AN ABSTRACT OF THE THESIS OF

LUIS FERNAN FIGUEROLA (Name) for the PH. D. (Degree)

in FARM CROPS (Major) presented on April 25, 1969

Title: THE INFLUENCE OF VARIOUS CLIMATIC AND EDAPHIC FACTORS ON THE TOXICITY OF 2-tert.butylamino-4-ethylamino-6-methylthio-s-triazine (Igran) TO WINTER WHEAT (Triticum aestivum Vill., Host)

Abstract approved: [redacted]
William R. Furtick

Several studies were conducted to determine the influence of various environmental factors on the toxicity of 2-tert.butylamino-4-ethylamino-6-methylthio-s-triazine (Igran) to winter wheat.

The effect of temperature on Igran toxicity was studied by growing wheat plants in pots submerged in water baths to control soil temperature and in controlled-environment chambers. Igran was more toxic to the test plants at 20-25 C than at 5-10 C. The lesser toxicity at low temperature appeared to be correlated in part with lower rates of absorption and translocation of the chemical.

Light intensity was shown to influence the activity of Igran. High light intensity produced an effect similar to that of high temperature and it was difficult to separate the individual action for

either climatic factor.

The effect of Igran on photosynthesis of wheat plants was studied by measuring the CO_2 uptake with an infrared gas analyzer. The activity of Igran was more pronounced at high light intensity.

Water availability in the soil influenced Igran action on winter wheat. The higher the water content in the soil, under high temperature and light intensity conditions, the higher the apparent absorption and translocation of Igran. This effect was related to the adsorptive capacity of soil particles. With increased water content in the soil, Igran apparently becomes more available to the roots than under low moisture conditions.

High nitrogen content in the growth medium favored Igran toxic action on winter wheat. With lower nitrogen levels, although the growth rate was diminished, chlorosis and necrosis were not as noticeable as under high nitrogen content conditions.

Igran was less toxic when applied directly to the soil surface than when incorporated into the soil. When the herbicide was placed close to the root system, the toxicity was greatly increased.

Postemergence applications of Igran to the soil under high illumination (2500-3000 ft-c) and high temperature (20-30 C) produced severe injury to wheat even at low rates and at several stages of growth. At low light intensity (500-800 ft-c) and low temperature (5-10 C) few or no injury symptoms were observed.

The determination of the factors affecting the toxicity of Igran on winter wheat will aid in making improved recommendations for its use to control a broad spectrum of undesired vegetation with a minimum chance for damage to wheat plants.

The Influence of Various Climatic and Edaphic Factors on the Toxicity of 2-tert.butyl-amino-4-ethylamino-6-methylthio-s-triazine (Igran) to Winter Wheat (Triticum aestivum Vill., Host)

by

Luis Fernan Figuerola

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

June 1969

APPROVED:

[redacted]

Professor of Agronomy
in charge of major

[redacted]

Head of Department of Farm Crops

[redacted]

Dean of Graduate School

Date thesis is presented April 25, 1969

Typed by Donna L. Olson for Luis Fernan Figuerola

ACKNOWLEDGEMENTS

The author expresses his eternal gratitude to his wife, Carmen, and family for their ever-willing aid, patience, understanding and sacrifice during the graduate program.

The author wishes to express his sincere appreciation to the following individuals:

Dr. William R. Furtick for continued financial support and kind guidance during the graduate program.

Dr. Larry Boersma for his valuable counseling and the use of the infrared gas analyzer.

Dr. Grant E. Blanch, Dr. David O. Chilcote, Dr. Oliver C. Compton, Mrs. Georgena S. Knapp, and Dr. Thomas C. Moore for their excellent suggestions in the writing of the thesis.

To the staff and graduate students in the Farm Crops department for their gracious and continued assistance throughout the graduate program.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

THE INFLUENCE OF VARIOUS CLIMATIC AND EDAPHIC FACTORS ON THE TOXICITY OF 2-tert.butylamino-4-ethylamino-6-methylthio-s-triazine (Igran) TO WINTER WHEAT (Triticum aestivum Vill., Host)

INTRODUCTION

The high biological activity of the triazine herbicides against a wide spectrum of undesirable plants has made them useful as soil sterilants and as selective herbicides on certain crops.

Theoretically, there exist several possibilities why selectivity occurs: (1) resistant plants may not be able to absorb the herbicide through the root system or foliage; (2) the herbicide may be accumulated in resistant plants without harmful effects; (3) the resistant plant may be able to detoxify the herbicide or (4) resistant plants, because of certain morphological features, may escape contact with the herbicide.

During the past several years, a number of triazine herbicides have been evaluated for weed control in cereals. Of the triazines included in the experiments, Igran has proved to be least toxic to wheat (Furtick, 1967).

Ellis (1968) reported that Igran was much less injurious to winter wheat when applied during the fall and winter than when applied in spring or summer.

Many examples can be cited of seasonal responses to various

herbicides under field conditions. Unfortunately, one can never be completely sure which environmental factor is most critical. Temperature, light, rainfall, relative humidity, soil type, application methods and stage of plant growth have all been shown to affect the response of plants to triazine herbicides. Therefore, it is necessary to control these factors within very narrow limits in order to determine precisely their relative roles and importance.

The objectives of this investigation were to study several environmental factors that might influence the activity of Igran on winter wheat.

The effect of water stress in the soil on Igran uptake by wheat plants was studied to observe its influence on the availability of the herbicide in the soil. Other studies investigated the timing, mode of herbicide application and stage of plant growth to determine the optimum margin of safety under several application methods and different environmental conditions.

The influences of temperature and light intensity on Igran phytotoxicity were studied to determine critical levels and possible correlations with herbicide activity. By using an infrared gas analyzer, carbon dioxide uptake by treated plants was measured under different light intensities.

The effect of nitrogen content in the soil on Igran activity was investigated to determine if there is an interaction.

In order to interpret in a more precise manner the results of the various experiments, several studies were developed to compare Igran with 2-chloro-4, 6-bis(ethylamino)-s-triazine (simazine) one of the oldest triazines used as an herbicide. Most of the field investigations on wheat have been made with simazine.

The various experiments performed under controlled-environment conditions were designed to determine the relative importance of each of the various physical factors studied.

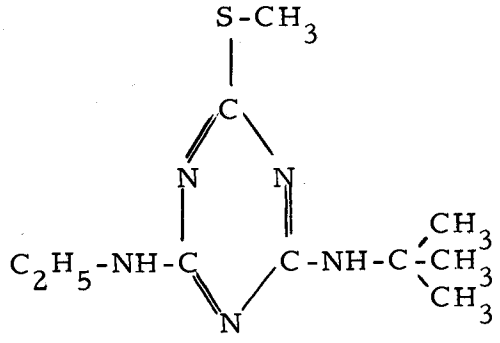
The findings of this investigation will contribute to a better understanding of the activity of Igran and to make better recommendations for more efficient use.

LITERATURE REVIEW

Very little research has been reported on Igran. The work with simazine and 2-chloro-4-ethylamino-6-isopropylamino-s-triazine (atrazine) which are closely related triazine herbicides, is used as the basis for the review of information concerning Igran activity.

The chemistry and herbicidal properties of triazine derivatives have been reviewed by Gysin (1963) and Knüsli (1964). The chloro-triazines are by far the most thoroughly studied representatives of the triazines. They act as soil sterilants at high application rates but some show striking herbicidal selectivities in certain crops at lower rates.

Igran has the following structural formula



It has a molecular weight of 241, water solubility at 20 C is 58 ppm and is very soluble in organic solvents. The melting point is 104-105 C. The acute oral toxicity (LD_{50}) in rats is 2980 mg/kg. It

is formulated as a wettable powder (80%) and granular (5%) and has relatively short residual life in the soil.

Mode of Action

The literature on the mode of action of the triazine herbicides has been reviewed by Knüsli (1964) and Moreland (1967).

Triazines penetrate plants through the cuticle and through the roots. Upward movement occurs in the xylem. Since the rate of triazine uptake varies from one plant species to another, it can be considered as one of the factors determining sensitivity or resistance of a plant.

The distribution pattern observed for the triazines is similar to that reported for 3-(p-chlorophenyl)-1,1-dimethylurea (monuron) in potato leaves and tuber tissue (Crafts, 1961). These findings suggest that upon entering the mesophyll, these herbicides diffuse predominantly along the cell walls and do not readily enter the living symplast. This apoplastic movement is accelerated by the flow of water and hence produces a rather typical wedge-shaped pattern of distribution in leaves of plants such as bean (Phaseoulus vulgaris L.) and cotton (Gossypium hirsutum L.).

In monocotyledons, as a result of transpiration, accumulation occurs at the tips and margins of leaves and injury progresses basipetally. This effect has been observed in many species, but varies

with the degree of penetration and the venation pattern of the species.

The inhibition of photosynthesis by the s-triazines is a well established fact. Evidence for this conclusion comes from several workers using different techniques. Gast (1958) demonstrated the inhibition of starch synthesis in Coleus blumei B. by simazine but the addition of sucrose counteracted this effect. Moreland et al. (1962) showed that the weed killing power of simazine can be reduced by supplying carbohydrates to the plant through the leaves. Roth (1967) observed that simazine inhibited photosynthesis in Elodea spp. in a similar way to that shown by Gast (1958) for Coleus blumei B.

Exer (1958), Moreland (1959), Good (1961) and Bishop (1962) concluded that triazines are among the most active inhibitors of the oxygen evolution system or Hill reaction. This inhibition occurs in a manner similar to that of 3-(3,4-dichlorophenyl)-1,1-dimethylurea (diuron) and thus indicates that the electron from water is prevented from being received by the quinones thereby blocking the photosynthetic mechanism.

Sing and West (1967) studying the influence of simazine on chloroplast ribonucleic acid and protein metabolism found that the quantities of chloroplast proteins and chlorophyll were lower in oat plants (Avena sativa L.) treated six days with simazine than in the

controls. They suggested an effect even in darkness on amino acid incorporation into chloroplasts. Total ribonucleic acid content and synthesis as measured by incorporation of P^{32} were altered by simazine treatments.

Ashton et al. (1966) found that atrazine has several profound effects on the morphology of red kidney beans (Phaseoulus vulgaris L.). The modification included: (a) precocious development of vacuoles and a modified ontogeny of chloroplasts in developing leaves; (b) chloroplast destruction and reduced airspace system in matured primary leaves; and (c) cessation of cambial activity and decreased thickness of the cell walls of the sieve and tracheary elements in the stem. Similarly, Hill et al. (1968), studying atrazine-induced ultrastructural changes of barnyardgrass (Echinocloa crusgalli), found that degradation of the chloroplast starts as a swelling and disruption of granal discs. In advanced stages of breakdown, the membranes of the grana and chloroplast envelope were ruptured. The changes were initiated two hours after treatment with rates of 2, 5, 10, and 20 ppm atrazine. The incidence of starch grains greatly decreased as the duration of treatment exceeded four hours. They concluded that the ultrastructural changes preceded any macroscopically discernible symptoms of tissue breakdown.

The s-triazines action on photosynthesis has also been examined by their effect on photosynthetic CO_2 fixation. Ashton

et al. (1960) demonstrated the effect of certain triazines on CO_2 fixation in red kidney beans. Simazine at a concentration of 0.25 ppm decreased CO_2 fixation by 30 percent and at 1.0 ppm fixation was almost completely inhibited. Van Oorschot (1965) monitored the CO_2 exchange of plants maintained in an enclosed chamber by infra-red analysis and found that CO_2 uptake of corn (Zea mays L.) was strongly inhibited by several s-triazines. The capacity of the plant to inactivate the triazines absorbed is reflected by an eventual recovery in the rate of CO_2 uptake. However, no indication is given of the nature of the inactivation in the plant. Dark CO_2 fixation is not affected according to Ashton et al. (1960 and 1962), Couch and Davis (1966) and Van Oorschot (1965).

Transpiration is known to influence the translocation of root-absorbed compounds. Sheets (1961) reported that simazine translocation was dependent on the rate of transpiration. Wills et al. (1963) and Smith and Buchholtz (1962) reported that atrazine reduced the transpiration of both resistant and susceptible species. This reduction in transpiration can be expected to reduce the upward translocation of root-absorbed compounds including atrazine. The amount of atrazine available for translocation from root to shoot of course depends on the amount of atrazine available in the soil and the amount of atrazine absorbed by the root. Shimabukuro et al. (1967) observed that reduction in translocation of atrazine-C^{14} to the

shoot apices of oat plants in early stages of herbicidal injury was not due to reduced absorption but very likely to some other factor such as reduced transpiration.

Adsorption

Several studies have shown that organic matter is the most important soil property affecting adsorption of herbicides in soil. The amount of soil-applied herbicide required to provide the same degree of biological activity may vary by as much as twenty-fold depending on the particular soil type involved (Upchurch and Mason, 1962).

Talbert (1965), investigating the adsorption of some s-triazines in soils, found that increased amounts of organic matter and/or clay in soil, generally were associated with increased adsorption of triazines. Day et al. (1964) found a broad positive correlation of simazine adsorption with organic matter and clay contents in several California soils. Multiple correlation analysis indicated that dosage of simazine is largely predictable on the basis of organic matter alone. Harris and Warren (1964) also found close correlation between simazine phytotoxicity and the amount of organic matter present in the soil. In another study Grover (1966) demonstrated that organic matter content reduced the effectiveness of simazine in Regina heavy clay soil. At high moisture levels, changes in the

relative amount of clay in the soil did not affect the toxicity of simazine.

Several investigators have found an inverse relationship between adsorption and an increase in pH (McGlamery et al., 1966; Harris et al., 1964). However the adsorption of simazine by 18 soils was not correlated significantly with soil pH according to Nearpass (1965) but was correlated significantly with percent of clay and highly significantly with organic matter. Sheets et al. (1962) reported that the differences in toxicity of s-triazine herbicides in a series of California soils were correlated with organic matter, cation exchange capacity and pH, with adsorption being increased as the pH is lowered.

Studying the soil adsorption of several triazines and monuron, Harris et al. (1964) found that 2,4-bis(isopropylamino)-6-methylthio-s-triazine (prometryne) closely related to Igran, was adsorbed by soil particles stronger than any other triazine or monuron. They suggested that the $-SCH_3$ group in prometryne influences the electron density of the molecule to cause strong binding forces between soil particles and prometryne. The effect of chloro-substitution (propazine), conversely, appears to lessen the attractive forces between the herbicide and soil particles according to Frissel et al. (1962) and Harris and Warren (1964).

Lack of effective precipitation and soil moisture may reduce

the effectiveness of herbicides by limiting their absorption and movement. The lack of precipitation to move triazines into the soil after treatments may account for the poor results observed in some seasons and in most areas.

Davis et al. (1959) studying toxicity levels for simazine in various crops found high toxicity in cucumber (Cucumis sativus L.), intermediate in cotton (Gossypium hirsutum L.) and slight toxicity in corn (Zea mays L.). The absorption and translocation of simazine from the soil followed the same pattern as from nutrient culture. More simazine was absorbed from soil that received simulated rainfall than from subirrigated soil.

Sund (1964) studied the relationship between weed control with atrazine, simazine, monuron and diuron in sugar cane (Saccharum officinarun L.) fields in Hawaii, and herbicide adsorption characteristics of the soils at the rainfall regimes encountered. Weed control was negatively correlated with herbicide adsorption by the soils and positively correlated with rainfall. Similarly Bailey and White (1964) have suggested that there is competition between the solute and solvent molecules for adsorption sites on the surface of soil colloids. Lambert et al. (1965) have shown that $E.D._{50}$ values divided by the percentage of available soil moisture, should give a straight line when plotted against the ratio of percent organic matter to percent available soil moisture.

Application Methods

Waldrep and Freeman (1964) reported that placing the herbicide in the soil, regardless of the method used, can result in a reduction in crop safety where selectivity is attributable to the differential position of sensitive organs of crops and the herbicide rather than to inherent selectivity. Placement is of most critical importance for selective preemergence weed control in annual crops. It also has considerable effect upon herbicide persistence and volatility losses due either to elevated temperature or photoinduced reactions.

Upchurch (1966) reported that application methods should depend on the physico-chemical properties of the herbicide which govern its behaviour in the environment, the specific soil factors involved and the response of various crops and weed organs or tissues to the herbicide being used.

Considerable research has been conducted on sites of uptake of soil applied herbicides (Knake et al., 1967; Nishimoto, 1968) but most studies have involved uptake by primary roots systems or by shoots prior to emergence. Coartney and Williams (1966) showed that atrazine positioned at the 0-1 and 1-2 inch depth was more effective in terms of rapidity of kill for giant foxtail (Setaria faberii Herrm.) seedlings, than the deeper placement regardless of planting

depth.

The effect of incorporation and method of irrigation on pre-emergence herbicides was studied by Jordan et al. (1963). They found the toxicity of some herbicides was increased by soil incorporation and/or sprinkler irrigation.

Prendeville et al. (1967 and 1968) stated that photosynthetic inhibitors such as diuron and atrazine, showed similarity in the site of uptake, which was mainly through the roots. Similarly Davis et al. (1959) and Sheets (1961) found, using autoradiography, that simazine was readily absorbed by roots of a wide range of plant species.

Illumination

The knowledge that certain herbicides inhibit the Hill reaction of photosynthesis in plants induced various researchers to study the behaviour of triazine sensitive plants in light and in dark. The influence of light on the toxicity of s-triazines has been demonstrated by several investigators and they concluded that light is indispensable for the morphological symptoms of toxicity. Tracing the movement of radiolabelled triazines through the plant, Crafts (1961), found a drastic change in the metabolism of living cells in the presence of light. Allen and Palmer (1963) also demonstrated the influence of light on simazine activity in barley (Hordeun vulgare

L.). The same species grown in the dark showed very little decrease in weight. Ashton (1965) studied light intensity and quality effects on the toxicity of atrazine. The degree of injury on oats was proportional to the increase in light intensity from 30 to 4000 ft-c. The greatest injury occurred at 428 and 658 mμ wavelength with the minimum being at 500, 528 and 607 mμ. The action spectrum indicated that chlorophyll was the principal absorbing pigment involved in this injury.

Light also affects the activity of triazine herbicides by influencing photodecomposition. Jordan et al. (1963 and 1964) stated that photodecomposition could be an important mechanism of herbicide detoxification on soil under field conditions, especially where surface applications are made without receiving subsequent incorporation, rainfall or overhead irrigation. They also stated that in some instances it is difficult to separate the effects of light and temperature on the decomposition of the triazines.

Upchurch (1966) said that any phenomenon which influences the excitation state of electrons of a molecule or their radiation absorptivity characteristics will influence their capacity to change under the impact of radiation. Comes and Timmons (1966) investigating the effect of sunlight on the phytotoxicity of some phenylurea and triazine herbicides on a soil surface found a significant decrease in toxicity to oats after 25 days exposure to sunlight.

Temperature

Temperature has complex effects in the soil and on plants. Relatively slight differences in temperature at critical periods may cause large differences in final growth responses.

Currier and Dybing (1959) suggested that some of the effects of temperature on penetration of herbicides are exerted through changes in physico-chemical processes, rates of diffusion, viscosity and so forth, and physiological factors such as acceleration of photosynthesis, phloem translocation, protoplasm streaming and growth. Drying of sprays droplets and closure of stomata under a water stress may also be important.

The role of temperature in the inactivation of some s-triazine herbicides was studied by Buchanan et al. (1963). As indicated by response of cucumber seedlings, atrazine and 2-chloro-4-diethylamino-6-isopropylamino-s-triazine (ipazine) were inactivated more rapidly when stored in soil at temperatures 30 to 45 C prior to planting. Growth of oats and soybeans indicated that simazine, atrazine and ipazine were inactivated in less than seven weeks during the summer when temperatures exceeded 30 C. Atratone (2-methoxy-4-ethylamino-6-isopropylamino-s-triazine) was shown to be resistant to changes in temperature.

Harris and Warren (1964) studied the effect of temperature on

the adsorption of various herbicides by different adsorbents. They showed that the effect of temperature on the adsorption of herbicides by soil particles does not hold for all cases. The adsorption of simazine, atrazine and monuron by bentonite was greater at 0 C than at 50 C while 6-7-dihydrodipyrido(1,2a;2',1c')pyrazidinium (as bromide salt) (diquat) was completely adsorbed at both temperatures.

Burnside and Behrens (1961) found that an increase in the soil temperature from 59 to 86 F resulted in an increase in the toxicity of simazine to corn. Sheets (1961) studying uptake and distribution of simazine by oats and cotton seedlings demonstrated that absorption of simazine from solution and the translocation of C^{14} upward were both greater at 37 C than at 26 C. Montgomery and Freed (1963) also studied the effect of temperature on the uptake of radioactive simazine by wheat (Triticum aestivum L.). At 80 F the radioactivity was much higher than at 60 F. Radioactivity was much greater when simazine was incorporated than when surface applied.

Talbert et al. (1965) studying the effect of temperature on adsorption found that increasing the temperature and pH resulted in decreased adsorption of simazine and atrazine. McGlamery et al. (1966) using clay loam soil and humic acid soil found adsorption of atrazine to be inversely related to pH but it was slightly affected by temperature and concentration of atrazine. Desorption of atrazine was greater with increasing temperature and pH.

Leonard (1967) observed that high temperature enhances the rate of transpiration and thus favors the translocation of photosynthesis inhibiting herbicides. Similarly, Sedgley and Boersma (1968) demonstrated the effect of soil temperature and soil water stress on diuron toxicity to wheat. Inhibition of photosynthesis occurred earlier at 24 C than at 10 C and also occurred earlier at an osmotic pressure of 0.3 compared with 2.5 bars. Both translocation and absorption have been reported as being accelerated at high temperatures. Most workers have failed to separate absorption from translocation or toxic effect and it is difficult to draw conclusions from much of the literature.

Jordan et al. (1964) stated that in some instances it is difficult to separate the effects of ultraviolet light and temperature and the decomposition of the triazines.

Holly et al. (1963) working on the persistance of phytotoxic residues of triazines observed that the time required for disappearance of 80 percent of the activity following application of simazine at two pounds per acre varied from seven to 27 weeks depending on the weather, especially rainfall and temperature. Reduction of phytotoxicity of some triazines and phenylureas was studied by Comes and Timmons (1965). With temperature above 180 F phytotoxicities were reduced to 65 and 90 percent regardless of whether they were exposed to sunlight or remained in darkness.

Studying effects of environment on atrazine phytotoxicity, Behrens (1964) found that atrazine injury symptoms were apparent first at the higher temperatures in soybeans and that the ultimate phytotoxic effect of atrazine was the same at all temperatures.

Microbial Degradation

Microbes are of primary importance in regulating the length of herbicide phytotoxicity in soil. Kaufman et al. (1964) have reported over a dozen specific soil microbes which degrade simazine. The pathway of degradation in soil has been demonstrated for the s-triazines and differs from the hydroxylation-ring cleavage process reported for plants (Hamilton and Moreland, 1962; Montgomery and Freed, 1964). However, hydroxysimazine has also been found in soils (Harris, 1965).

Nitrogen Interaction

Recently, it has been reported that atrazine applications increased the nitrogen content in some plants. This discovery aroused the interest of various researchers and stimulated research on the mode of action of this herbicide in plants.

Shirman and Buchholtz (1966) studied the influence of atrazine on the control of rhizome carbohydrate reserves of quackgrass (Agropyron repens (L) Beauv). They observed a depletion of

carbohydrate reserves in the rhizomes, which increased with the time after application. Addition of nitrogen increased the rate of carbohydrate depletion.

Gramlich and Davis (1967) studied the effect of atrazine on nitrogen metabolism of resistant plant species. They found that treated plants of all species tested showed a lower rate of nitrogen metabolism than controls and contained higher nitrogen percentages.

Ries and Gast (1965) found that the addition of simazine to the culture solution where corn was grown, increased the nitrogen level in plants much more than could be accounted for by the nitrogen available in simazine. Tweedy and Ries (1966) also found that simazine at 0.08 ppm caused an increase in the dry weight and total nitrogen content in corn plants grown in a solution with nitrate as the nitrogen source and temperatures of 72 F by day and 62 F by night. When the temperatures were increased from 72 F to 82 F during the day and from 62 F to 72 F at night, or when ammonia was substituted for nitrate, simazine had no effect on the dry weight or total nitrogen content of the corn plants.

Metabolism of Triazines

The degradation of triazines by certain plants has been shown in several studies (Freed et al., 1961; Foy, 1961; Castelfranco et al., 1961; and Hamilton, 1962). The evidence for metabolism was

confirmed by means of ion exchange and paper chromatography where it was shown that only trace amounts, if any, of the triazines used remained unchanged in plants. This information, coupled with the demonstration that the corn plant is able to degrade the triazines to $C^{14}O_2$, leads to the conclusion that corn plants readily metabolize these compounds.

Montgomery and Freed (1964) stated that the metabolism of the triazine herbicides by plants appears to be a general phenomenon. Although there is a good correlation between resistance and extent of metabolism, even the highly susceptible plants have a limited capacity for degrading these chemicals. A common pathway of degradation is indicated by the presence of the 2-hydroxy analogs in plants treated with different triazines. Resistant species converted at least twice as much atrazine to hydroxy atrazine as did the susceptible soybeans and oats in a metabolism study by Negi et al. (1964).

The spectrum of plant tolerance to prometryne, a methylthio triazine closely related to Igran, is different from that of the chlorodiamino-triazines according to Knüsli (1964). Prometryne and related analogs are more basic than the corresponding chlorodiamino-triazines. Consequently, they more easily form salts with acids and the salts are more stable with respect to dissociation in aqueous media. Studies conducted at Geigy laboratories in Switzerland have

revealed an oxidative degrading process for methylthio-derivatives. The production of sulfone and sulfoxide analogs, which are not phytotoxic, have been achieved by Payot and Müller (Knüsli, 1964) on peas but as they said, these findings can naturally not yet be generalized to other plant species.

GENERAL MATERIALS AND METHODS

Several studies were conducted in the greenhouse and controlled environment chambers to determine the influence of climatic and edaphic factors on the toxicity of Igran to winter wheat (Triticum aestivum Vill., Host.) var. Druchamp.

In some experiments Chehalis loam with the characteristics indicated in Table 1 and in others, washed quartz sand (El Monte EI-20), were the root media for the wheat plants.

Plastic pots 10x10x10 cm each containing one kilogram of air dry soil or white sand were used to grow the plants. Except as noted, 12 seeds were planted 2 cm deep in each pot. One week after emergence the stand was thinned to eight plants per pot.

Periodic applications of a complete nutrient solution (Hoagland and Arnon 1950) were made according to the conditions of each experiment.

A Tee jet 8001-E nozzle 35 cm above the soil surface was used for applications in experiments where the herbicide was sprayed. The same type of nozzle was used for soil incorporation with a stationary sprayer in a soil blender.

Sufficient water was added to a given dose of Igran to make 100 ml of solution which was applied evenly on the surface of the medium in some experiments. It was assumed that the herbicide

would remain in the root zone since no drainage was permitted from the time of treatment to harvest.

Foliage and/or root dry weights of all wheat plants per pot were the common parameters measured for each experiment. The samples were put into 50 x 40 mm weighing bottles and placed in a forced air oven at about 90 C for 24 hours.

The experimental design and other pertinent details are indicated for each experiment.

Light intensity in the greenhouse was usually low (500 to 1500 ft-c) with the highest registered at 6000 ft-c for a short period under full sunlight during the summer months. No supplemental light was provided for any greenhouse study except for experiments performed in controlled environment chambers where wheat seeds were initially germinated in the greenhouse. The greenhouse air temperature averaged 24 C most days with a minimum of 15 C and a maximum of 32 C. Relative humidity fluctuated between fifty and seventy percent.

The light sources in controlled environment chambers were eight F 72T12/cool white/CW XHO Ken Rad fluorescent tubes and eight 25 watts incandescent bulbs. In these chambers, illumination and temperature were changed according to the requirements of each study. Photoperiod and temperature variations, except as noted, were in twelve-hour intervals. The relative humidity was constant

in all experiments.

Further specific information is described for each particular study.

Table 1. Characteristics of the soil (Chehalis loam) used.

pH	6.1	Sand (%) 2-0.05 mm	50.12
P ppm	18.2	Silt (%) 0.05-0.002 mm	32.33
K me/100g	0.9	Clay (%) $\leq$ 0.002 mm	17.55
Ca me/100g	8.6	Organic matter (%)	1.74
Mg me/100g	5.2	Moisture (%) (0.33 atm)	19.09
CEC me/100g	16.91	Moisture (%) (15.0 atm)	9.65

EXPERIMENT I. THE EFFECT OF SOIL TEMPERATURE ON THE TOXICITY OF IGRAN TO WINTER WHEAT

Soil temperature influences the rate of chemical, physical and biological processes. In this study simazine and Igran were compared at four different soil temperatures to observe the influence of temperature of herbicide activity.

Materials and Methods

Four experiments were conducted in which winter wheat was grown in plastic pots submerged in a water bath at four different temperatures: 7, 15, 24 and 32 C.

Each plastic pot contained one kilogram of Chehalis loam. Igran and simazine were applied on the soil surface at five rates: 0, 0.5, 1, 2 and 4 pounds per acre immediately after seeding.

Light intensity was low during the experiment and air temperature averaged 24 C. Light intensity and air temperature were the same for the four soil temperatures studied.

Foliage dry weights harvested four weeks after seeding were used as parameters for statistical comparisons.

Results

Tables 2, 3, 4, and 5 show the results obtained in the four experiments as well as the pertinent analysis of variance. Igran

Table 2. Winter wheat response to Igran and simazine applications at 7 C soil temperature.

Herbicide	Lbs/A	Foliage dry wt. per pot in mg					% of control
		I	II	III	IV	Avg.	
Igran	0	701	497	690	637	631.2	
	0.5	755	700	673	638	691.5	109.5
	1.0	575	607	596	616	598.5	94.8
	2.0	568	590	519	543	555.0	87.9
	4.0	451	551	649	590	560.2	88.7
Simazine	0	680	646	623	667	654.0	
	0.5	493	487	671	482	533.2	81.5
	1.0	422	571	451	548	498.0	76.1
	2.0	109	451	600	577	434.2	66.3
	4.0	132	153	296	134	178.75	27.3
LSD (0.05) Treatments						137.80	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	9	85066.91	9.32**
Rates	4	93508.71	10.24**
Herbicides	1	218005.23	23.88**
R x H	4	43390.53	4.75**
Error	30	9126.59	

**Significant at 1% level.

$\bar{x} = 533.4$ $s = 95.5$ $CV = 17.9\%$

Table 3. Winter wheat response to Igran and simazine applications at 15 C soil temperature.

Herbicide	Lbs/A	Foliage dry wt. per pot in mg					% of control
		I	II	III	IV	Avg.	
Igran	0	921	960	867	1010	939.5	
	0.5	1014	1110	879	877	970.0	103.2
	1.0	896	897	828	878	874.7	93.1
	2.0	647	641	731	842	715.2	76.1
	4.0	694	694	796	833	754.2	80.2
Simazine	0	905	921	911	1013	937.5	
	0.5	854	937	768	820	844.7	90.1
	1.0	716	553	728	656	633.2	70.7
	2.0	660	554	657	610	620.2	66.1
	4.0	270	203	269	259	250.2	26.6
LSD (0.05) Treatments						375.3	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	9	186158.41	3.80**
Rates	4	257124.02	5.25**
Herbicides	1	351750.03	7.18**
R x H	4	73794.90	1.50
Error	30	48925.08	

**Significant at 1% level.

$\bar{x}$ = 756.9 s = 221.1 CV = 29.2%

Table 4. Winter wheat response to Igran and simazine applications at 24 C soil temperature.

Herbicide	Lbs/A	Foliage dry wt. per pot in mg					% of control
		I	II	III	IV	Avg.	
Igran	0	1057	1052	1170	1057	1084.0	
	0.5	1090	1228	1061	1002	1095.2	101.0
	1.0	1138	1105	967	1060	1067.5	98.4
	2.0	956	1009	951	1191	1026.7	94.7
	4.0	1151	843	794	966	938.5	86.5
Simazine	0	1025	1110	1175	1015	1081.2	
	0.5	1040	1120	1006	888	1013.5	93.7
	1.0	596	767	1123	723	802.2	74.1
	2.0	873	959	794	648	818.5	75.7
	4.0	453	418	134	183	297.0	27.4
LSD (0.05) Treatments						185.6	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	9	239147.87	14.44**
Rates	4	272113.47	16.43**
Herbicides	1	575520.10	34.75**
R x H	4	122089.22	7.37**
Error	30	16558.83	

**Significant at 1% level.

$\bar{x} = 922.4$ $s = 128.6$ $CV = 13.9\%$

Table 5. Winter wheat response to Igran and simazine applications at 32 C soil temperature.

Herbicide	Lbs/A	Foliage dry wt. per pot in mg					% of control
		I	II	III	IV	Avg.	
Igran	0	1019	944	1040	1039	1010.5	
	0.5	1109	911	1042	1309	1092.7	108.1
	1.0	946	998	1033	1309	1071.5	106.0
	2.0	974	777	900	917	892.0	88.2
	4.0	740	934	970	975	904.7	89.5
Simazine	0	1037	978	1025	960	1000.0	
	0.5	906	776	1008	860	887.5	88.7
	1.0	508	561	580	571	555.0	55.5
	2.0	651	516	275	458	475.0	47.5
	4.0	260	105	141	220	181.5	18.1
LSD (0.05) Treatments						155.3	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	9	363783.60	31.35**
Rates	4	315518.27	27.19**
Herbicides	1	1402502.50	120.89**
R x H	4	152369.20	13.13**
Error	30	11600.71	

**Significant at 1% level.

$\bar{x}$ = 807.0 s = 107.7 CV = 13.3%

was much less toxic to the wheat plants than simazine at all soil temperatures. The differences were highly significant.

The greatest dry weight was obtained at 24 C, while at 32 C the plants did not look healthy and lodging was evident in most plants. At 15 and 7 C, the plants were smaller than at higher temperature but when treated with Igran the plants were very healthy and had a dark green color. Plants which were treated with simazine were chlorotic with some necrotic leaves.

Wheat plants treated with Igran at the rate of 0.5 pounds per acre showed growth stimulation at all temperatures. At the rate of one pound per acre a slight reduction occurred at all but the 32 C temperature. Growth was reduced at the two and four pounds per acre rate but the reduction was not significant. Simazine was much more toxic at all rates and injury symptoms appeared less than one week after emergence. Foliage dry weights were significantly lower than the controls when simazine was applied at the rate of four pounds per acre at 15 C or at 1, 2 and 4 pounds per acre rate at the 24 C and 32 C temperatures.

EXPERIMENT II. APPLICATION METHODS STUDY

Some triazines are absorbed mainly through the roots and very little through the foliage. The objective of this experiment was to determine the difference between surface applied and soil incorporated applications made prior to emergence. Also comparisons were made on postemergence applications 15 and 30 days after emergence.

Materials and Methods

Plastic pots each containing one kilogram of Chehalis loam and eight wheat plants were used in this study. The experiment was completed in a greenhouse where light intensity was low and air temperature averaged 25 C. Water was applied to each pot every 48 hours to maintain an adequate moisture level.

Incorporation of Igran into the soil was made using a stationary sprayer in a soil blender. Surface applications were made using a single nozzle sprayer and postemergence applications were made in an identical manner to the preemergence surface sprayed applications.

Four rates (0, 2, 4 and 8 pounds per acre) of Igran were compared according to a completely randomized design, factorial arrangement, with three replications.

Foliage dry weights harvested six weeks after seeding were

used for statistical comparisons.

Results

Table 6 lists the results obtained in this experiment. Highly significant differences were obtained only at the rate of eight pounds per acre on preemergence applications. At this rate, Igran was more toxic to wheat when incorporated into the soil. Lower rates, two and four pounds per acre, produced slight chlorosis and stimulation in growth was observed at the rate of two pounds per acre.

Postemergence applications were more toxic to wheat plants than preemergence applications. Young plants (two weeks old) were injured more than old plants at all rates with differences from the control plants being highly significant. At the rate of eight pounds per acre, young plants were killed while old plants only showed chlorosis and apical necrosis.

Table 6. The effect of different application methods on the toxicity of Igran to winter wheat.

Application method	Igran Lbs/A	Foliage dry wt. per pot in mg				% of control
		I	II	III	Avg.	
Preemergence surface sprayed	0	2010	1790	1850	1883.3	
	2	2391	1558	1758	1902.3	101.00
	4	1491	1942	1758	1730.3	91.87
	8	1067	734	662	821.0	43.59
Preemergence incorporated	0	1940	1650	1770	1786.6	
	2	1343	2482	1598	1807.6	101.17
	4	1581	1387	1625	1531.0	85.69
	8	282	166	202	216.6	12.12
15 days after emergence	0	1820	1670	2025	1838.3	
	2	811	1100	1069	993.3	54.03
	4	510	326	468	434.6	23.64
	8	94	159	186	146.3	7.95
30 days after emergence	0	2126	1335	1905	1788.6	
	2	1073	1474	1510	1352.3	75.60
	4	971	1003	1276	1083.3	60.56
	8	780	655	1154	863.0	48.25
LSD (0.05) Treatments					434.2	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	15	1151638.71	16,94**
Rates	3	3787883.43	55.72**
Applications	3	1105944.27	16.26**
R x A	9	288121.95	4.23**
Error	32	67976.64	

**Significant at 1% level.

$\bar{x}$ = 1261.18 s = 260.72 CV = 20.67%

EXPERIMENT III. SITE OF UPTAKE OF IGRAN BY WINTER WHEAT

Herbicide placement in the soil is considered a very important factor for selectivity. This experiment was designed to study the site of uptake of Igran by winter wheat and to determine the most appropriate placement for Igran to prevent injury to wheat.

Materials and Methods

Igran was incorporated into the soil (Chehalis loam) at two different rates: 8 and 16 ppm with a stationary sprayer in a soil blender. Each pot contained one kilogram of soil divided into four layers of approximately 3 cm width as shown in Figure 1. The treatments consisted in placing soil treated with Igran in a specific layer or layers to observe the influence on wheat growth. Five placement sites were studied which included treated layers above, within and below the seed containing layer. The other two treatments consisted in placing soil treated with Igran in the four layers and no herbicide at all as a control.

Two weeks after emergence, water was applied to all pots to bring the soil to approximately field capacity.

All pots were harvested four weeks after seeding to obtain foliage dry weight expressed in milligrams for statistical comparisons.

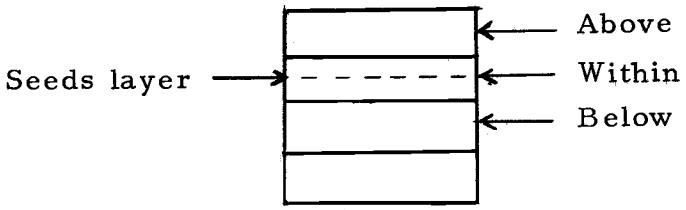


Figure 1. Graphical distribution of the placement sites studied.

Results

The results of this experiment are presented in Table 7. No significant difference was obtained between the two rates but a highly significant difference was obtained among the five placement sites.

When the herbicide was placed in a layer above the seed, the wheat plants showed no injury. The injury symptoms were more noticeable when the seed was placed in the treated soil. When the herbicide was placed below the seed, close to the root system, the plants were severely injured and some plants died before harvest. Severe injury resulted when all layers were treated with the herbicide.

These findings support the concept that Igran is absorbed through the roots, enters the transpiration stream and is translocated upward with water. Similarly, it is concluded that little or no Igran is absorbed through the shoots. Figure 2 shows the results obtained comparing the different placement sites at two rates of application.

Table 7. The effect of Igran placement in the soil on toxicity to winter wheat.

Placement site	ppm Igran	Foliage dry wt. per pot in mg					% of control
		I	II	III	IV	Avg.	
None	8	740	612	1078	678	777.0	
Above	8	822	865	727	950	841.0	108.20
Within	8	449	634	530	482	523.7	67.40
Below	8	309	211	422	237	294.7	37.92
All	8	254	268	249	261	258.0	33.20
None	16	719	714	989	1000	855.5	
Above	16	937	655	776	776	786.0	91.87
Within	16	449	553	514	516	508.0	59.38
Below	16	249	250	260	235	248.5	29.04
All	16	220	296	218	326	265.0	30.97

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	9	270312.22	24.30**
Placement	4	602390.80	54.16**
Rates	1	396.90	0.03
Placement x rates	4	5712.47	0.51
Error	30	11121.45	

**Significant at 1% level.

$\bar{x}$ = 535.7 s = 10545 CV = 19.68%

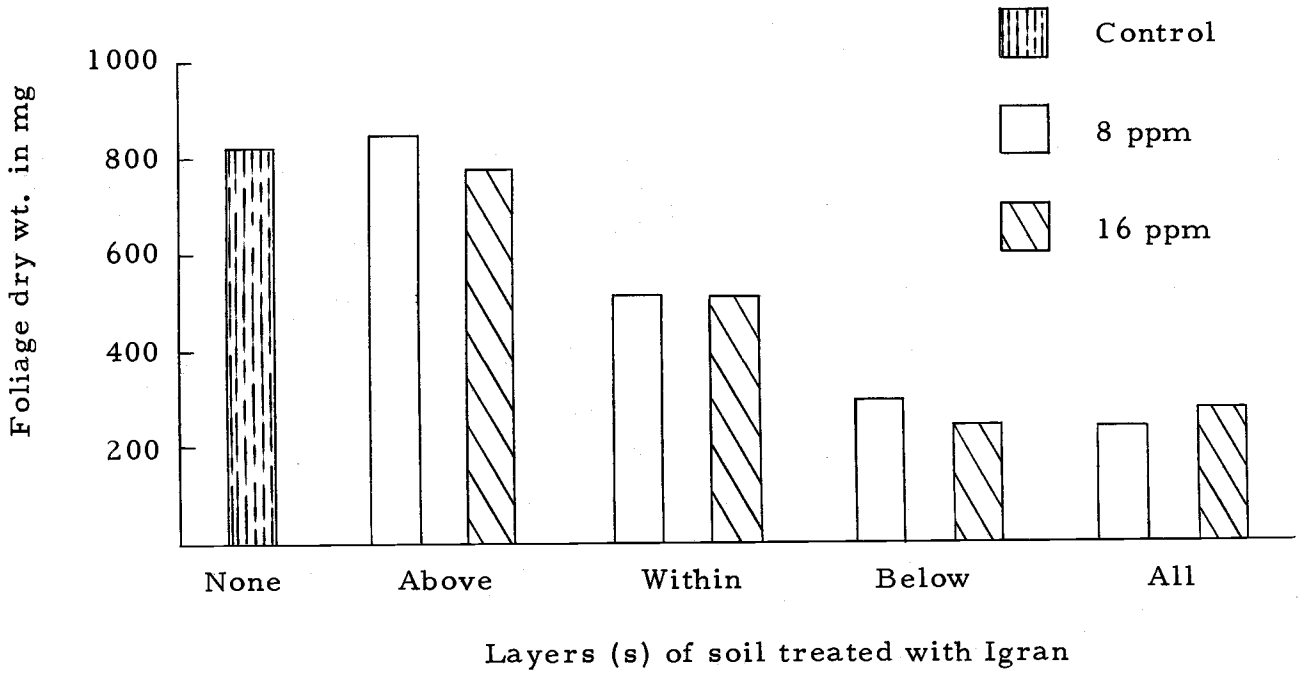


Figure 2. Effect of Igran placement in the soil on the toxicity to winter wheat.

EXPERIMENT IV. THE EFFECT OF SOIL MOISTURE CONTENT ON THE TOXICITY OF IGRAN TO WINTER WHEAT

Available soil moisture is necessary for good plant growth. Soil water also influences the availability of herbicide for plant absorption by changing the binding forces between the herbicide and soil particles.

The objective of this experiment was to study the role of soil water on the toxicity of Igran to winter wheat.

Materials and Methods

The soil used for this experiment was a Chehalis loam. Igran was incorporated at four rates 0, 2, 4, and 8 pounds per acre using a stationary nozzle in a soil blender. Wheat seeds were planted two cm deep in pots containing one kilogram of treated soil.

Soil moisture was maintained at the desired level by weighing each pot every day. Three soil moisture levels were compared. They were 75%-100% of field capacity, 50%-75% of field capacity and 25% to 50% of field capacity. Water was not applied to any pot until the lower limit was reached in each pot. The experiment was completed during August 1967 and lasted three weeks. The temperature averaged 30 C and high light intensity prevailed throughout the period.

Foliage dry weights were used for statistical comparisons in a completely randomized design, factorial arrangement, with three moisture levels, four rates of application and four replications.

Results

The results of the experiment comparing three moisture levels and four rates of Igran are included in Table 8. Highly significant differences were found among the moisture levels. Wheat growth was faster and greater at the higher moisture level. Injury symptoms were more noticeable at the highest moisture level. The plants developed chlorosis and necrosis much earlier than at lower moisture levels. A graphical representation of the results is shown in Figure 3.

The differences among rates and the interaction of moisture levels by rates were also statistically significant.

Two pounds per acre caused serious injury at the highest moisture level but almost no injury at the lowest moisture level. At four pounds per acre more injury was observed at all three moisture levels than at the two pound per acre rate. At eight pounds per acre no noticeable difference was observed among the three moisture levels with most plants stunted and with necrotic leaves.

The results of this study indicate that soil moisture content has a very important effect on the toxicity of Igran to winter wheat under conditions of high light intensity and high temperature.

Table 8. The effect of soil moisture content on the toxicity of Igran to winter wheat.

Water availability	Igran Lbs/A	Foliage dry wt. per pot in mg					% of control
		I	II	III	IV	Avg.	
100 - 75%	0	614	661	789	680	686.0[1/]	
75 - 50%	0	323	412	466	533	433.5	
50 - 25%	0	309	292	263	337	300.2	
100 - 75%	2	190	149	143	194	169.0	24.6
75 - 50%	2	164	203	202	166	183.7	42.3
50 - 25%	2	283	217	302	190	248.0	82.6
100 - 75%	4	152	130	91	118	122.7	17.8
75 - 50%	4	193	131	151	141	154.0	35.5
50 - 25%	4	170	211	97	159	159.2	53.0
100 - 75%	8	119	101	122	115	114.2	16.6
75 - 50%	8	100	133	93	114	110.0	25.3
50 - 25%	8	122	114	71	135	110.5	36.8
LSD (0.05) Treatments						63.0	

[1/] Control treatment.

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	11	118090.36	61.24**
Moisture level	2	20581.99	10.67**
Rates	3	324877.79	168.48**
M. L. x R.	6	38866.10	20.15**
Error	36	1928.20	

**Significant at 1% level.

$\bar{x} = 232.6$ $s = 43.9$ CV = 18%

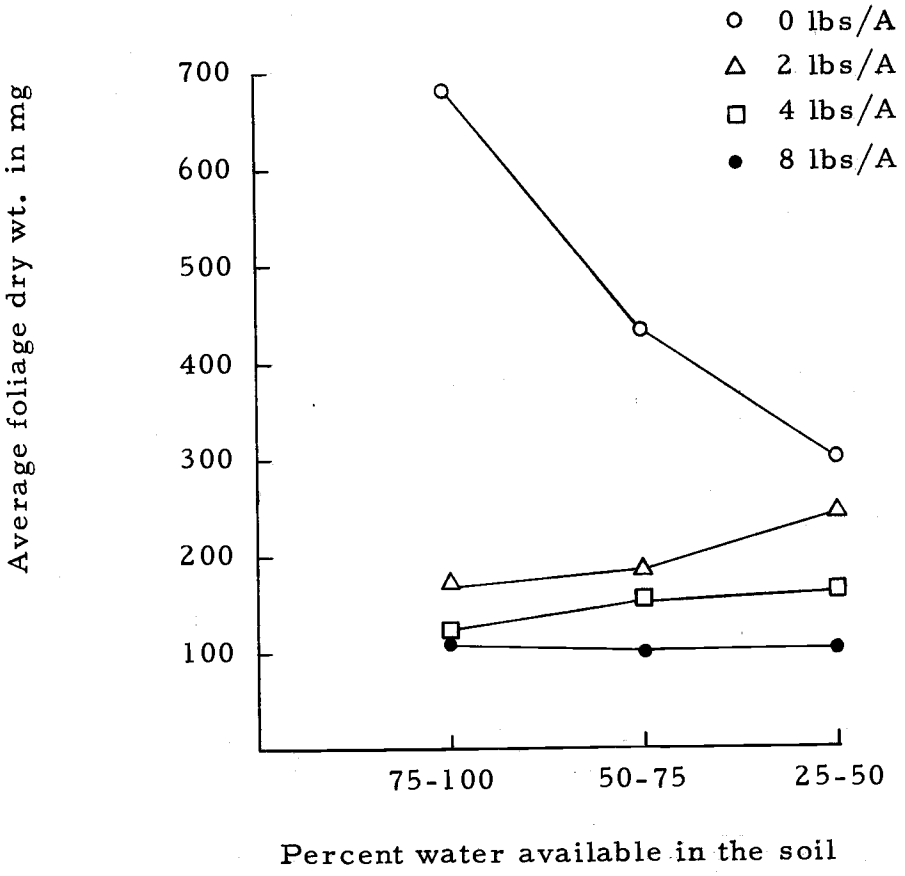


Figure 3. The effect of water available in the soil on the toxicity of Igran to winter wheat.

EXPERIMENT V. DOSAGE RESPONSE STUDY IN SAND CULTURE SOLUTION

The objective of this experiment was to determine the toxicity levels for Igran in winter wheat grown in sand culture solution. From this study three or four rates were selected to be used when quartz sand was the root media and when the herbicide was not sprayed.

Materials and Methods

In a greenhouse study, Igran was applied at 0, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09 and 0.1 ppm to wheat plants grown in quartz sand. Each pot contained eight wheat seedlings which were in the two leaf stage at the time of treatment. Nutrient solution was applied every 48 hours to maintain an adequate moisture and nutrient level.

Light intensity was low (800 ft-c) and air temperature varied in a wide range (20-30 C) with an average of 24 C.

Plants were harvested two weeks after Igran application when the plants were four weeks old. Foliage dry weight of the eight plants contained in each pot were used for statistical comparisons.

Results

The results of the experiment comparing the ten different rates

of Igran are listed in Table 9 along with the statistical analysis.

At lower rates (0.02 and 0.03 ppm) visual observations and statistical comparisons showed no difference from the untreated plants. At higher rates the plants were smaller and exhibited apical necrosis. Higher rates showed a decreasing rate of growth but chlorosis was not very noticeable. A 50 percent reduction in growth was observed at 0.08 ppm.

Table 9. Winter wheat response to different rates of Igran in sand culture solutions.

Igran PPM	Foliage dry wt. per pot in mg					% of control
	I	II	III	IV	Avg.	
0.00	592	526	469	502	522.2	
0.02	580	436	487	357	465.0	89.0
0.03	449	466	469	408	448.0	85.7
0.04	362	410	341	449	390.5	74.7
0.05	199	349	395	349	323.0	61.8
0.06	294	382	295	292	315.7	60.4
0.07	262	274	272	402	302.5	57.9
0.08	364	223	283	175	261.2	50.0
0.09	235	207	274	167	220.7	42.2
0.10	134	318	167	161	195.0	37.3
LSD (0.05) Treatments					95.5	

Analysis of Variance

Source of variation	df	Means square	F value
Among treatments	9	47373.84	10.79**
Within treatments	30	4388.70	

**Significant at 1% level.

$\bar{x} = 344.4$ $s = 66.24$ $CV = 19.2\%$

EXPERIMENT VI. NITROGEN-IGRAN INTERACTION

This study was conducted in the greenhouse to investigate the relationship between nitrogen level in the soil and the toxicity of Igran to winter wheat.

Materials and Methods

Three different Hoagland solutions were prepared to represent three different nitrogen levels. The three nitrogen levels were high (N = 100%), medium (N = 75%) and low (N = 50%). Fifty milliliters of the proper nutrient solution were applied to each pot every 48 hours. Each pot contained eight wheat seedlings planted in one kilogram of washed quartz sand. Igran was applied at four rates (0, 0.025, 0.05, 0.075 and 0.1 ppm) at the two leaf stage.

Air temperature averaged 24 C and light intensity was low during the duration of the experiment.

A completely randomized design, factorial arrangement, with five rates of Igran, three nitrogen levels and four replications was used. Foliage dry weight of the eight plants contained in each pot was the parameter used for statistical comparisons when the plants were four weeks old.

Results

Table 10 shows the results obtained comparing three nitrogen levels and five rates of Igran. Highly significant differences were obtained among the three nitrogen levels. Plants grown in the highest nitrogen level produced more foliage dry weight than either of the other two nitrogen levels. The greatest effect of Igran was observed at the highest nitrogen level. Differences among rates, using N = 100% at 0 ppm as the control, were statistically significant with a proportional decrease in dry weight as the rate of Igran was increased.

The interaction between nitrogen level and rates of application was not statistically significant.

Table 10. The effect of different nitrogen levels in the soil on the toxicity of Igran to winter wheat.

Nitrogen level	Igran PPM	Foliage dry wt. per pot in mg					% of control
		I	II	III	IV	Avg.	
N - 100%	0	638	574	583	504	574.7[1/]	
	0.025	385	571	488	529	493.2	85.8
	0.05	582	380	415	476	463.2	80.5
	0.075	476	475	379	399	432.2	75.2
	0.1	415	415	388	328	386.5	67.2
N - 75%	0	323	296	373	350	335.5	
	0.025	335	272	271	292	292.5	87.1
	0.05	283	303	305	295	296.5	88.3
	0.075	265	327	300	237	282.2	84.1
	0.1	264	349	236	220	267.2	79.6
N - 50%	0	343	338	319	246	311.5	
	0.025	230	229	187	390	259.0	83.1
	0.05	226	208	199	288	230.2	73.9
	0.075	245	224	208	238	228.7	73.4
	0.1	229	214	204	247	223.5	71.7
LSD (0.05) Treatments						74.0	

[1/] Control treatment.

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	14	46452.63	17.12**
N levels	2	269283.47	99.25**
Rates	4	22792.63	8.40**
N x R	8	2574.93	.94
Error	45	2713.15	

**Significant at 1% level.

$\bar{x}$ = 338.46 s = 52.08 CV = 15.38%

EXPERIMENT VII. THE INFLUENCE OF LIGHT INTENSITY ON THE TOXICITY OF IGRAN TO WINTER WHEAT

Light intensity is a basic requisite for carbohydrate formation in plants and also for triazine activity.

The objective of this experiment was to study the activity of Igran on winter wheat at three different light intensities in controlled environment chambers.

Materials and Methods

Light intensities of 2500, 1500 and 800 ft-c were employed at a temperature of 15-20 C.

Two wheat seedlings were planted two cm deep in test tubes 15 cm long and 2.5 cm in diameter containing 70 g of washed quartz sand. Periodic applications of a complete nutrient solution were made.

Igran was applied to the sand culture solution at the two leaf stage at four different rates: 0, 0.025, 0.05 and 0.1 ppm.

Foliage dry weights were obtained for statistical comparisons in a split plot design with light intensity as the main plots, Igran rates as subplots and with three replications.

Results

Pertinent data on foliage dry weight are given in Table 11

Table 11. The effect of different light intensities on the toxicity of Igran to winter wheat.

Light intensity	Igran PPM	Foliage dry wt. per tube in mg				% of control
		I	II	III	Avg.	
2500 ft-c	0	175	129	122	142.0	
	0.025	60	54	64	59.3	41.76
	0.05	42	44	44	43.3	30.49
	0.1	36	38	39	37.7	26.54
1500 ft-c	0	77	72	76	75.0	
	0.025	53	55	58	55.3	73.73
	0.05	44	48	43	45.0	60.00
	0.01	34	28	38	33.3	44.40
800 ft-c	0	78	76	76	76.6	
	0.025	58	52	67	59.0	77.02
	0.05	53	50	44	49.0	63.96
	0.1	39	44	42	41.7	54.43

Analysis of Variance

Source of variation	df	Means square	F value
Replications	2	73.69	
Light intensity	2	1109.36	19.07**
Reps. x L. I.	4	58.15	
Rates	3	6437.55	72.48**
Rates x L. I.	6	1121.02	12.62**
Rates x Reps.	6	88.81	
Rates x Reps. x L. I.	12		

**Significant at 1% level.

Main plots s = 7.6 CV = 12%

Sub-plots s = 9.4 CV = 15%

which includes a summary of the analysis of variance.

Highly significant differences were found among the different light intensities and rates of herbicide application. The interaction between light intensity and rates was also highly significant.

The symptoms of injury appeared much earlier in plants at high light intensity. The untreated plants at the highest light intensity level were much more developed than the plants at lower light intensity.

No visible injury was observed when wheat plants were treated with Igran at 0.025 ppm with a light intensity of 800 or 1500 ft-c. However, at 2500 ft-c with the same dosage only chlorosis was observed. The 0.05 ppm dosage produced slight chlorosis at 800 and 1500 ft-c but with a light intensity of 2500 ft-c showed chlorotic and necrotic leaves. When 0.1 ppm dosage was compared at the three different light intensities, chlorosis was observed at lower light intensity levels (800 and 1500 ft-c) while at 2500 ft-c plants looked stunted with necrotic leaves.

No appreciable difference was observed between plants grown at 800 and 1500 ft-c except a slight reduction in growth at the higher rate.

This description was aimed to make more explicit the results presented in Figure 4.

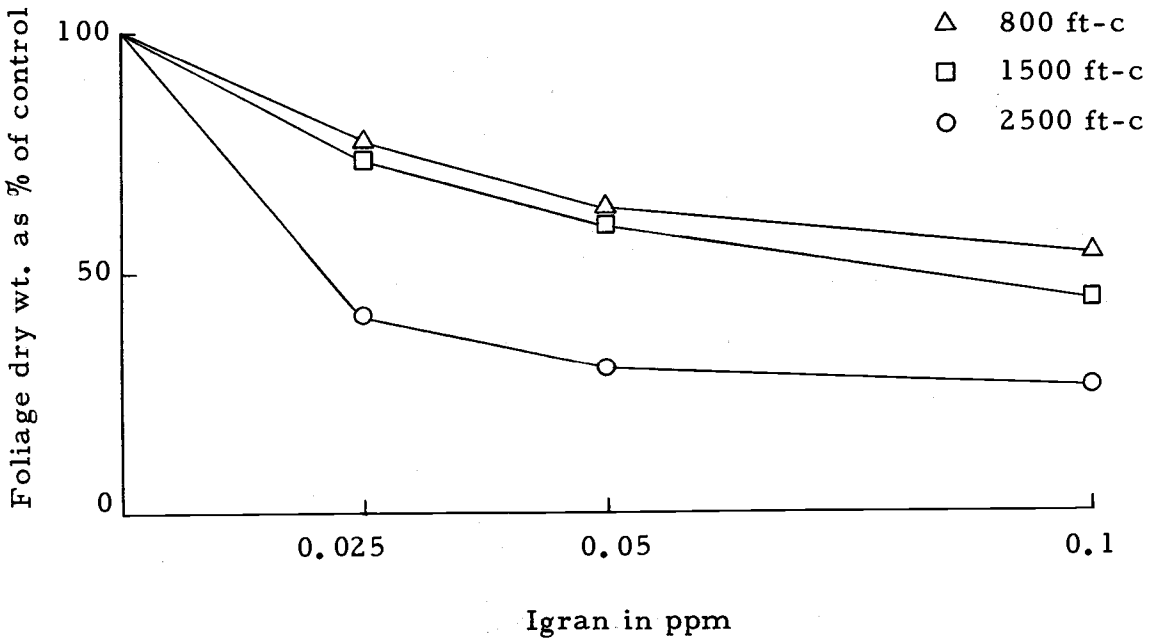


Figure 4. Light intensity effect on Igran toxicity to winter wheat.

EXPERIMENT VIII. LIGHT AND TEMPERATURE VARIATION STUDIES

Light intensity and temperature have been found to affect the activity of Igran on winter wheat. The objective of these studies was to determine the effect of these variables at intervals after herbicide treatment.

Materials and Methods

General procedures were followed to prepare wheat seedlings grown in sand culture solutions.

To study the effect of air temperature, plants were grown at 5 C and 2500 ft-c. Immediately after Igran application at the rate of two pounds per acre, one group of plants consisting of four treated and four untreated or control plants, was moved to another growth chamber at the same light intensity but different temperature (20 C). The same procedure was continued at 24, 48, 72, 96, and 120 hours after Igran application. One group of plants remained at low temperature (5 C).

To study the effect of light intensity, plants were grown at 500 ft-c and 13-18 C. Immediately after Igran application at the rate of two pounds per acre, plants were moved in the same pattern as for temperature to another growth chamber at 2500 ft-c and the same temperature. All other procedures were the same in both

experiments.

Foliage dry weights of eight plants contained in each pot were used for statistical comparisons. The results are expressed as a percent of control obtained by comparing each group that consisted of four treated and four untreated or control pots.

Results

The results of the two experiments are listed in Tables 12 and 13. When temperature was the variable under study, injury symptoms appeared in all treatments at high temperature. The treated plants that remained at low temperature also developed injury symptoms but these appeared much later. In general, foliage reductions greater than 60 percent from untreated plants were observed.

In the experiment where light intensity was the variable under study, all plants treated with Igran and growing at high light intensity developed injury symptoms, specially chlorotic and necrotic leaves. However at low light intensity growth was retarded but plants did not develop the injury symptoms observed in the plants grown at high light intensity.

The first plants moved to high light intensity showed the most severe injury and the plants moved 120 hours after Igran application produced the least injury among the treated plants moved from low to high light intensity.

Table 12. The effect of light intensity variation (from 500 to 2500 ft-c) on the toxicity of Igran to winter wheat expressed as a percent of control.

Light intensity variation	Igran Lbs/A	Foliage dry wt. as % of control				
		I	II	III	IV	Avg.
None	2	70.2	54.2	62.3	65.9	63.1
At 0 hours	2	49.7	35.7	59.7	28.8	43.4
At 24 hours	2	54.6	41.5	38.7	47.5	45.5
At 48 hours	2	46.6	40.5	44.9	53.1	46.2
At 72 hours	2	45.2	60.3	42.8	51.3	49.9
At 96 hours	2	45.2	49.2	64.5	42.9	50.4
at 120 hours	2	36.0	39.3	54.6	72.3	50.5
LSD (0.05)						15.1

Analysis of Variance

Source of variation	df	Means square	F value
Among treatments	6	166.27	1.55
Within treatments	21	106.70	

$\bar{x} = 49.91$ $s = 10.32$ $CV = 20.67$

Table 13. The effect of temperature variation (from 5 to 20 C) on the toxicity of Igran to winter wheat expressed as a percent of control.

Temperature variation	Igran Lbs/A	Foliage dry weight				
		I	II	III	IV	Avg.
None	2	29.9	38.6	23.9	22.8	28.8
At 0 hours	2	26.7	37.8	27.7	28.4	30.1
At 24 hours	2	32.1	37.6	33.1	34.7	34.3
At 48 hours	2	33.5	28.7	30.0	27.7	29.9
At 72 hours	2	23.1	35.9	36.6	28.7	31.0
At 96 hours	2	34.4	30.0	37.3	37.5	34.8
At 120 hours	2	38.5	39.0	40.8	28.2	36.6
LSD (0.05)						7.38

Analysis of Variance

Source of variation	df	Means square	F value
Among treatments	6	35.35	1.399
Within treatments	21	25.26	

$\bar{x} = 32.2$ $s = 5.02$ $CV = 15.59$

EXPERIMENT IX. THE EFFECT OF IGRAN ON THE PHOTOSYNTHESIS AND RESPIRATION OF WINTER WHEAT

Materials and Methods

The mode of action of triazine herbicides is expressed as an inhibition of the photosynthetic system.

Two experiments were conducted in controlled environment chambers to determine the influence of Igran on the photosynthesis of wheat plants under two different light intensities. The light intensities used were 2200 and 800 ft-c.

One wheat plant was grown in each plastic pot containing 330 g of washed quartz sand. The plants were kept at 5 C until 48 hours before Igran was applied at five different rates: 0, 0.025, 0.05, 0.075 and 0.1 ppm.

A Beckman IR model 215 infrared gas analyzer was used to measure CO_2 exchange in the winter wheat plants. Nitrogen gas was used to zero the instrument and gas containing 375 ppm CO_2 was used to calibrate CO_2 levels within the analyzer.

Measurements were made in ppm of CO_2 taken up in the light or evolved in the dark during four minutes. At the time of Igran application the plants were five weeks old with four to five tillers. After CO_2 uptake was recorded in the light, a black plastic bag was placed over the plexiglass chamber containing the wheat plant to

measure respiration rates or CO_2 evolution.

Readings were recorded at the beginning of each experiment, then at 8, 12, 24, 48, 72, 96, 120, 144, and 168 hours after Igran application. The first reading, at 0 time, was recorded just before Igran application.

Results

Carbon dioxide uptake by wheat plants treated with Igran was reduced considerably at high light intensity (2200 ft-c). The effects were less severe at lower light intensity (800 ft-c). At high light intensity the reduction in CO_2 uptake occurred much earlier than at low light intensity. Figures 5 and 6 present the results obtained at the two different light intensities. In these figures, it can be observed that the rate of recovery was more rapid at lower light intensity.

Comparing the highest rate of application at the two different light intensities it is observed that at high light intensity a rapid reduction was produced 24 hours after Igran application but at low light intensity the effect was much less severe and developed later. Only at high light intensity was there a complete inhibition in CO_2 uptake with the highest rate of Igran (0.1 ppm).

As a general response a stimulation of CO_2 uptake was observed at all rates of application a few hours after Igran application

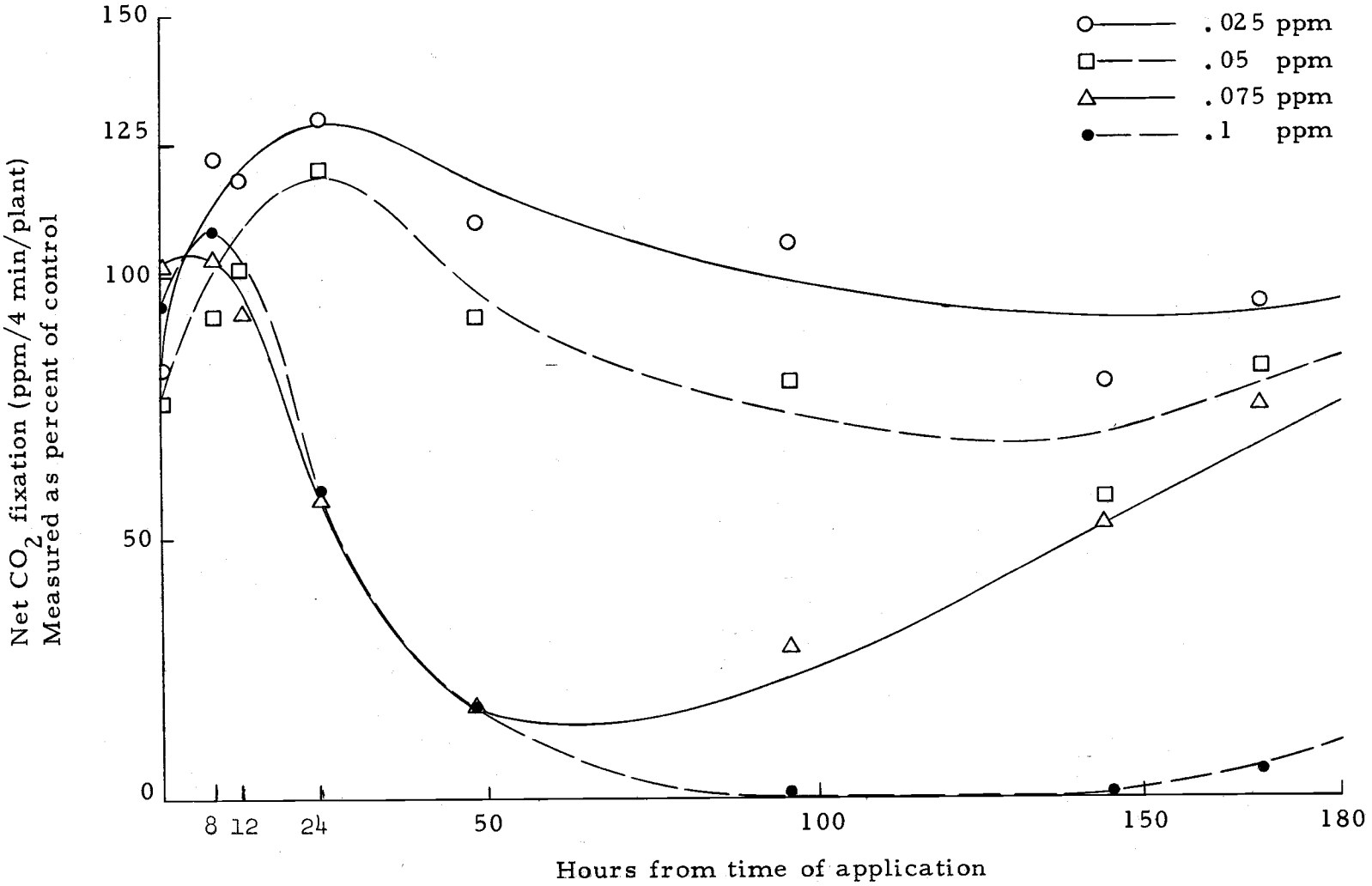


Figure 5. The effect of Igran on the CO_2 uptake by winter wheat grown at 2500 ft-c.

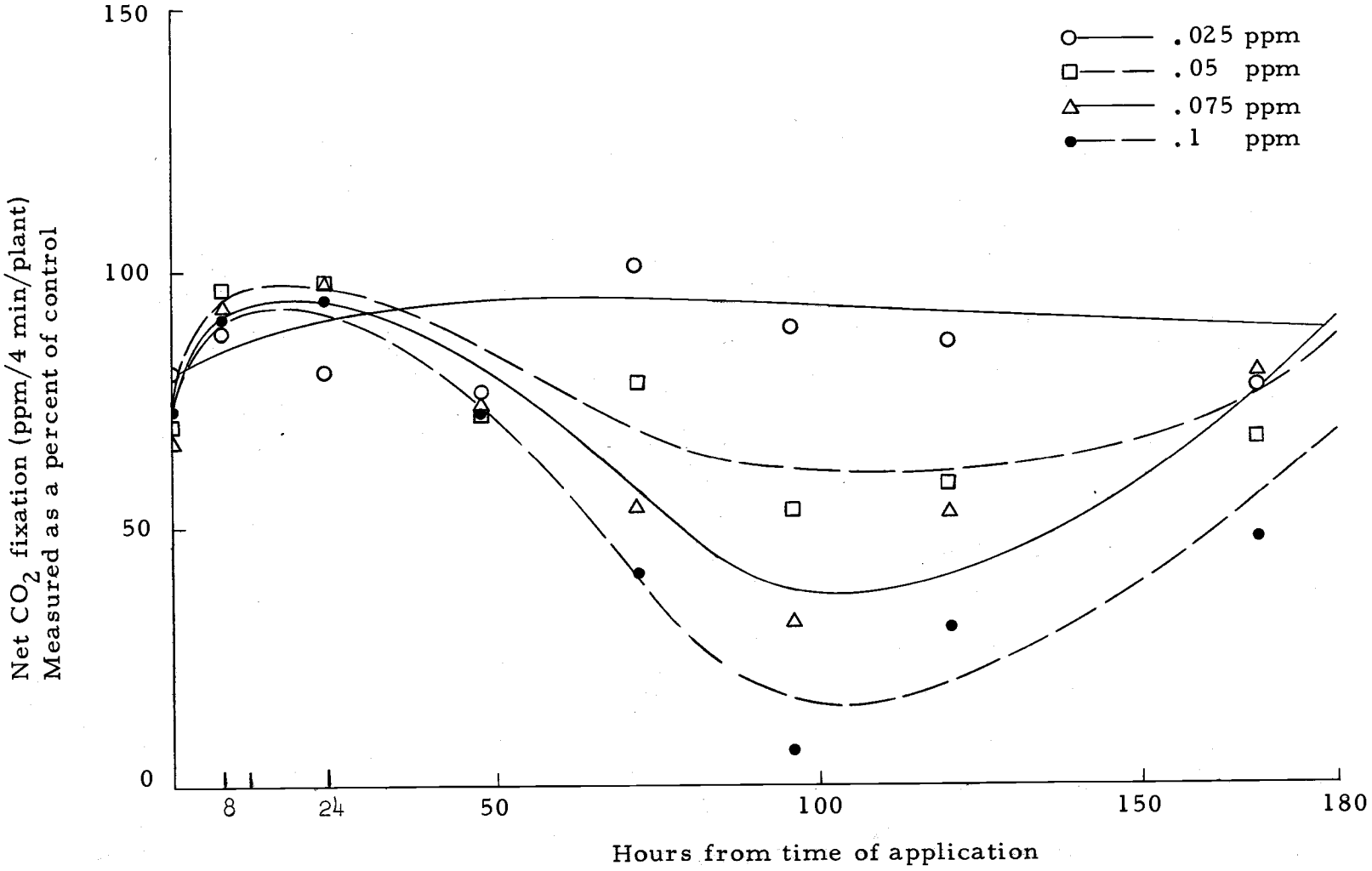


Figure 6. The effect of Igran on the CO_2 uptake by winter wheat grown at 800 ft-c.

at both light intensities.

Respiration measurements (CO_2 evolved in the dark) showed reduction only with the highest rates of application at both light intensities. Lower rates did not show appreciable difference from untreated plants. A general stimulation in respiration was observed at all rates and light intensities about 24 hours after Igran application as shown in Figures 7 and 8.

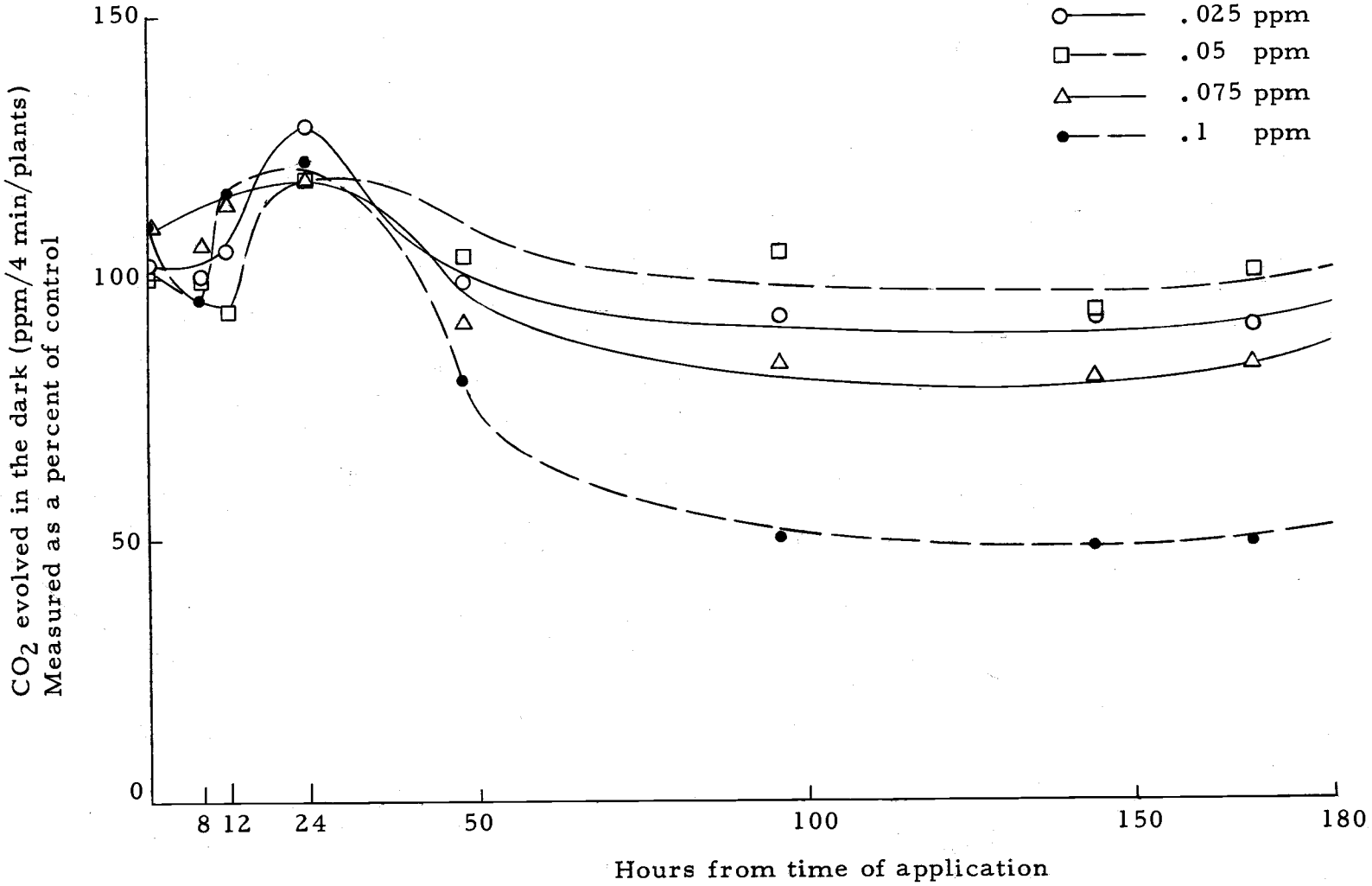


Figure 7. The effect of Igran on dark respiration of winter wheat grown at 2500 ft-c.

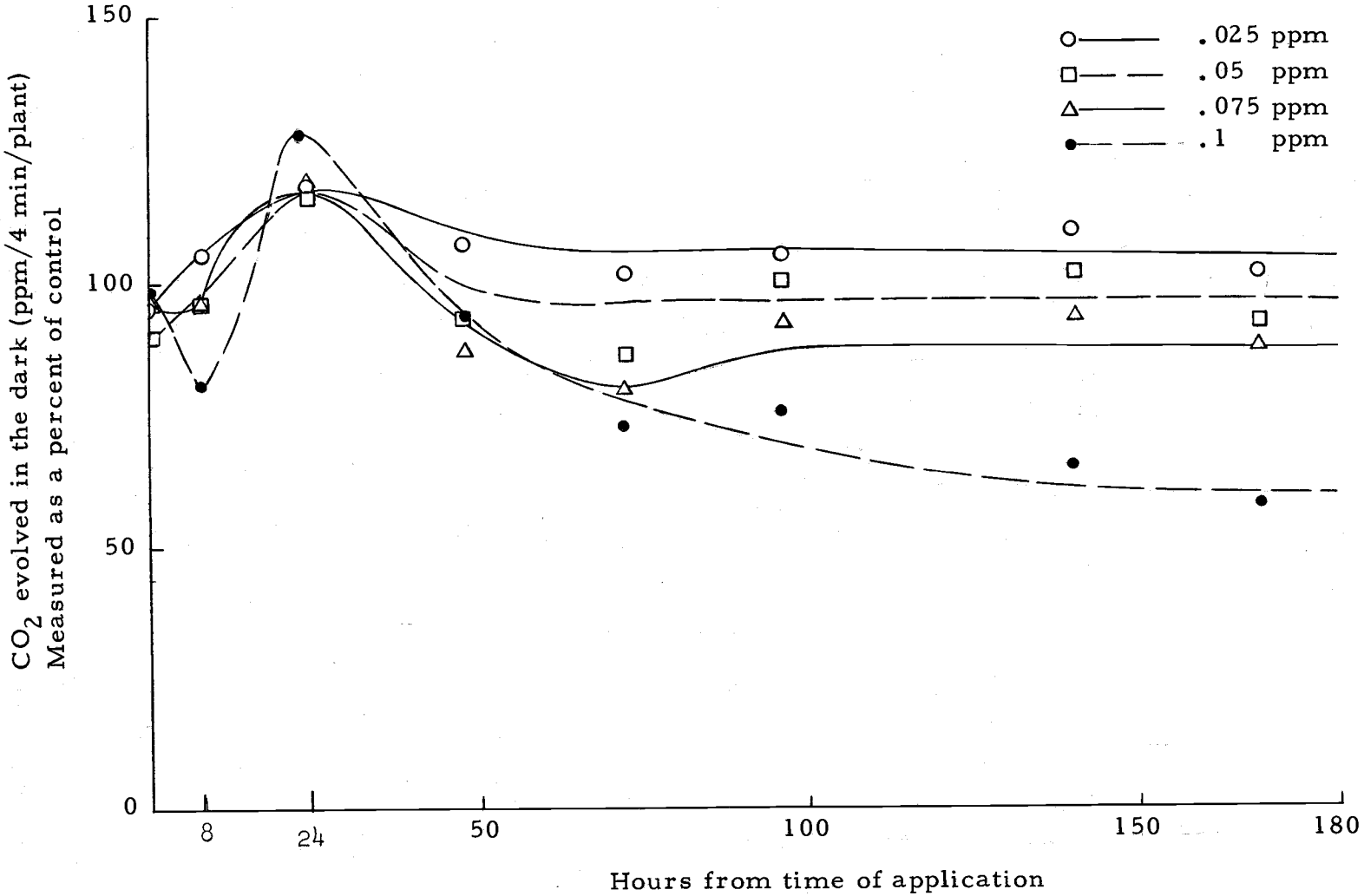


Figure 8. The effect of Igran on dark respiration of winter wheat grown at 800 ft-c.

EXPERIMENT X. COMPARISON OF SOIL VERSUS FOLIAGE APPLICATIONS OF IGRAN TO WINTER WHEAT

Soil texture and herbicide uptake by the foliage or roots have much influence on the crop selectivity of certain herbicides. The objective of these experiments was to determine the difference in absorption of Igran by wheat when grown on two soils having different texture. Also to compare the effect of soil and foliage applications.

Materials and Methods

Foliage and soil applications of Igran were studied with two different soil media and two different temperatures (5-10 C and 15-20 C). Light intensity was the same (2500 ft-c) in all experiments.

Igran was applied at four rates: 0, 2, 4 and 8 pounds per acre to wheat plants at the two leaf stage which were two weeks old.

One kilogram of Chehalis loam or washed quartz sand was placed in each plastic pot. Eight wheat seedlings were grown in each pot and 50 ml of a complete nutrient solution were added to the pots with washed quartz sand every 48 hours. The pots containing Chehalis loam received nutrient solution only once immediately after seeding, then only water was applied every 48 hours.

Vermiculite was used to cover the soil surface to prevent the herbicide from reaching the soil in the foliage application treatment.

Plastic straws were used to cover the plants to prevent foliage application on the soil treatment. The vermiculite and plastic straws were removed immediately after Igran application was made with a single nozzle sprayer.

The wheat seedlings were germinated in a greenhouse. Four days after germination all pots were moved to a controlled environment chamber at 15 C and 2500 ft-c. Forty-eight hours before Igran application, plants were separated into two groups, one grown at 5-10 C and the other at 15-20 C.

Two weeks after Igran application, plants were harvested and foliage dry weight was used as a parameter for statistical analysis in a completely randomized design with four replications.

Results

When the experiment was conducted with plants grown in washed quartz sand, highly significant differences were observed between soil and foliage applications and among rates at both temperatures. Tables 14 and 15 show the results obtained in this study. Injury symptoms appeared first in plants receiving soil applications and grown at high temperatures. Chlorosis followed by apical necrosis was the common symptom observed. At low temperature plants were very healthy with slight chlorosis in plants treated with the highest rate of Igran. Foliage applications injured

Table 14. The effect of application method on the toxicity of Igran to winter wheat at 15-20 C in sand culture.

Application method	Igran Lbs/A	Foliage dry wt. per pot in mg					% of control
		I	II	III	IV	Avg.	
Soil	0	180	282	180	210	213.0	
	2	139	147	135	181	150.5	70.65
	4	128	132	124	145	132.2	62.06
	8	111	127	164	117	129.7	60.89
Foliage	0	196	217	197	204	203.5	
	2	168	172	192	135	166.7	81.91
	4	143	151	153	149	149.0	73.21
	8	147	158	144	147	149.0	73.21
LSD (0.05) Treatments						14.3	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	7	3851.74	39.63**
Applications	1	913.78	9.40**
Rates	3	8317.11	85.59**
A x R	3	365.70	3.76**
Error	24	97.17	

**Significant at 1% level.

$\bar{x} = 161.7$ $s = 9.85$ $CV = 6.09\%$

Table 15. The effect of application method on the toxicity of Igran to winter wheat at 5-10 C in sand culture.

Application method	Igran Lbs/A	Foliage dry wt. per pot in mg					% of control
		I	II	III	IV	Avg.	
Soil	0	384	459	394	372	402.2	
	2	166	196	179	167	177.0	44.00
	4	153	161	154	161	157.2	39.08
	8	148	136	162	180	156.5	38.91
Foliage	0	359	460	480	419	429.5	
	2	249	266	274	308	274.2	63.84
	4	265	216	231	298	252.5	58.78
	8	286	260	216	153	228.7	53.24
LSD (0.05) Treatments						52.2	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	7	44776.85	34.85**
Applications	1	42632.00	33.18**
Rates	3	88150.83	68.60**
A x R	3	2117.83	1.65
Error	24	1284.83	

**Significant at 1% level.

$\bar{x}$ = 259.7 s = 35.84 CV = 13.80%

the plants less than soil applications and chlorosis was the only symptom observed.

When the experiments were conducted on plants grown in Chehalis loam, there was a general reduction in toxicity for soil applications as compared to the experiment with washed quartz sand. The results of these two experiments are shown in Tables 16 and 17. At high temperature no significant differences were obtained between foliage and soil applications. Plants treated with two pounds per acre were not different from the untreated plants. At four and eight pounds per acre rate, the injury was observed with chlorosis and necrosis of the leaves as the most important symptoms. At low temperatures, highly significant differences were obtained among rates. The differences between soil and foliage applications was significant at the 5 percent level.

Table 16. The effect of application method on the toxicity of Igran to winter wheat at 15-20 C in Chehalis loam.

Application method	Igran Lbs/A	Foliage dry wt. per pot in mg					% of control
		I	II	III	IV	Avg.	
Soil	0	909	680	1004	686	819.7	
	2	577	701	619	575	618.0	75.39
	4	527	402	451	513	473.2	57.72
	8	380	460	492	415	436.7	53.27
Foliage	0	831	757	831	780	799.7	
	2	607	636	666	852	690.2	86.30
	4	554	481	410	440	471.2	58.92
	8	399	464	313	389	391.2	48.91
LSD (0.05) Treatments						122.9	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	7	113305.42	15.89**
Applications	1	11.00	0.00
Rates	3	259250.00	36.38**
A x R	3	5125.66	0.71
Error	24	7126.16	

** Significant at 1% level.

$\bar{x}$ = 587.5 s = 84.41 CV = 14.36%

Table 17. The effect of application method on the toxicity of Igran to winter wheat at 5-10 C in Chehalis loam.

Application method	Igran Lbs/A	Foliage dry wt. per pot in mg					% of control
		I	II	III	IV	Avg.	
Soil	0	659	676	632	669	659.0	
	2	508	673	549	629	529.7	80.37
	4	525	477	453	513	492.0	74.65
	8	476	490	505	385	464.0	70.40
Foliage	0	648	643	590	590	617.7	
	2	686	654	643	655	659.5	106.76
	4	572	664	526	467	557.2	90.20
	8	519	495	508	571	523.2	84.70
LSD (0.05) Treatments						71.6	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	7	21867.85	9.02**
Applications	1	11704.00	4.83
Rates	3	41468.33	17.12**
A x R	3	5655.33	2.33
Error	24	2422.16	

**Significant at 1% level.

$\bar{x}$ = 585.93 s = 49.22 CV = 8.40%

EXPERIMENT XI. IGRAN TIME OF APPLICATION STUDY

Stage of plant development is a very important factor in determining the response of plants to herbicide application.

The objective of this study was to determine wheat response to different rates of Igran at four different stages of growth and at two different temperatures.

Materials and Methods

Two experiments were conducted in controlled environment chambers, one at 5-10 C and the other at 15-20 C. Light intensity was the same (2500 ft-c) in both experiments.

Eight wheat plants were grown in plastic pots containing one kilogram of washed quartz sand. Fifty milliliters of a complete nutrient solution were applied to each pot at 15-20 C every 48 hours and every 72 hours to pots at 5-10 C.

Igran was applied with a single nozzle sprayer at 0, 2, 4 and 8 pounds per acre to wheat plants 1, 2, 3 and 4 weeks old.

Visual evaluations were made at one and two weeks after herbicide application. Foliage and roots dry weights were harvested two weeks after Igran application.

Results

The results of both experiments with the pertinent analysis of variance are presented in Tables 18, 19, 20, and 21. Highly significant differences were obtained in both experiments among rates, stages of growth and for interaction between stages of growth and rates of application.

Plant populations were very homogenous at both temperatures before Igran application. In the first evaluation, at high temperature, the youngest plants showed the most severe injury. Chlorosis and apical necrosis were more pronounced as the rates were increased. At low temperature, no difference was noticed among the treated and untreated plants at any stage of development. Plants in general looked healthy with no lack of turgidity as was observed at the high temperature.

The second evaluation was made two weeks after Igran application. Stunting and chlorosis were the symptoms observed at all rates and stages of growth in plants grown at high temperature. The youngest plants continued to show the most severe injury with no appreciable difference among the 2, 4, and 8 pounds per acre rate. Only untreated plants looked very healthy with no lack of turgidity.

A very noticeable difference was observed among rates at low

Table 18. The effect of stage of growth on the toxicity of Igran to winter wheat at 15-20 C (foliage dry weight).

Stage of growth	Lbs/A Igran	Foliage dry wt. in mg I	II	III	IV	Avg.	LSD	% of control
1 week	0	307	239	246	194	246.5		
	2	129	164	143	134	142.5		57.8
	4	134	106	132	126	124.5		50.5
	8	111	103	133	143	122.5	60.3	49.6
2 weeks	0	415	632	334	566	486.7		
	2	306	298	279	286	292.2		60.0
	4	303	250	242	290	271.2		55.7
	8	317	275	250	281	280.7	50.5	57.6
3 weeks	0	1163	884	1013	1180	1060.0		
	2	637	622	618	565	610.5		57.5
	4	522	502	613	631	567.0		53.4
	8	562	512	578	605	564.2	64.8	53.2
4 weeks	0	1310	1318	1226	1052	1226.5		
	2	580	769	757	660	691.5		56.3
	4	716	583	706	692	674.2		54.9
	8	793	698	777	842	777.5	61.7	63.3

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	15	433168.00	86.70**
Rates	3	433729.70	86.81**
Ages	3	1607426.54	321.73**
Rates x ages	9	40450.08	8.09**
Error	48	4996.05	

**Significant at 1% level.

$\bar{x}$ = 508.65 s = 70.68 CV = 13.8%

Table 19. The effect of stage of growth on the toxicity of Igran to winter wheat at 15-20 C (root dry weight).

Stage of growth	Igran Lbs/A	Root dry wt. in mg I	II	III	IV	Avg.	LSD	% of control
1 week	0	176	124	130	119	137.2		
	2	104	97	97	84	95.5		69.5
	4	103	148	108	91	112.5		81.9
	8	88	81	121	108	99.5	31.46	72.5
2 weeks	0	190	306	174	233	225.7		
	2	137	219	139	185	170.0		75.3
	4	163	165	122	144	148.5		65.7
	8	165	170	143	137	153.7	57.93	68.0
3 weeks	0	1020	476	850	648	748.5		
	2	365	380	390	393	382.0		51.0
	4	327	316	343	556	385.5		51.5
	8	380	214	284	326	301.0	208.97	40.2
4 weeks	0	1104	975	899	979	989.2		
	2	515	545	654	592	596.5		60.3
	4	481	496	789	656	605.5		61.2
	8	662	542	650	772	656.5	155.15	66.3

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	15	303093.12	39.55**
Rates	3	190319.02	29.83**
Ages	3	1202958.85	156.98**
Rates x ages	9	40729.25	5.31**
Error	48	7662.70	

**Significant at 1% level.

$\bar{x} = 361.71$ $s = 87.5$ $CV = 24.19\%$

Table 20. The effect of stage of growth on the toxicity of Igran to winter wheat at 5-10 C (foliage dry weight).

Stage of growth	Igran Lbs/A	Foliage dry wt. in mg I	II	III	IV	Avg.	LSD	% of control
1 week	0	381	363	370	370	371.0		
	2	182	180	202	194	189.5		51.0
	4	158	163	154	174	162.2		43.7
	8	170	144	121	153	147.0	19.70	39.6
2 weeks	0	565	525	555	547	548.0		
	2	246	308	378	274	301.5		55.0
	4	250	242	261	274	256.7		46.8
	8	248	255	245	238	246.5	47.30	44.9
3 weeks	0	598	825	638	780	710.2		
	2	505	485	503	474	491.7		69.2
	4	521	506	444	484	488.7		68.8
	8	423	402	390	553	442.0	105.94	62.2
4 weeks	0	1012	1123	1059	1119	1078.2		
	2	683	710	680	635	677.0		62.7
	4	670	627	716	605	654.5		60.7
	8	583	559	631	602	593.7	63.39	55.0

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	15	249946.49	131.14**
Rates	3	343635.51	180.30**
Ages	3	872744.01	457.91**
Rates x ages	9	11117.64	5.83**
Error	48	1905.90	

**Significant at 1% level.

$\bar{x}$ = 459.92 s = 43.6 CV = 9.47%

Table 21. The effect of stage of growth on the toxicity of Igran to winter wheat at 5-10 C (root dry weight).

Stage of growth	Igran Lbs/A	Root dry wt. in mg I	II	III	IV	Avg.	LSD	% of control
1 week	0	294	288	297	318	299.2		
	2	138	125	141	179	145.7		48.6
	4	122	135	144	150	137.7		46.0
	8	144	110	90	111	113.7	28.34	38.0
2 weeks	0	367	368	419	465	404.7		
	2	255	248	224	172	224.7		55.5
	4	235	182	165	244	213.5		52.7
	8	157	164	147	179	161.7	56.02	39.9
3 weeks	0	447	502	464	573	496.5		
	2	329	305	289	300	305.7		61.5
	4	301	273	264	251	242.2		48.7
	8	275	238	265	316	273.5	53.84	55.0
4 weeks	0	995	851	915	800	890.2		
	2	584	532	534	528	544.5		61.1
	4	541	436	605	453	508.7		57.1
	8	453	488	488	485	478.5	92.21	53.7

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	15	166787.51	103.05**
Rates	3	239634.30	148.06**
Ages	3	566432.76	349.98**
Rates x ages	9	9290.16	5.74**
Error	48	1618.44	

**Significant at 1% level.

$\bar{x}$ = 341.51 s = 40.22 CV = 11.77%

temperature. The oldest plants treated when four weeks old with four or eight pounds per acre showed slight chlorosis. No visual difference was observed between untreated plants and those treated with two pounds per acre of Igran. The second oldest group produced similar results to the oldest plants. In plants that were one and two weeks old at the time of Igran application, noticeable differences were shown among the rates applied. Chlorosis was the primary sign of injury with some necrotic leaves at four and eight pounds per acre rate. Untreated plants, at any stage of development were healthy and much more developed than plants treated with Igran.

EXPERIMENT XII. COMPARISON OF IGRAN AND SIMAZINE TOXICITY ON WINTER WHEAT UNDER DIFFERENT ENVIRONMENTAL CONDITIONS

To have a better knowledge of the activity of Igran on winter wheat, several comparisons were made with simazine under different light intensity and temperature conditions.

Materials and Methods

Three experiments were conducted in controlled-environment chambers to compare the toxicity of simazine and Igran to winter wheat when grown in sand culture solution. The first experiment was conducted at 20-25 C and 2500 ft-c, the second at 20-25 C and 500 ft-c and the third at 5-10 C and 500 ft-c. The photoperiod was 12 hours and the same period was used for temperature change.

Eight wheat seedlings were grown for four weeks in a plastic pot containing one kilogram of quartz sand. Fifty milliliters of a complete nutrient solution were distributed evenly on the surface of the medium every 48 hours.

Igran and simazine were applied when the plants were two weeks old and in the two leaf stage. The herbicides were applied at four rates: 0, 0.025, 0.05 and 0.1 ppm. Foliage and root dry weights were compared in a completely randomized design with four replications.

All experiments were terminated two weeks after herbicide application.

Results

Tables 22, 23, and 24 show the effects of the treatments on foliage dry weights. Tables 25, 26 and 27 show the root dry weights from the same experiment. Analysis of variance is included next to each table.

Highly significant differences were found between simazine and Igran at high light intensity (2500 ft-c) and high temperature (20-25 C). These differences were similar for the foliage or root dry weights. When the rate of application exceeded 0.05 ppm both herbicides severely injured all plants. At low rates (0.025 ppm) significant differences were found between the two herbicides. Igran was much less toxic at the lowest rate at which a stimulation in growth was also observed.

In the second experiment made at high temperature (20-25 C) and low light intensity (500 ft-c) the only significant differences were among rates. Again the lowest rate of Igran stimulated growth. Similar results were obtained when root dry weights were used in the statistical analysis.

When the two herbicides were compared at low temperatures (5-10 C) and low light intensity (500 ft-c) differences among rates

Table 22. The response of wheat plants (foliage dry weight) to Igran and simazine treatments under 2500 ft-c and 20-25 C.

Herbicide	PPM	Foliage dry wt. per pot in mg I	II	III	IV	Avg.	% of control
Simazine	0	1181	1225	1382	1138	1231.5	
	0.025	865	865	631	847	802.0	65.1
	0.06	215	495	289	450	362.2	29.4
	0.12	155	125	122	155	139.2	11.3
	0.25	129	136	102	120	121.7	9.8
Igran	0	1130	1281	1282	1094	1196.7	
	0.025	1230	940	1326	1358	1213.5	101.4
	0.06	542	317	807	417	520.7	43.5
	0.12	163	198	101	156	154.5	12.9
	0.25	126	118	118	123	121.2	10.1
LSD (0.05) Treatments						167.5	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	9	934096.40	69.23**
Rate	4	2003769.45	148.52**
Herbicide	1	121000.00	8.96**
H x R	4	67697.45	5.01**
Error	30	13491.35	

**Significant at 1% level.

$\bar{x}$ = 586.3 s = 116.1 CV = 19.8%

Table 23. The response of wheat plants (foliage dry weight) to Igran and simazine treatments under 500 ft-c and 20-25 C.

Herbicide	PPM	Foliage dry wt. per pot in mg I	II	III	IV	Avg.	% of control
Simazine	0	328	378	316	309	332.7	
	0.025	236	245	306	265	263.0	79.0
	0.05	204	182	182	216	196.0	58.9
	0.1	220	206	197	161	196.0	58.9
Igran	0	295	198	307	217	254.2	
	0.025	316	278	341	283	304.5	119.7
	0.05	274	270	242	229	253.7	99.8
	0.1	200	269	238	185	223.0	87.7
LSD (0.05) Treatments						47.8	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	7	9435.63	8.72**
Herbicide	1	1140.02	1.05
Rates	3	14050.77	12.79**
H x R	3	7585.70	7.01**
Error	24	1080.88	7.01**

**Significant at 1% level.

$\bar{x} = 252.9$ $s = 32.8$ CV = 12.9%

Table 24. The response of wheat plants (foliage dry weight) to Igran and simazine treatments under 500 ft-c and 5-10 C.

Herbicide	PPM	Foliage dry wt. per pot in mg					% of control
		I	II	III	IV	Avg.	
Simazine	0	337	318	354	327	334.0	
	0.025	236	247	299	303	271.2	81.1
	0.05	220	264	273	220	244.2	73.1
	0.1	240	137	239	186	200.5	60.0
Igran	0	343	331	275	345	323.5	
	0.025	292	311	285	188	269.0	83.1
	0.05	273	313	294	287	291.7	90.1
	0.1	279	260	299	311	287.2	88.7
LSD (0.05) Treatments						42.0	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	7	7351.12	8.81**
Herbicide	1	10731.12	12.87**
Rates	3	10212.87	12.25**
H x R	3	3662.71	40.34**
Error	24	833.54	

**Significant at 1% level.

$\bar{x}$ = 280.81 s = 28.8 CV = 10.25%

Table 25. The response of wheat plants (root dry weight) to Igran and simazine treatments under 2500 ft-c and 20-25 C.

Herbicide	PPM	Root dry wt. per pot in mg I	II	III	IV	Avg.	% of control
Simazine	0	703	488	401	350	485.5	
	0.025	492	462	351	381	421.5	86.8
	0.06	125	300	156	296	219.2	45.1
	0.12	107	94	127	116	111.0	22.8
	0.25	86	118	98	88	97.5	20.0
Igran	0	424	689	896	664	668.2	
	0.025	677	895	779	962	828.2	123.9
	0.06	361	126	361	246	273.5	40.9
	0.12	105	106	108	102	105.2	15.7
	0.25	85	88	85	84	85.5	12.7
LSD (0.05) Treatments						146.6	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	9	276881.98	26.79**
Rate	4	522002.85	50.51**
Herbicide	1	156750.40	15.17**
H x R	4	61794.02	5.90**
Error	30	10333.13	

**Significant at 1% level.

$\bar{x}$ = 329.5 s = 101.6 CV = 30.8%

Table 26. The response of wheat plants to Igran and simazine treatments under 500 ft-c and 20-25 C.

Herbicide	PPM	Root dry wt. per pot in mg I	II	III	IV	Avg.	% of control
Simazine	0	135	196	141	190	165.5	
	0.025	121	147	125	141	133.5	80.6
	0.05	99	128	114	186	131.7	79.5
	0.1	122	102	123	90	109.2	65.9
Igran	0	129	130	137	120	129.0	
	0.025	134	122	172	154	145.5	112.7
	0.05	99	192	160	111	140.5	108.9
	0.1	88	109	116	90	100.7	78.0
LSD (0.05) Treatments						38.1	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	7	1646.96	2.40
Herbicide	1	294.03	.42
Rates	3	2759.53	4.02*
H x R	3	985.36	1.43
Error	24	685.67	

*Significant at 5% level.

$\bar{x} = 131.9$ $s = 26.1$ CV = 19.7%

Table 27. The response of wheat plants (root dry weight) to Igran and simazine treatments under 500 ft-c and 5-10 C.

Herbicide	PPM	Root dry wt. per pot in mg I	II	III	IV	Avg.	% of control
Simazine	0	191	253	234	224	225.5	
	0.025	207	170	219	245	210.2	93.2
	0.05	153	286	201	144	196.0	86.9
	0.1	141	213	233	184	192.7	85.4
Igran	0	238	223	217	219	224.2	
	0.025	201	342	187	198	232.0	103.4
	0.05	326	240	225	276	266.0	118.6
	0.1	215	210	207	201	208.2	92.8
LSD (0.05) Treatments						63.1	

Analysis of Variance

Source of variation	df	Means square	F value
Treatments	7	2244.17	1.19
Herbicide	1	5697.81	3.03
Rates	3	1422.79	.75
H x R	3	1914.35	1.01
Error	24	1877.86	

and herbicides were highly significant. Igran produced no injury at any rate. Only slight reduction in growth was observed. Simazine produced a reduction in growth with slight injury at higher rates. At low temperature and light intensity conditions, no stimulation was observed at the lowest rate of Igran.

DISCUSSION AND CONCLUSIONS

The studies were conducted to obtain information which would explain the activity of Igran on winter wheat under different environmental conditions.

Several climatic and edaphic factors have been shown to have definite influence on the activity of this herbicide. The findings will help to elucidate wheat response under different environmental conditions and to make better recommendations for more efficient use of this herbicide.

The studies on soil factors have shown an influence on Igran activity in several aspects. Placement studies have indicated that roots are responsible for the absorption of the herbicide. Therefore, incorporation of the herbicide into the soil near the root system will increase the possibilities of injury to wheat. Surface applications were more favorable for wheat causing little or no injury.

A combination of high soil moisture content, high light intensity and high temperature produced the environment that caused the earliest and more severe injury to wheat. At lower moisture levels, although a decrease in the growth rate was observed, the injury symptoms were slower to develop and not as severe as at high moisture levels.

The availability of nitrogen in the growth medium had a significant influence in the toxicity of Igran to winter wheat. Plants grown at high nitrogen levels showed an early and more severe effect than plants grown at lower nitrogen levels. The difference was more pronounced at the highest rate when percent of control values were compared at the three different nitrogen levels.

The effect of soil temperature was studied in a greenhouse where the light intensity and air temperature were the same for the four soil temperatures. High soil temperatures increased the toxicity of Igran to wheat. At lower temperatures, the toxicity was less noticeable and wheat plants grew healthier and showed insignificant injury symptoms. When simazine and Igran were compared at four different soil temperatures and five rates of application, simazine caused more injury under all soil temperatures. The best wheat growth was obtained at 7 C and 15 C, but the greatest foliage dry weight was obtained at 24 C. At 32 C, plants looked stunted with lodging being the most general response even in untreated plants. This can be attributed to the effect of temperature on plant growth since 32 C is an excessive temperature for winter wheat.

To better understand the effect of light intensity and temperature and make better conclusions as to any environmental factors or complex of factors, several experiments were completed in controlled environment chambers. Light intensity showed a very

significant effect on the wheat response to Igran applications. Several experiments indicated that injury symptoms, chlorosis and necrosis, occurred earlier and were more severe at high light intensities. At lower light intensity levels, plant growth was reduced but the injury symptoms were much less noticeable than at high light intensity.

The influence of light intensity on the response of wheat plants to Igran applications was also determined by measuring the CO_2 uptake by wheat plants treated with Igran at two different light intensities. A much earlier and severe decrease in CO_2 uptake was observed at high light intensity while at low light intensity, the plants were not as seriously affected and they recovered after a week from Igran application. These findings indicate a more precise effect of Igran on wheat is the impairing of the photosynthetic mechanism and is expressed as a reduction in carbon dioxide uptake.

Carbon dioxide evolution measurements in the dark indicated a fast increase within a few hours after herbicide application. After 24 hours plants returned to normal at all except the highest rate. The highest rate produced a reduction much more noticeable than lower rates of application. Similar effects were observed at low and high light intensity treatments. At high light intensity treatment and at the highest rate, the reduction in growth was more severe than at low light intensity.

The variation from low to high light intensity after Igran application produced severe injury. Plants remaining at low light intensity did not show the common injury symptoms. The greatest effect was observed in plants moved to high light intensity immediately after chemical treatment.

Temperature variation from low (5 C) to high (20 C) at a constant high light intensity produced similar effects to those observed when light intensity was the variable studied. At low temperature, the injury symptoms appeared much later. At the end of the experiment or three weeks after chemical treatment, all treated plants at low or high temperature showed the same degree of injury.

The effect of Igran application at high (15-20 C) and low (5-10 C) temperatures on the 1, 2, 3 and 4 weeks old wheat plants were examined.

At high temperature, the youngest plants (one week old) were the most severely injured with no appreciable difference among the 2, 4 and 8 pounds per acre rate. For older plants, although the injury was not as pronounced as for the youngest ones, the plants showed a lack of turgidity and slight chlorosis with no appreciable difference among the 2, 4, and 8 pounds per acre rates. These observations were made one and two weeks after Igran application.

At low temperature, no visual difference was observed between the 0 and 2 pounds per acre rate of Igran. Higher rates progressively

reduced growth and increased chlorosis and apical necrosis.

In general, injury symptoms were much less pronounced at low than at high temperature with younger plants being more injured than older ones.

When simazine and Igran were compared at high light intensity and high temperature the toxicity of simazine and Igran was very noticeable except for the lowest rate of Igran. At 0.025 ppm, Igran produced some growth stimulation with no noticeable difference in color from the untreated plants. At high light intensity and high temperature, wheat plants did not look turgid and lodging was very notorious.

When the light intensity was lowered and the temperature continued high, the toxicity of both herbicides was reduced. Under these conditions, plants grew much better. Igran showed less toxicity to wheat. At the lowest rate, a growth stimulation by Igran was observed similar to that observed in the first experiment under high light intensity and high temperature.

Comparisons of simazine and Igran at low light intensity and low temperature indicated the best results obtained with Igran. The difference from simazine was significant but less than under the other two climatic conditions studied previously. At low light intensity and low temperature no growth stimulation was observed. Under these conditions even the highest rate of Igran did not produce

any injury on wheat and plants were very healthy, similar to untreated plants. It can be concluded that, the injury cannot be attributed to one individual factor but to a complex of environmental factors.

The rate of transpiration in wheat plants was faster at the higher temperature and higher light intensity. The more severe injury observed under these conditions may be related to a more rapid translocation of Igran from the roots to the leaves.

Soil water content, soil temperature and nutrient availability in the soil will provide a more apparent medium for a faster translocation when at optimum conditions. The placement of the herbicide near the root system, together with the factors mentioned previously, will augment the possibility of injury to wheat.

From the studies conducted under controlled environment conditions, it can be concluded that, temperature and more obviously, light intensity will determine the activity of Igran on winter wheat. Low light intensities and low temperatures were shown to be the basic requirements for an effective use of Igran without causing injury to wheat.

BIBLIOGRAPHY

Allen, W. S. and R. D. Palmer. 1963. The mode of action of simazine in barley. Weeds 11:27-31.

Ashton, F. M., G. Zweig and W. Mason. 1960. The effect of certain triazines on $C^{14}O_2$ fixation in red kidney beans. Weeds 8:448-451.

Ashton, F. M. and E. G. Uribe. 1962. Effect of atrazine on sucrose-C^{14} and serine-C^{14} metabolism. Weeds 10:295-297.

Ashton, F. M. 1965. Relationship between light and toxicity symptoms caused by atrazine and monuron. Weeds 13:164-168.

Ashton, F. M., T. Bisalputra and E. B. Risley. 1966. Effect of atrazine on Chlorella vulgaris. American Journal of Botany 53:217-219.

Audus, L. J. 1964. The physiology and biochemistry of herbicides. New York, Academic. 555p.

Bailey, G. W. and J. L. White. 1964. Review of adsorption and desorption of organic pesticides by soil colloids. Journal of Agricultural and Food Chemistry 12:324-332.

Behrens, R. 1964. Effects of environment on atrazine phytotoxicity. (Abstract) Weed Society of America, Abstracts, 1964, p. 73.

Bishop, N. I. 1962. Inhibition of the oxygen evolving system of photosynthesis by amine-triazines. Biochimica et Biophysica Acta 57:186-189.

Buchanan, G. A. and E. G. Rodgers. 1963. Role of temperature in the inactivation of some s-triazine herbicides. Southern Weed Conference, Proceedings 16:393-400.

Burnside, O. C. and R. Behrens. 1961. Phytotoxicity of simazine. Weeds 9:145.

Castelfranco, P., C. L. Foy and D. B. Deutsch. 1961. Non-enzymatic detoxification of simazine by extracts of Zea mays. Weeds 9:580-591.

Coartney, J. S. and J. L. Williams, Jr. 1966. Atrazine placement in the soil as related to uptake by giant foxtail (Setaria faberii) seedlings. (Abstract) Weed Society of America, Abstracts, 1966, p. 7.

Comes, R. D. and F. L. Timmons. 1965. Effect of sunlight on the phytotoxicity of some phenylurea and triazine herbicides on a soil surface. Weeds 13:81-84.

Couch, R. W. and D. E. Davis. 1966. Effect of atrazine, bromacil and diquat on $C^{14}O_2$ fixation in corn, cotton and soybean. Weeds 14:251-255.

Crafts, A. S. 1961. The chemistry and mode of action of herbicides. New York, Interscience. 269p.

Currier, H. B. and C. D. Dybing. 1959. Foliar penetration of herbicides: Review and present status. Weeds 7:195-213.

Davis, D. E., H. H. Funderburk, Jr. and H. G. Sansing. 1959. The absorption and translocation of C^{14}-labelled simazine by corn, cotton and cucumber. Weeds 7:300-309.

Day, B. E. and L. S. Jordan. 1964. Influence of soil properties on adsorption and phytotoxicity of simazine. (Abstract) Weed Society of America, Abstracts, 1964, p. 8-9.

Ellis, J. F. 1968. Research specialist - herbicides, Geigy Chemical Corporation, Geigy Agricultural Chemicals Division. Personal communication. Ardsley, New York. January.

Exer, R. 1958. Uber Pflanzenwachstumsregulatoren. Der Einfluss von Simazin auf den Pflanzenstoffwechsel. Experientia 14: 136-137.

Freed, V. H. and M. Montgomery. 1961. The uptake, translocation and metabolism of simazine and atrazine by corn plants. Weeds 9:231.

Frissel, M. J. and G. H. Bolt. 1962. Interactions between certain ionizable organic compounds (herbicides) and clay minerals. Soil Science 94:284-291.

Furtick, W. R. 1967. Professor, Oregon State University, Dept. of Farm Crops. Personal Communications. Corvallis. June.

Gast, A. 1958. Uber Pflanzenwachstumregulatoren. Beitrage zur Kenntnis der phytotoxischen Wirkung von Triazinen. Experientia 14: 134-136.

Geronimo, J. and H. Beevers. 1964. Effects of aging and temperature on respiratory metabolism of green leaves. Plant Physiology 39: 786-793.

Good, N. E. 1961. Inhibitors of the Hill reaction. Plant Physiology 36: 788-803.

Gramlich, J. V. and D. E. Davis. 1967. Effect of atrazine on nitrogen metabolism of resistant species. Weeds 15: 157-160.

Grover, R. 1966. Influence of organic matter, texture and available water on the toxicity of simazine in soil. Weeds 14: 148-151.

Gysin, H. 1962. Triazine herbicides; their chemistry, biological properties and mode of action. Chemistry and Industry, 1962, p. 1393-1400.

Hamilton, R. H. and D. E. Moreland. 1962. Simazine degradation by corn seedlings. Science 135: 373-374.

Harris, C. I. and G. F. Warren. 1964. Adsorption and desorption of herbicides by soils. Weeds 12: 120-125.

Harris, C. I. 1965. Hydroxysimazine in soil. Weed Research 5: 275-276.

Hill, E. R., E. C. Putala and J. Vengris. 1968. Atrazine-induced ultrastructural changes of barnyardgrass chloroplasts. Weeds 16: 377-380.

Hoagland, D. R. and D. I. Arnon. 1950. The water culture method for growing plants without soil. Berkeley. 39p. (California. Agricultural Experiment Station. Circular 347) (revised)

Holly, K. and H. A. Roberts. 1963. Persistance of phytotoxic residues of triazine herbicides in the soil. Weed Research 3: 1-10.

Jordan, L. S., B. E. Day and W. A. Clerx. 1963. Effect of incorporation and method of irrigation on preemergence herbicides. Weeds 11: 157-160.

Jordan, L. S., B. E. Day and W. A. Clerx. 1964. Photodecomposition of triazines. Weeds 12: 5-6.

Kaufman, D. D. and P. C. Kearney. 1964. Degradation of simazine by soil microorganisms. (Abstracts) Weed Society of America, Abstracts, 1964, p. 12.

Knake, E. L., A. P. Appleby and W. R. Furtick. 1967. Soil incorporation and site of uptake of preemergence herbicides. Weeds 15:228-232.

Knüsli, E. 1964. Some new findings on the mode of action and the metabolism of triazine herbicides. In: Proceedings of the Seventh British Weed Control Conference, Brighton, England, 1964. Vol. 1. London. p. 287-294.

Lambert, S. M., P. E. Porter and R. H. Schieferstein. 1965. Movement and sorption of chemicals applied to soils. Weeds 13: 185-190.

Leonard, O. A. 1967. Action and effectiveness of certain classes of herbicides. Agrichemical West 10: 6-10.

McGlamery, M. D. and F. W. Slife. 1966. The adsorption and desorption of atrazine as affected by pH, temperature and concentration. Weeds 14:237-239.

Montgomery, M. and V. H. Freed. 1963. The effect of temperature on the uptake of simazine by wheat. Western Weed Control Conference, Research Progress Report, 1963, p. 90.

Montgomery, M. and V. H. Freed. 1964. Metabolism of triazine herbicides by plants. Journal of Agricultural and Food Chemistry 12: 11-14.

Moreland, D. E., W. A. Gentner, J. L. Hilton and K. L. Hill. 1959. Studies of the mechanism of herbicidal action of 2-chloro-4, 6bis (ethylamino)-s-triazine. Plant Physiology 34: 432-435.

Moreland, D. E. and K. L. Hill. 1962. Interference of herbicides with the Hill reaction of isolated chloroplasts. Weeds 10: 229-236.

Moreland, D. E. 1967. Mechanism of action of herbicides. Annual Review of Plant Physiology 18: 365-386.

Nearpass, D. C. 1965. Effect of soil acidity on the adsorption, penetration and persistance of simazine. Weeds 13: 341-346.

Negi, N. S., H. H. Funderburk and D. E. Davis. 1964. Metabolism of atrazine by susceptible and resistant plants. Weeds 12: 53-57.

Nishimoto, R. K. 1968. The influence of herbicide placement in soil on toxicity to emerging seedlings. Master's thesis. Corvallis, Oregon State University. 68 numb. leaves.

Prendeville, G. N., Y. Eshel, M. M. Schreider and G. F. Warren. 1967. Site of uptake of soil applied herbicides. Weed Research 7: 316-322.

Prendeville, G. N. 1968. Shoot uptake of soil applied herbicides. Weed Research 8: 106-114.

Ries, S. K. and A. Gast. 1965. The effect of simazine on nitrogenous components of corn. Weeds 13: 272-274.

Roth, Willy. 1957. Etude comparee de la reaction du Mais et du Ble a la Simazine, substance herbicide. L'Academie des Sciences, Comptis Rendus 245: 942-944.

Sedgley, R. H. and L. Boersma. 1968. Effect of diuron on photosynthesis and transpiration of wheat, as a function of soil water stress and soil temperature. Corvallis, Oregon State University, Soils Department. 15 numb. leaves.

Sheets, T. J. 1961. Uptake and distribution of simazine by oat and cotton seedlings. Weeds 9: 1-13.

Sheets, T. J., A. S. Crafts and H. R. Drever. 1962. Influence of soil properties on the phytotoxicities of the s-triazine herbicides. Journal of Agricultural and Food Chemistry 10: 458-462.

Shimabukuro, R. H. and A. J. Linck. 1967. Root absorption and translocation of atrazine in oats. Weeds 15: 175-178.

Shirman, R. and K. P. Buchholtz. 1966. Influence of atrazine on control of rhizome carbohydrate reserves of quackgrass. Weeds 14: 233-236.

Sing, R. P. and S. H. West. 1967. Influence of simazine on chloroplast ribonucleic acid and protein metabolism. Weeds 15:31-34.

Smith, D. and K. P. Buchholtz. 1962. Transpiration rate reduction in plants with atrazine. Science 136:263-264.

Sund, K. A. 1964. An evaluation of atrazine, simazine, monuron and diuron on tem Hawaiian sugar cane plantations. Weeds 12; 215-219.

Talbert, R. E. and O. H. Fletchall. 1965. The adsorption of some s-triazines in soils. Weeds 13:46-52.

Tweedy, J. A. and S. K. Ries. 1966. The influence of simazine on growth and nitrogen metabolism of corn grown at different temperatures. (Abstracts) Weed Society of America, Abstracts, 1966, p. 40.

Upchurch, R. P. and D. D. Mason. 1962. The influence of soil organic matter on the phytotoxicity of herbicides. Weeds 10: 9-14.

Upchurch, R. P. 1966. Behavior of herbicides in soil. Residue Reviews 16:46-85.

Van Oorschot, J. L. P. 1965. Selectivity and physiological inactivation of some herbicides inhibiting photosynthesis. Weed Research 5:84-97.

Waldrep, T. W. and J. F. Freeman. 1964. EPTC injury to corn as affected by depth of incorporation in the soils. Weeds 12:315-331.

Wills, G. D., D. E. Davis and H. H. Funderburk. 1963. The effect of atrazine on transpiration in corn, cotton and soybeans. Weeds 11:253-255.