 1951.

Results Of The Field Experiments To Determine The Toxicity Of 3-Chloro IPC To Various Crops

The survival of the seedlings of 9 crops grown in field plots treated with pre-planting, and pre-emergence applications of 3-chloro IPC is shown in Table 7. The survival of weed seedlings in the same plots is presented in Table 8. The data, summarizing the effect of pre-planting, pre-emergence and post-emergence applications of 3-chloro IPC on the fresh weight of roots and shoots, the total fresh weight, the percentage of the total weight of the control, and the shoot-root ratio of the various crops tested, are

TABLE 6

WEATHER DATA OF THE SUMMER OF 1951 FROM THE LANSING AIRPORT SHOWING THE TOTAL RAINFALL AND AVERAGE TEMPERATURE DURING THE 12 WEEK PERIOD IN WHICH FIELD EXPERIMENTS TO DETERMINE THE RESIDUAL ACTION OF 3-CHLORO IPC WERE CARRIED ON

Time of application	Total inches of precipitation from the time of application to 12 weeks after application			
	July	August	September	Total
July 3	1.06	2.84	1.80	5.70

Time of application	Average temperature from time of application to 12 weeks after application			
	July	August	September	Total average
July 3	69.5	66.4	60.3	65.4

TABLE 7

PERCENTAGE OF CROP SEEDLINGS SURVIVING TREATMENTS OF 3-CHLORO IPC APPLIED (1) BEFORE PLANTING AND (2) AFTER PLANTING BUT BEFORE EMERGENCE OF THE CROP

Application	Pounds per acre			
	1	3	6	12
		Corn*		
Pre-planting	84	74	63	16
Pre-emergence	100	100	100	63
		Soybeans**		
Pre-planting	100	90	74	90
Pre-emergence	95	95	79	84
		Wheat**		
Pre-planting	8	0	0	0
Pre-emergence	49	48	36	36
		Oats**		
Pre-planting	46	4	2	0
Pre-emergence	66	41	34	14
		Rye**		
Pre-planting	16	0	0	0
Pre-emergence	60	56	42	50
		Sorghum**		
Pre-planting	85	11	13	10
Pre-emergence	100	55	40	51
		Alfalfa**		
Pre-planting	64	49	45	4
Pre-emergence	81	87	30	8
		Red Clover**		
Pre-planting	78	21	8	5
Pre-emergence	73	17	46	3
		Ladino Clover**		
Pre-planting	65	21	14	2
Pre-emergence	88	87	79	5

*Percentage of hills surviving per plot
**Percentage of seedlings surviving per square foot

TABLE 8

PERCENTAGE OF WEEDS PER SQUARE FOOT SURVIVING TREATMENTS OF 3-CHLORO IPC APPLIED (1) BEFORE PLANTING AND (2) AFTER PLANTING BUT BEFORE EMERGENCE OF THE CROP

Application	Pounds per acre			
	1	3	6	12
		Corn		
Pre-planting	79	57	34	23
Pre-emergence	57	59	39	11
		Soybeans		
Pre-planting	64	36	60	14
Pre-emergence	75	57	29	7
		Wheat		
Pre-planting	100	55	36	41
Pre-emergence	91	64	23	9
		Oats		
Pre-planting	115	50	35	30
Pre-emergence	70	75	45	5
		Rye		
Pre-planting	180	140	100	70
Pre-emergence	90	60	80	20
		Sorghum		
Pre-planting	70	60	30	30
Pre-emergence	90	55	40	30
		Alfalfa		
Pre-planting	80	33	30	7
Pre-emergence	77	50	30	7
		Red Clover		
Pre-planting	78	33	39	8
Pre-emergence	81	42	78	11
		Ladino Clover		
Pre-planting	73	38	46	8
Pre-emergence	119	43	14	5

shown in Tables 9 through 17 and in Figure XII. The information concerning the injury to each crop is presented in the following order: alfalfa, red clover, Ladino clover, soybeans, rye, oats, wheat, sorghum, and corn.

Alfalfa. The pre-planting treatments appear to be very toxic even at the lowest rate, while the pre-emergence treatment resulted in a 10 to 20 percent reduction of crop plant emergence in the 1 to 3 pound rates. The pre-emergence application reduced weeds from 20 to 50 percent in the plots treated with 1 and 3 pounds. Pre-planting treatments above 1 pound and pre-emergence treatments above 3 pounds caused a severe stunting of many plants. Some seedlings grew to a height of 1/2 inch and remained in that condition throughout the summer. The main axis and leaves failed to elongate, resulting in the formation of tiny rosettes. A few of these seedlings died in 4 to 5 weeks.

Post-emergence applications resulted in a very noticeable chlorotic condition on the terminal leaves. Although this condition became more noticeable at the higher concentrations, it was present in plots treated with as little as 1 pound. These leaves eventually dried as can be seen in Figure XIII. Because of the location of the growing point and its lack of protection, post-emergence applications terminated growth.

There was a tendency for shoot-root ratio to increase with the dosage in the pre-planting and pre-emergence treatments. This increase in shoot growth was due to the lack of

TABLE 9

EFFECTS OF TREATMENTS OF 3-CHLORO IPC ON THE FRESH WEIGHT OF ALFALFA PLANTS. APPLICATIONS WERE MADE (1) BEFORE PLANTING, (2) AFTER PLANTING BUT BEFORE EMERGENCE, AND (3) AFTER EMERGENCE AND DEVELOPMENT OF THE CROP. DATA BASED ON THE WEIGHT IN GRAMS OF 24 PLANTS TAKEN FROM EACH PLOT.

Treatment	Weight of shoots	Weight of roots	Total weight	Percent of control	Shoot-root ratio
Control	14.8	3.4	18.2	100	4.4
1. Pre-planting					
1 lbs./acre	19.0	4.8	23.8	131	4.0
3 lbs./acre	15.5	3.5	19.0	104	4.4
6 lbs./acre	15.3	3.3	18.6	102	4.6
12 lbs./acre	20.5	3.0	23.5	129	6.8
2. Pre-emergence					
1 lbs./acre	13.5	3.3	16.8	92	4.1
3 lbs./acre	14.0	3.3	17.3	95	4.2
6 lbs./acre	16.3	3.8	20.1	110	4.3
12 lbs./acre	26.0	3.8	29.8	164	6.8
3. Post-emergence					
1 lbs./acre	13.8	3.3	17.1	94	4.2
3 lbs./acre	12.3	2.8	15.1	83	4.4
6 lbs./acre	9.8	2.8	12.6	69	3.5
12 lbs./acre	9.8	2.3	12.1	67	4.3

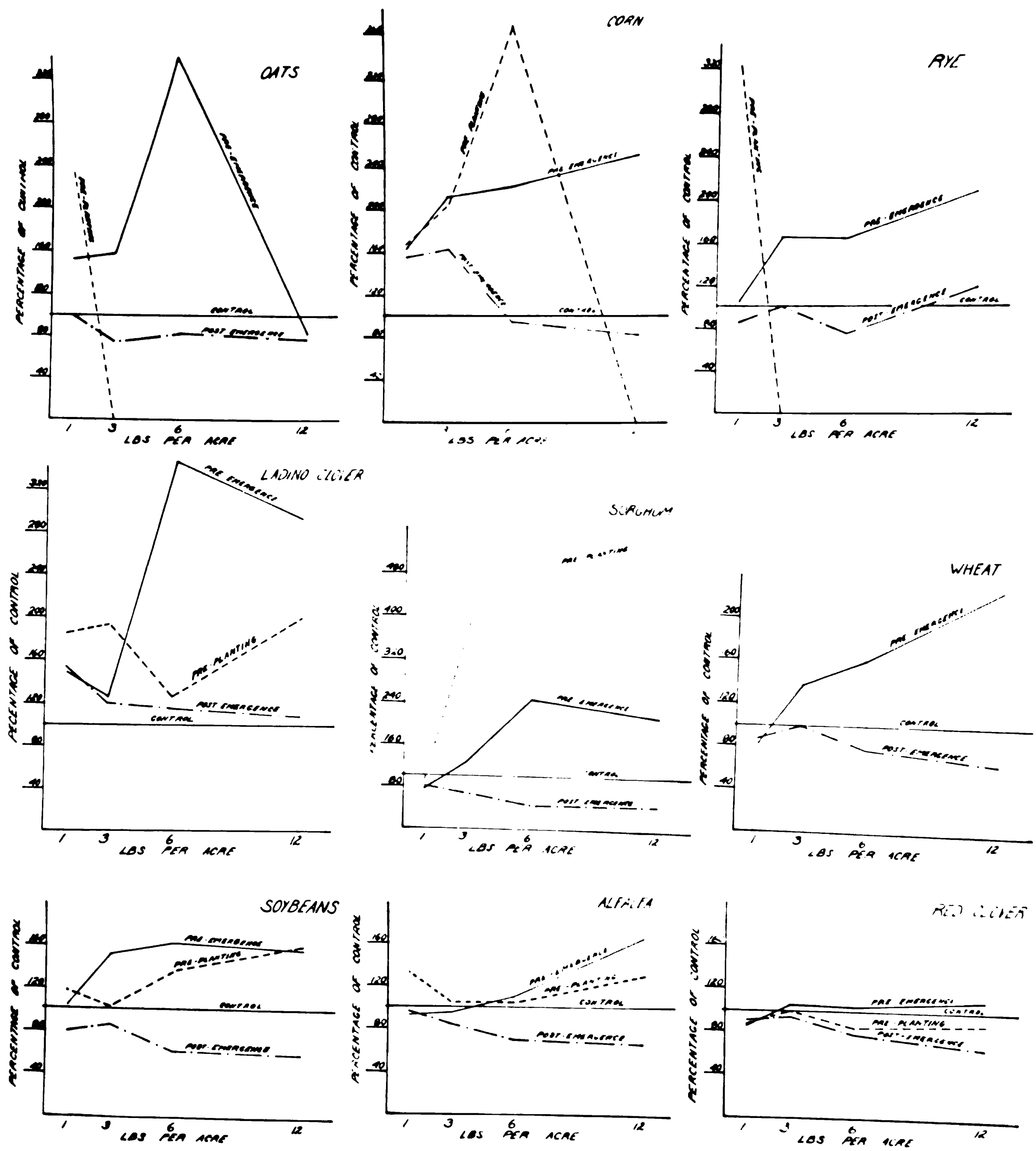


Figure XII. Graphs showing the effects of 3-chloro IPC on the fresh weights of 9 crops grown in plots treated at various times with 1, 3, 6, and 12 pounds per acre.

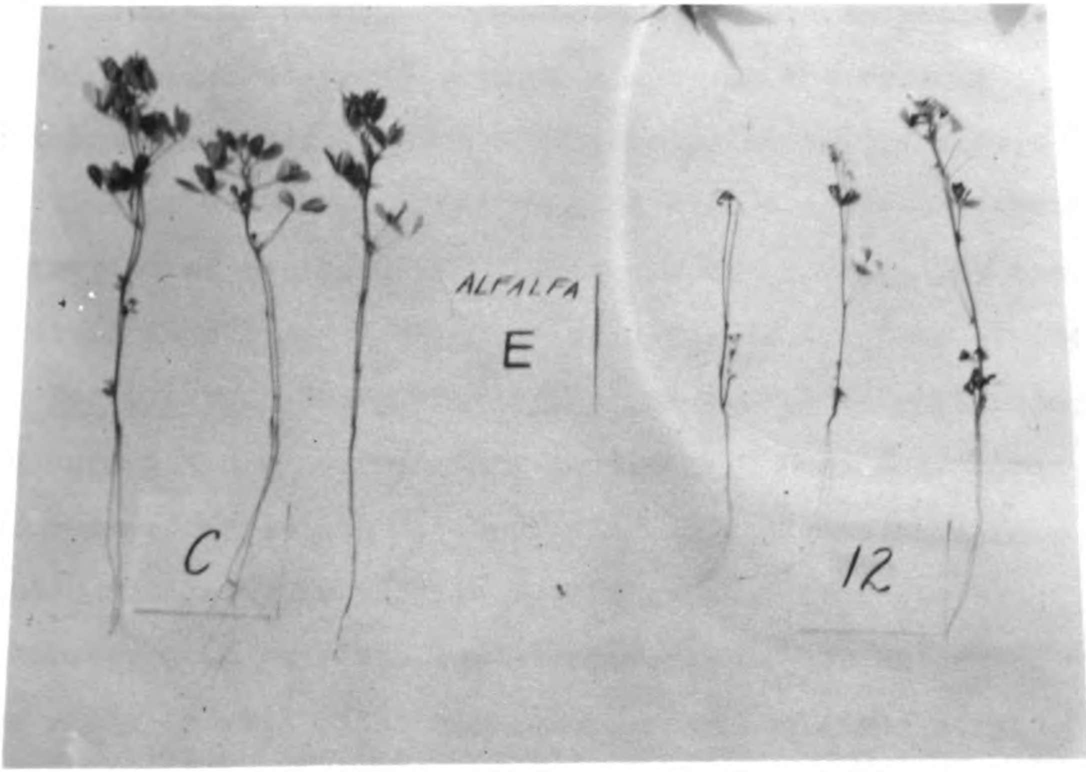


Figure XIII. The reduced foliage of alfalfa plants caused by post-emergence applications of 12 lbs./acre of 3-chloro IPC is shown at the right, and control plants are shown at the left.

Figure XVII. The spiraling of the leaves of stunted rye plants caused by pre-emergence applications of 6 lbs./ acre of 3-chloro IPC is shown at the right, and control competition with weeds. Figure XIV shows the increase in branching which occurred on many plants as the rate of treatment increased. These data also point to the severe reduction in weight of crops treated with a post-emergence application of 3-chloro IPC. This can be explained by the reduction in photosynthetic activity due to the loss of foliage.

Red Clover. Pre-planting and pre-emergence applications were very toxic to germinating seedlings. Weed growth was also reduced effectively. Surviving crop plants were stunted similarly to alfalfa seedlings, but this stunting was observed at even the lowest rates used. At harvest time plots treated with the higher rates contained many plants which were sending out stolons. Again, as in the case of alfalfa, this was probably due to the lack of competition with weeds, although the data do not show the tremendous increase in weight of treated plants as do the data for alfalfa.

Post-emergence treatments showed very nearly the same effects on red clover as on alfalfa. In alfalfa the leaves became chlorotic after treatment and then died, while the leaves of red clover became necrotic almost immediately after treatment. However, because the growing point was protected, some plants appeared to return to normal growth with new leaves arising to function in place of the old ones. It is possible that these plants would survive.

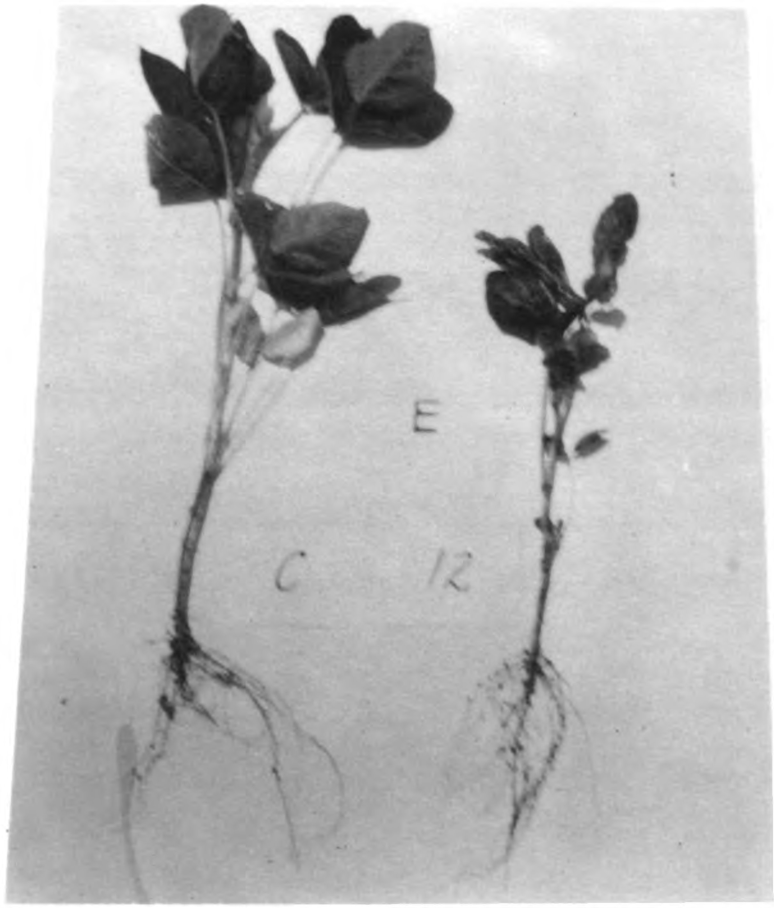


Figure XVI. The reduced foliage of soybeans caused by post-emergence applications of 12 lbs./acre is shown on the right, and a control plant is shown on the left.

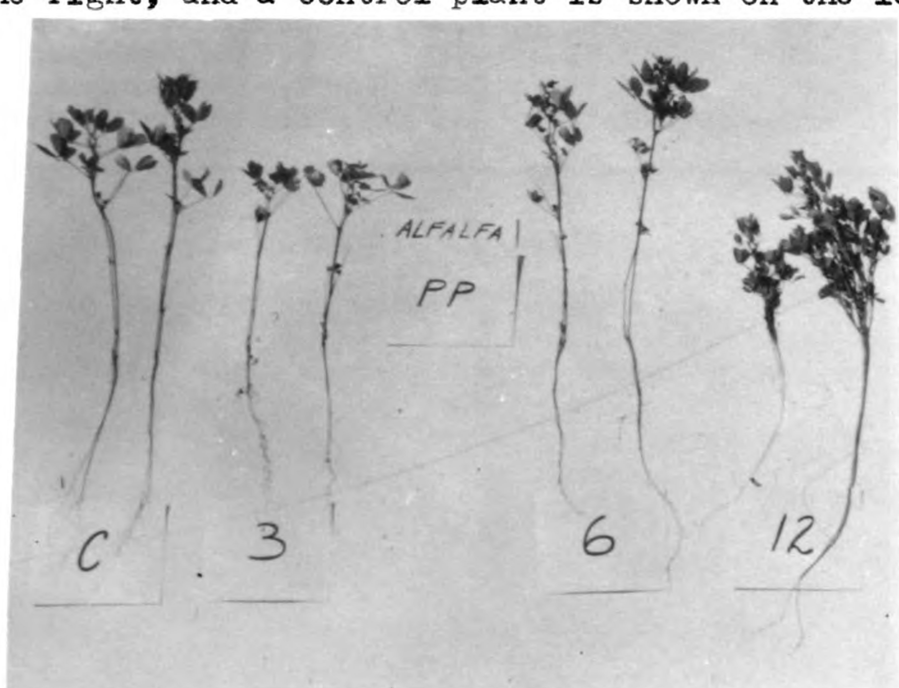


Figure XIV. The effects of 3, 6, and 12 lbs./acre of 3-chloro IPC applied as pre-planting treatments, on alfalfa as compared to control plants shown on the left.

TABLE 10

EFFECTS OF TREATMENTS OF 3-CHLORO IPC ON THE FRESH WEIGHT OF RED CLOVER PLANTS. APPLICATIONS WERE MADE (1) BEFORE PLANTING, (2) AFTER PLANTING BUT BEFORE EMERGENCE, AND (3) AFTER EMERGENCE AND DEVELOPMENT OF THE CROP. DATA BASED ON THE WEIGHT IN GRAMS OF 24 PLANTS TAKEN FROM EACH PLOT.

Treatment	Weight of shoots	Weight of roots	Total weight	Percent of control	Shoot-root ratio
Control	23.9	3.4	27.3	100	7.0
1. Pre-planting					
1 lbs./acre	20.0	3.3	23.3	85	6.1
3 lbs./acre	25.0	2.0	27.0	99	12.5
6 lbs./acre	20.0	2.8	22.8	84	7.1
12 lbs./acre	21.1	2.8	23.9	88	7.5
2. Pre-emergence					
1 lbs./acre	20.1	2.9	23.0	84	6.9
3 lbs./acre	24.8	3.6	28.4	104	6.9
6 lbs./acre	24.9	3.3	28.2	103	7.6
12 lbs./acre	25.8	3.9	29.7	109	6.6
3. Post-emergence					
1 lbs./acre	19.5	3.3	23.8	87	5.9
3 lbs./acre	22.6	2.9	25.5	93	7.8
6 lbs./acre	17.9	3.6	21.5	79	5.0
12 lbs./acre	15.2	2.4	17.6	65	6.3

Ladino Clover. The data presented show plants in all treated plots to be stimulated over controls. This is assumed to be due to the fact that seeds were sown too thickly causing the crop plants in the controls to compete with each other resulting in reduced growth, while the thinning of plants resulting from treatments increased growth. There is, however, the same trend in the weight at harvest as was observed for alfalfa. Post-emergence applications caused a necrosis of the leaves shortly after the chemical was sprayed over the plants, but the growing point was not injured and the crop may have eventually resumed normal growth. The higher rates, applied as pre-planting and pre-emergence sprays, caused many plants to send out stolons, probably because of the lack of competition.

Pre-emergence applications at the rate of 3 pounds per acre were fairly successful. In this case, only 10 percent of the seedlings were killed while weed growth was reduced almost 60 percent. Because of the thickness of the planting, this thinning of 10 percent appeared to be more satisfactory than if no thinning had occurred.

Soybeans. The reduction of seedlings, due to treatments of 3-chloro IPC, was fairly low. Crop plants growing in plots treated with pre-planting and pre-emergence applications in the 6 to 12 pound range responded in various ways. Some of the seedlings grew to a height of 2 inches and remained in this dwarfed condition for 5 to 6 weeks, and then died. These dwarfed plants failed to grow satis-

TABLE 11

EFFECTS OF TREATMENTS OF 3-CHLORO IPC ON THE FRESH WEIGHT OF LADINO CLOVER PLANTS. APPLICATIONS WERE MADE (1) BEFORE PLANTING, (2) AFTER PLANTING BUT BEFORE EMERGENCE, AND (3) AFTER EMERGENCE AND DEVELOPMENT OF THE CROP. DATA BASED ON THE WEIGHT IN GRAMS OF 24 PLANTS TAKEN FROM EACH PLOT.

Treatment	Weight of shoots	Weight of roots	Total weight	Percent of control	Shoot-root ratio
Control	6.5	0.9	7.4	100	7.2
1. Pre-planting					
1 lbs./acre	12.0	1.7	13.7	185	7.1
3 lbs./acre	12.9	1.5	14.4	195	8.6
6 lbs./acre	8.5	0.8	9.3	126	10.6
12 lbs./acre	13.6	1.2	14.8	200	11.3
2. Pre-emergence					
1 lbs./acre	9.9	1.2	11.1	150	8.3
3 lbs./acre	8.5	0.8	9.3	126	10.6
6 lbs./acre	21.9	3.0	24.9	337	7.3
12 lbs./acre	20.1	1.7	21.8	295	11.8
3. Post-emergence					
1 lbs./acre	10.4	1.1	11.5	155	9.5
3 lbs./acre	8.1	0.8	8.9	120	10.1
6 lbs./acre	7.6	1.0	8.6	116	7.6
12 lbs./acre	7.2	0.8	8.0	108	9.0

TABLE 12

EFFECTS OF TREATMENTS OF 3-CHLORO IPC ON THE FRESH WEIGHT OF SOYBEAN PLANTS. APPLICATIONS WERE MADE (1) BEFORE PLANTING, (2) AFTER PLANTING BUT BEFORE EMERGENCE, AND (3) AFTER EMERGENCE AND DEVELOPMENT OF THE CROP. DATA BASED ON THE WEIGHT IN GRAMS OF 24 PLANTS TAKEN FROM EACH PLOT.

Treatment	Weight of shoots	Weight of roots	Total weight	Percent of control	Shoot-root ratio
Control	250	42	292	100	6.0
1. Pre-planting					
1 lbs./acre	301	43	344	118	7.0
3 lbs./acre	252	47	299	102	5.4
6 lbs./acre	338	62	400	137	5.5
12 lbs./acre	414	51	465	159	8.1
2. Pre-emergence					
1 lbs./acre	266	36	302	103	7.4
3 lbs./acre	389	52	441	151	7.5
6 lbs./acre	414	58	472	162	7.1
12 lbs./acre	397	54	451	155	7.4
3. Post-emergence					
1 lbs./acre	200	33	233	80	6.1
3 lbs./acre	212	38	250	86	5.6
6 lbs./acre	148	29	177	61	5.1
12 lbs./acre	132	36	168	58	3.7

factory roots so death was probably due to the lack of water absorption. Other crop plants grew to normal size, and many produced large numbers of branches. Most of the plants, growing in plots treated at the higher rates, developed a swelling of the tissues at the crown of the plant, and in some cases the plants would bend at this point and the stem would lay on the ground until growth proceeded upward from a node higher up on the shoot. This is illustrated in Figure XV.

The post-emergence applications injured the foliage of soybeans more than any other crop tested. This was probably due to the ease with which the leaves retained the individual droplets of the spray. The serious reduction in growth due to post-emergence treatments is illustrated by the data and shown in Figure XVI. The growth curves for the various pre-planting and pre-emergence rates are similar to those discussed for previous crops. Again, shoot-root ratios indicate that the increase in weight due to these treatments is due to greater photosynthetic activity caused by the lack of competing weeds.

Rye. Pre-planting treatments were severely toxic to rye. Only 16 percent of the crop plants survived the 1 pound rate applied before planting. These surviving plants, however, sent up extremely large numbers of shoots from the crown. This tillering was also observed in plots treated with pre-emergence sprays, but to a lesser extent. These shoots were very dark green in color as compared to

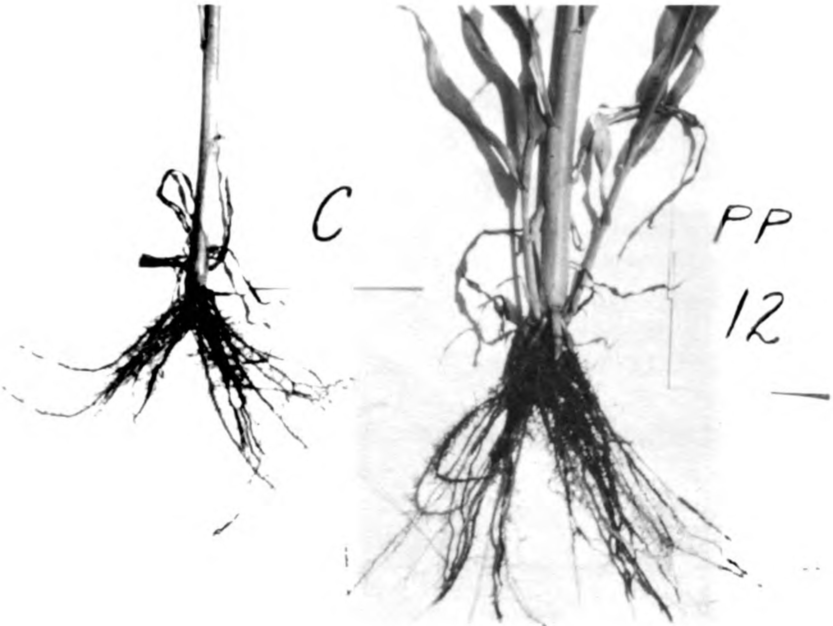


Figure XIX. The increased number of shoots at the base of sorghum plants caused by pre-planting treatments of 3-chloro IPC at the rate of 12 lbs./acre is shown at the right, and a control plant is shown at the left.

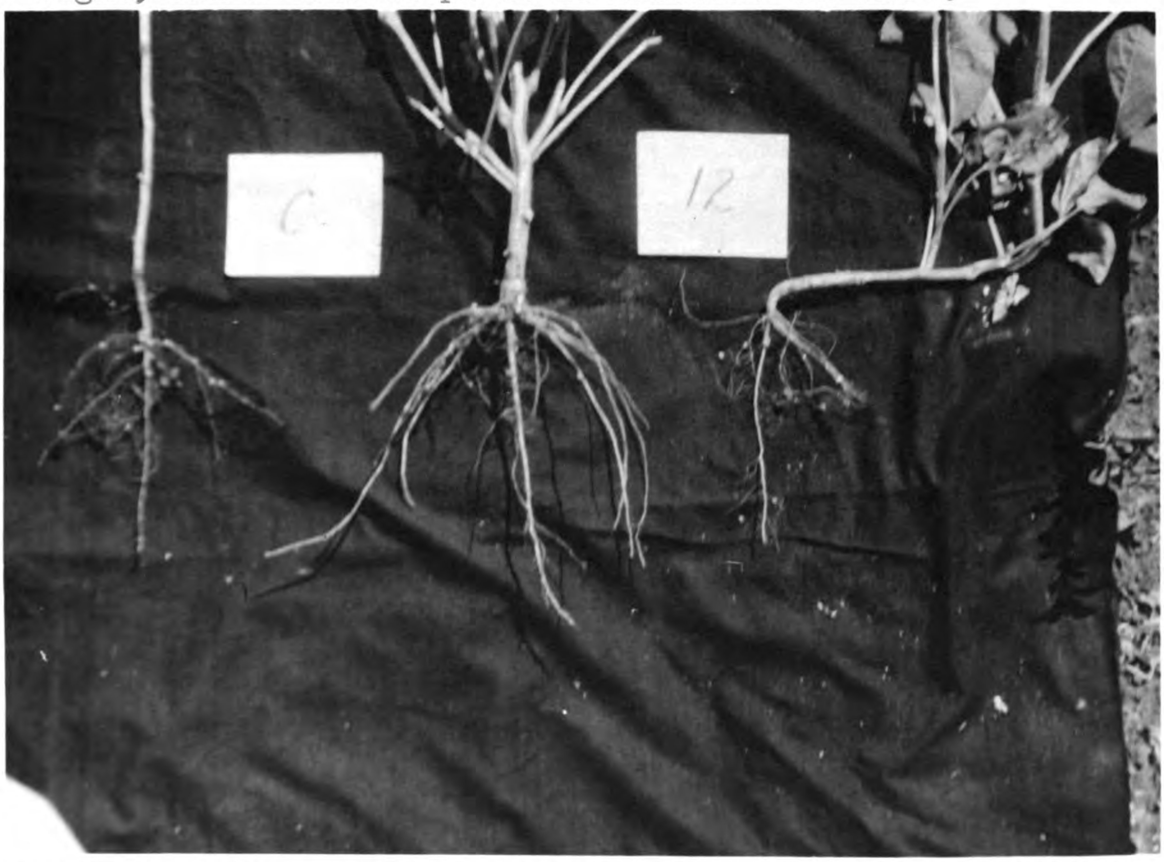


Figure XV. The swelling and breaking of the tissues at the base of soybean plants, and also the increased branching caused by pre-planting applications of 3-chloro IPC is shown by the two plants on the right, and a control plant

TABLE 13

EFFECTS OF TREATMENTS OF 3-CHLORO IPC ON THE FRESH WEIGHT OF RYE PLANTS. APPLICATIONS WERE MADE (1) BEFORE PLANTING, (2) AFTER PLANTING BUT BEFORE EMERGENCE, AND (3) AFTER EMERGENCE AND DEVELOPMENT OF THE CROP. DATA BASED ON THE WEIGHT IN GRAMS OF 24 PLANTS TAKEN FROM EACH PLOT.

Treatment	Weight of shoots	Weight of roots	Total weight	Percent of control	Shoot-root ratio
Control	33	12	45	100	2.8
1. Pre-planting					
1 lbs./acre	117	28	145	322	4.2
3 lbs./acre	0	0	0	0	0
6 lbs./acre	0	0	0	0	0
12 lbs./acre	0	0	0	0	0
2. Pre-emergence					
1 lbs./acre	35	12	47	104	2.9
3 lbs./acre	61	13	74	164	4.6
6 lbs./acre	65	9	74	164	7.9
12 lbs./acre	83	10	93	207	8.3
3. Post-emergence					
1 lbs./acre	26	13	39	87	2.0
3 lbs./acre	32	13	45	100	2.5
6 lbs./acre	26	9	35	77	2.9
12 lbs./acre	35	18	53	118	1.9

the control plants, and the growth of the plant was low and spreading. Most of the crop plants surviving the pre-planting and pre-emergence treatments had leaves which were tightly curled in a spiral type of growth, but this condition did not persist beyond the first few weeks of growth. Figure XVII illustrates this type of injury. (See page 54).

The growth curve for the pre-emergence treatment shows that, similar to crops previously discussed, lack of competitions has increased growth. Post-emergence treatments did not consistently reduce the weight of the crop, but the shoot-root ratio shows that the shoot growth was reduced in proportion to that of the roots. When the chemical was applied to the mature plant the leaves wilted and in a few cases died. However, the crop recovered fairly rapidly.

The rye plants grown under control conditions made such early growth that it crowded out most of the weeds, so that the reduction of weeds was greater in the control plots than in many of the treated plots. Because of a severe infestation of rust, the validity of these tests on rye may have been reduced.

Oats. The data presented for oats are very similar to that of rye, except that growth was reduced by the 12 pound rate applied after planting, and the weight of the crop was reduced by post-emergence applications.

As was the case with rye, the applications of 3-chloro IPC before and after planting caused many plants to tiller more abundantly than the plants grown in the control plots.

TABLE 14

EFFECTS OF TREATMENTS OF 3-CHLORO IPC ON THE FRESH WEIGHT OF OAT PLANTS. APPLICATIONS WERE MADE (1) BEFORE PLANTING, (2) AFTER PLANTING BUT BEFORE EMERGENCE, AND (3) AFTER EMERGENCE AND ESTABLISHMENT OF THE CROP. DATA BASED ON THE WEIGHT IN GRAMS OF 24 PLANTS TAKEN FROM EACH PLOT.

Treatment	Weight of shoots	Weight of roots	Total weight	Percent of control	Shoot-root ratio
Control	116	12	128	100	9.7
1. Pre-planting					
1 lbs./acre	280	20	300	234	14.0
3 lbs./acre	0	0	0	0	0
6 lbs./acre	0	0	0	0	0
12 lbs./acre	0	0	0	0	0
2. Pre-emergence					
1 lbs./acre	134	10	144	112	13.4
3 lbs./acre	190	12	202	158	15.8
6 lbs./acre	416	15	431	337	27.7
12 lbs./acre	96	9	105	82	10.7
3. Post-emergence					
1 lbs./acre	115	13	128	100	8.9
3 lbs./acre	85	9	94	73	9.4
6 lbs./acre	91	14	105	82	6.5
12 lbs./acre	86	13	99	77	6.6

Many of the seedlings responded as did the oats planted in treated soil in the greenhouse. The primary leaf was bluish-green, cupped at the end, and very brittle. Seedlings injured in this way grew about 1 inch above the soil, and soon died. At the higher concentrations surviving plants developed a swelling at the nodes, with a corresponding change in the direction of the growth of the shoot. It was due to this response, pictured in Figure XVIII, that the plants grown in treated soil lodged so severely. The leaves of surviving plants retained the same dark color and brittle tissue as described for seedlings. Post-emergence applications delayed the emergence of flower spikes from 1 to 2 weeks.

Wheat. All pre-planting treatments were eventually lethal to wheat. The response to pre-emergence treatments was similar to that of the grains previously mentioned. Post-emergence applications reduced the weight of the crop at harvest but did not decrease the shoot-root ratio, which contradicts the previous statement that the chemical, when applied to the mature plant, reduces shoot growth over that of root growth.

Treatments applied to the soil caused many seedlings to remain dwarfed. Those plants which grew more normally tillered extensively. Treatments applied to the leaves caused wilting and, in some cases, death of the leaf tissue.

The entire crop of wheat was infested with rust, as was the rye, so that the results of this experiment may not be the results that would be obtained from a non-infested crop.

Figure XVIII. The swelling at the nodes and the lodging of oats caused by pre-emergence applications of 3-chloro IPC at the rate of 6 lbs./acre is shown at the left, and a control plant is shown at the right.

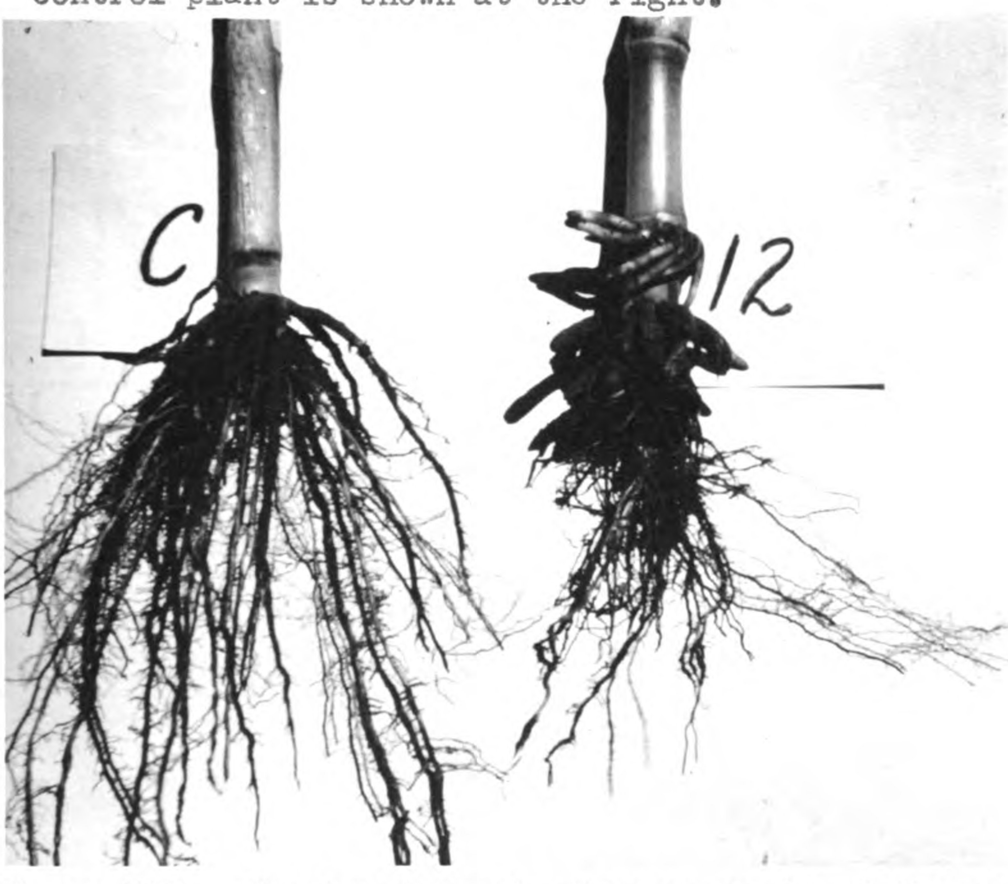


Figure XXI. The development of brace roots at the second node of corn plants caused by pre-planting applications of 3-chloro IPC at the rate of 12 lbs./acre is shown at the

TABLE 15

EFFECTS OF TREATMENTS OF 3-CHLORO IPC ON THE FRESH WEIGHT OF WHEAT PLANTS. APPLICATIONS WERE MADE (1) BEFORE PLANTING, (2) AFTER PLANTING BUT BEFORE EMERGENCE, AND (3) AFTER EMERGENCE AND DEVELOPMENT OF THE CROP. DATA BASED ON THE WEIGHT IN GRAMS OF 24 PLANTS TAKEN FROM EACH PLOT.

Treatment	Weight of shoots	Weight of roots	Total weight	Percent of control	Shoot-root ratio
Control	45	9	54	100	5.0
1. Pre-planting					
1 lbs./acre	0	0	0	0	0
3 lbs./acre	0	0	0	0	0
6 lbs./acre	0	0	0	0	0
12 lbs./acre	0	0	0	0	0
2. Pre-emergence					
1 lbs./acre	38	6	44	81	6.3
3 lbs./acre	64	10	74	137	6.4
6 lbs./acre	79	8	87	161	9.9
12 lbs./acre	113	9	122	226	12.6
3. Post-emergence					
1 lbs./acre	38	8	46	85	4.8
3 lbs./acre	47	7	54	100	6.7
6 lbs./acre	36	6	42	78	6.0
12 lbs./acre	31	5	36	67	6.2

Sorghum. The data show the tremendous growth which can occur when competition is reduced. Here again, however, the shoot-root ratios do not support the idea that the increase in weight, shown by plants grown in treated soil, is entirely due to the lack of competition, or that the reduction of photosynthetic leaf area, caused by the application to the plant itself, is responsible for the decrease in weight.

Pre-planting and pre-emergence treatments were for the most part toxic to germinating seeds. Many surviving seedlings remained dwarfed and eventually died, while others grew to a much larger size than the control plants. At the very high rates, several shoots would arise from the crown and grow vigorously as illustrated in Figure XIX. Treated plants, in the early stages of growth, exhibited a marked purpling of the leaf margins.

Post-emergence applications caused a severe necrosis of the upper leaves. However, the crop was very quick to form new leaves, and resume normal growth.

Corn. Corn, like sorghum, made tremendous growth when weed competition was eliminated.

Pre-emergence treatments in the 1 to 6 pound range were highly successful. The crop showed no apparent injury and the weeds were controlled. Pre-planting treatments reduced the germination, and the 12 pound rate was eventually lethal to all plants. Many seedlings in these plots displayed a swollen, distorted coleoptile, and similar effects on the

TABLE 16

EFFECTS OF TREATMENTS OF 3-CHLORO IPC ON THE FRESH WEIGHT OF SORGHUM PLANTS. APPLICATIONS WERE MADE (1) BEFORE PLANTING, (2) AFTER PLANTING BUT BEFORE EMERGENCE, AND (3) AFTER EMERGENCE AND DEVELOPMENT OF THE CROP. DATA BASED ON THE WEIGHT IN GRAMS OF 24 PLANTS TAKEN FROM EACH PLOT.

Treatment	Weight of shoots	Weight of roots	Total weight	Percent of control	Shoot-root ratio
Control	258	33	291	100	7.8
1. Pre-planting					
1 lbs./acre	229	34	263	90	6.7
3 lbs./acre	945	171	1116	383	5.5
6 lbs./acre	1182	210	1392	478	5.6
12 lbs./acre	1347	209	1556	535	6.4
2. Pre-emergence					
1 lbs./acre	189	39	228	78	4.9
3 lbs./acre	324	42	366	126	7.7
6 lbs./acre	618	90	708	243	6.9
12 lbs./acre	566	67	633	218	8.4
3. Post-emergence					
1 lbs./acre	210	25	235	81	8.4
3 lbs./acre	175	21	196	67	8.3
6 lbs./acre	116	17	133	46	6.8
12 lbs./acre	108	13	121	42	8.3

TABLE 17

EFFECTS OF TREATMENTS OF 3-CHLORO IPC ON THE FRESH WEIGHT OF CORN PLANTS. APPLICATIONS WERE MADE (1) BEFORE PLANTING, (2) AFTER PLANTING BUT BEFORE EMERGENCE, AND (3) AFTER EMERGENCE AND DEVELOPMENT OF THE CROP. DATA BASED ON THE WEIGHT IN GRAMS OF 24 PLANTS TAKEN FROM EACH PLOT.

Treatment	Weight of shoots	Weight of roots	Total weight	Percent of control	Shoot-root ratio
Control	811	95	906	100	8.5
1. Pre-planting					
1 lbs./acre	1368	158	1526	168	8.7
3 lbs./acre	1498	360	1858	205	4.2
6 lbs./acre	2828	589	3417	377	4.8
12 lbs./acre	0	0	0	0	0
2. Pre-emergence					
1 lbs./acre	1316	182	1498	165	7.2
3 lbs./acre	1685	234	1919	212	7.2
6 lbs./acre	1736	275	2011	222	6.3
12 lbs./acre	1931	350	2281	252	5.5
3. Post-emergence					
1 lbs./acre	1273	154	1427	158	8.3
3 lbs./acre	1367	107	1474	163	12.7
6 lbs./acre	793	78	871	96	10.2
12 lbs./acre	689	59	748	83	11.7

young roots. The dwarfing of these seedlings is pictured in Figure XX. Those crop plants which survived the pre-planting treatments often showed signs of injury similar to those found in sorghum, in that the margins of the leaves became purple. Plants grown in plots treated with a 6 pound pre-planting treatment or a 12 pound pre-emergence treatment developed many brace roots at the second node, as shown in Figure XXI. The root systems of plants in the same plots were weak and many of the plants were blown over in a severe wind storm on July 27, 1951.

The flower structures appeared from 1 to 1 1/2 weeks earlier on crop plants in plots treated with pre-planting and pre-emergence applications. Also the color of the leaves of plants grown in those plots was dark green in contrast to the pale green leaves of plants grown on the control plots. These responses were at least in part due to the reduced competition with weeds.

Post-emergence applications caused a chlorotic band across the new leaves which developed shortly after the crop was sprayed. This was probably because the chemical ran down the leaves and accumulated at the growing point, and injured the meristematic leaf tissues. The tissue in this yellow band eventually died and the leaf broke in half. The plant recovered very quickly, however, and the crop grew normally.

General remarks. The weather data for the pre-planting, pre-emergence, and post-emergence treatments are presented in Table 18. Small amounts of rainfall occurred after the pre-planting and pre-emergence treatments, but it is probable that moistening of the soil only served to distribute the 3-chloro IPC more evenly. No rain fell for 5 days after the post-emergence applications.

Weeds were killed only by pre-planting and pre-emergence applications. Although no attempt was made to determine the differential control of grasses and broadleaved weeds, the greatest reduction was of crab grass (Digitaria sanguinalis (L.) Scop.), which seriously infested the control plots. Nut grass (Cyperus esculentus L.) and witch grass (Panicum capillare L.) were also reduced markedly due to applications of 3-chloro IPC. Among the broadleaved weeds that appeared to be reduced were purslane (Portulaca oleracea L.) and rough cinquefoil (Potentilla norvegica L.). Those weeds surviving the treatments were lamb's quarters (Chenopodium album L.) and rough pigweed (Amaranthus retroflexus L.). Weeds which grew in the plots treated with the highest rates, were dwarfed and flowering was delayed.

Post-emergence applications did not kill the weeds that had germinated, but the growth of all of the weeds mentioned above, with the exception of rough pigweed, was noticeably delayed. The delay was in direct proportion to the concentration of the chemical applied.

TABLE 18

WEATHER DATA OF THE SUMMER OF 1951 FROM THE LANSING AIRPORT SHOWING THE TOTAL RAINFALL AND AVERAGE TEMPERATURE DURING THE PERIOD OF FIELD EXPERIMENTS INVOLVING THE TOXICITY OF 3-CHLORO IPC ON VARIOUS CROPS

Type and time of application	Total inches of precipitation from time of application until harvest			
	May	June	July	Total
Pre-planting May 20	1.39	3.26	0.97	5.62
Pre-emergence May 26	1.02	3.26	0.97	5.25
Post-emergence June 29	--	0.00	0.97	0.97

Type and time of application	Average temperature from time of application until harvest			
	May	June	July	Total*
Pre-planting May 20	62.0	65.8	70.3	66.0
Pre-emergence May 26	60.7	65.8	70.3	65.3
Post-emergence June 29	--	66.5	70.3	68.4

*Average

DISCUSSION

The data presented indicate that 3-chloro IPC is leached from the soil, but at concentrations up to 24 pounds per acre, the degree of leaching is not materially affected by an increase in the amount of surface water added to the soil. The practicality of the cucumber seedling test with low concentrations of 3-chloro IPC is doubtful. The use of this test to determine the depth of leaching or the concentration in the surface soil might well be adapted to testing other growth regulators.

The length of time that 3-chloro IPC persists in the soil is definitely influenced by the type of soil to which it is applied. Contrary to previous investigations with certain other herbicides, this compound remains toxic longer in soils high in organic matter than in soils low in organic material. Since traces of the chemical were found in the lower layers of light and heavy soils, while none appeared in the lower layers of the organic soil it seems probable that the organic soil holds the molecules of 3-chloro IPC at the surface in greater concentrations than do the other soils tested.

Previous work with other growth regulators has shown that the acid soils are the first to lose toxicity, with the alkaline soils tending to be toxic the longest. This was the case when low concentrations of 3-chloro IPC were used. However, at the 24 pound rate the alkaline soil lost the toxic effects of the chemical very rapidly in relation to the neutral and acid soils. The black alkaline condition mentioned previously may have been the reason for this rapid loss in toxicity. If anaerobic conditions were established in these alkaline soils then it may be reasonable to assume that breakdown of 3-chloro IPC is more rapid under anaerobic conditions. The reason for the breakdown of the chemical in acid soils being delayed at the high concentration may be that the soil organisms were continually being inhibited by such an extreme pH level. In other words, the factors causing the early disappearance of the compound in acid soil were eventually overcome by the inhibiting effect of the acid medium on soil organisms.

Speculation as to what factors may cause the rapid breakdown in acid soils, when the chemical is present in a low concentration, is of value. It may be that the molecule of 3-chloro IPC must dissociate before it is taken up by the plant, and that the undissociated form is not toxic to plant growth. Therefore, as the hydrogen ion concentration in the soil is increased the amount of dissociated form would decrease with a corresponding decrease in toxic action. Other factors influencing the loss of the chemical, dispersion in the soil by leaching, and microbiological decomposition, would occur, but these factors

would be working on a lower concentration of the active form. Conversely, as the hydrogen ion concentration is reduced to the point of alkalinity, equilibrium of the undissociated form with the dissociated form would be pushed in the opposite direction, causing a very high concentration of the active form.

One might postulate from this, that the use of a test crop to determine the concentration in the soil does not indicate the total concentration but rather that of the active form only. A radical change in soil pH under normal conditions may then liberate or tie up the active form and effect the toxic action. For example, acid salts applied as fertilizer might reduce the toxic action of 3-chloro IPC in the soil.

The effect of low temperatures on the residual action of 3-chloro IPC is similar to that found on the residual action of other herbicides which have been investigated. Retarded activity by the soil microorganisms which act to decompose 3-chloro IPC is probably the best explanation that can be given for the slower loss of toxic effects at lower temperatures. From these results it appears that caution must be used in treating the soil in the fall with the expectation of growing a sensitive crop on that same soil in the spring.

The temperature at which treated pots were kept in the greenhouse was probably higher than the outside summer temperatures in Michigan. This is illustrated by the fact that, while the 2 pound rate lasted from 2 to 4 weeks in the greenhouse, a similar dosage lasted up to 8 weeks in the field, where the temperature was 10 degrees lower.

There was a definite trend, in the greenhouse experiments, for the heavy soil to lose its toxicity earlier than the other two soils tested (Figure VI). As the rate of application became greater, the difference in the properties of the various soils to retain toxic effects, was accentuated. Perhaps, if experiments involving residual properties were carried out using greater rates, more distinct differences between soils would be observed.

That 3-chloro IPC lasts longer in the soil than IPC at similar concentrations, has been shown. Another point of interest, however, is that 3-chloro IPC disappears from the soil in the order of its concentration, while IPC appears to disappear independently of the rate applied to the soil.

Where the soil treatments of 3-chloro IPC became toxic to the various crops tested, a stunting of growth was always observed. This dwarfing effect appeared to be preceded by a distortion of the new tissue arising from the embryo, as exemplified by the swollen coleoptile, and root tips of the grains. This type of injury is similar to that described by other investigators as occurring due to the action of IPC. This stunting probably occurs because the root tissues fail to take up sufficient amounts of water

and nutrients. Purple margins on the leaves of corn and sorghum seedlings and the dark green, brittle leaves of the oat seedlings indicated a lack of phosphorus.

The curvature or spiral effect observed in the young leaves of the oat and rye plants may be caused by phototropic responses due to hormonal effects of 3-chloro IPC.

The abundance of shoots arising from the crown of certain crop plants grown in plots treated with 3-chloro IPC, demands emphasis. The distortion of tissues at the cotyledonary plate, so evident on soybeans, may have caused this increase in shoot growth on plants that had the capacity to develop shoots from that point. However, the increased growth caused by the elimination of weeds can not be overlooked as an explanation for the increase in shoot production.

It is obvious that pre-planting treatments were far more lethal to the crops tested than were the pre-emergence treatments. This was undoubtedly due to a greater penetration of the chemical into the soil before planting, and to the greater distribution throughout the soil occurring as the soil is disturbed in the planting process. The ability of corn to survive pre-emergence treatments of such high rates may be due, at least in part, to the depth at which the seed was planted.

The development of a large number of brace roots at the second node of many corn plants, accompanied by an abundant development of fibrous roots, is a response similar to that observed by Hamner, Tukey, and Carlson (17) on sweet corn treated with 2,4-dichlorophenoxyacetic acid. This type of response again appeared to be due to the distortion of tissues at the crown of the plant. In rare cases the corn plants broke off at the crown.

Post-emergence treatments produced effects much like those of a contact herbicide, which leads to the conclusion that the injury was due to the xylene included in the formulation rather than the 3-chloro IPC. Currier (7) has shown xylene to be strongly toxic to several plant species. He has described this injury as a darkening of the leaves shortly after treatment, with loss of turgor resulting in a drooping of the stems and leaves. He also states that, in bright sunlight chlorophyll was destroyed, often causing a bleaching of the tissue. Broadleaved plants were injured more than the grasses by post-emergence treatments, which indicates that the area of the leaf surface was involved.

In general, the use of 3-chloro IPC on wheat, oats, and rye for the control of weeds could not be recommended from the results of these experiments. Applications in the 1 to 3 pound range on sorghum, Ladino clover, and alfalfa deserve further investigation. Soybeans and corn responded very well to several of the treatments with good control of grass weeds. The data show red clover to be the most sensitive of the legumes to applications of 3-chloro IPC and therefore the use of the chemical on this crop is not advisable.

SUMMARY

1. High concentrations of 3-chloro IPC were leached from 5 gram samples of light, heavy, and organic soils. For the most part the amount of the chemical leached from the soil was independent of the concentration.
2. Light, heavy, and organic soils treated with 2, 6, 12, and 24 pounds per acre of 3-chloro IPC were leached with 1, 1 1/2, and 2 inches of surface water each week. The amount of water used in leaching did not effect the loss of toxicity from the soil. The chemical persisted 30, 60, 76, and 104 days in the light and heavy soil, and 44, 76, 90, and 148 days in the organic soil.
3. A 2 pound rate of 3-chloro IPC became non-toxic in heavy, light, and organic soils adjusted to pH 3 in 9, 18, and 37 days. The same soils adjusted to pH 8.5 were non-toxic in 18, 37, and 47 days. The 2 pound rate lasted in neutral light soil 29 days and in heavy and organic soils 47 days. Twenty-four pounds per acre lasted 72 days in the heavy alkaline soil and 95 days in the light and organic alkaline soils. The heavy acid soil was non-toxic in 108 days and the light acid and organic acid soils were still toxic after 159 days. The neutral light and heavy soils were free of toxic

effects in 84 days, while the chemical remained active after 159 days in the neutral organic soil.

4. Temperatures of 35 and 55 degrees Fahrenheit delayed the breakdown of 3-chloro IPC in light, heavy, and organic soils. Two and 24 pound rates were toxic in the light and heavy soils for more than 12 weeks at these temperatures. The organic soil when treated with 2 pounds per acre lost its residual action in 6 weeks, while the 24 pound rate was toxic for more than 12 weeks. At a temperature of 75 degrees toxicity persisted 2 to 4 weeks in the light, heavy, and organic soil treated with 2 pounds per acre. While heavy soil which had received an application of 24 pounds per acre lost its toxicity in 10 weeks, the light and organic soils treated with the same rate were still toxic after 12 weeks.

5. In a field comparison of IPC with 3-chloro IPC it was found that IPC at the rates of 2, 6, and 12 pounds per acre lasted only 6 weeks despite the dosage used. The 3-chloro IPC lasted 8 weeks at the 2 pound rate, and more than 12 weeks at the 6 and 12 pound rates.

6. Pre-planting, pre-emergence, and post-emergence applications were made on corn, sorghum, wheat, oats, rye, soybeans, Ladino clover, red clover, and alfalfa at rates of 1, 3, 6, and 12 pounds per acre. Post-emergence applications reduced the weight of most crop plants and delayed the growth of most weeds. Pre-planting

applications to all crops were more toxic than pre-emergence applications. The best weed control, with the least injury, occurred in corn and soybeans. Oats, wheat, and rye were very sensitive to applications of 3-chloro IPC. Treatments applied to the soil gave excellent control of grass weeds.

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