AN ABSTRACT OF THE THESIS OF

Wylie Buress Homesley for the Ph. D.
(Name of student) (Degree)

in Farm Crops presented on February 6, 1969
(Major) (Date)

Title: The Influence of Selected Environmental Factors on Diuron Toxicity to Winter Wheat

Abstract approved: Redacted for Privacy
Dr. William R. Furtick

Previous work has shown that diuron (3-(3, 4-dichlorophenyl)-1, 1-dimethylurea) is less toxic to fall-planted wheat than to wheat planted in the spring. Diuron has been a significant factor in increasing yields of winter wheat grown in Oregon's Willamette Valley. The influence of several selected environmental factors on diuron toxicity to Nugaines winter wheat (Triticum aestivum L.) were observed. Glasshouse, field and growth chamber studies were conducted using Chehalis loamy sand.

Wheat grown in water temperature baths indicated that soil temperature had an important influence on diuron toxicity. Plants grown at 20 C were injured more severely than at 5 C soil temperature.

Two intensities were used to study the effects of light in a range from 400 to 1600 ft-c. In these experiments strict control of other environmental factors was not achieved, but evidence was obtained that increased injury from diuron occurs with increased light

intensity. Injury symptoms occurred earlier and were more severe under the higher intensities. In another study, plants were kept under 1000 ft-c light until minor symptoms developed. When one-half of these plants were exposed to eight hours of full sunlight almost complete chlorosis was observed in diuron-treated plants. No visible change occurred in treated plants left in the growth chamber. This study indicated that sunlight has an effect other than its influence on transpiration rate in causing injury to wheat.

Soil moisture at the time of diuron application was studied in a glasshouse. Treated plants grown in soil which was wet when sprayed were not different from those grown in soil which was dry when sprayed and then watered.

Fertility experiments produced conflicting results. In one, increased fertility increased injury. In another, experimental plants receiving one rate of complete fertilizer had less injury than plants receiving twice this rate or those receiving no added fertility. Further studies are needed to clarify the relationship of fertility level to diuron toxicity.

Wheat grown in a glasshouse in soil maintained at field capacity was injured more by diuron than when the soil was maintained below field capacity. No difference in injury was found between plants grown in soil maintained at 70 or 85% field capacity.

A field experiment was conducted to see what effect date of planting would have on pre-emergence applications of diuron to Nugaines wheat. Excessive injury occurred at all rates used. Less injury occurred to wheat following pre-emergence application of diuron in a late fall than in an early fall development.

The resistance of Nugaines, a new variety, to diuron was compared in a glasshouse to the resistance of a standard variety, Druchamp. Nugaines was injured more by diuron than Druchamp.

In a soil placement study, diuron was found to be taken up through the roots with little or no uptake through the emerging coleoptile. Herbicide effectiveness varied with closeness to seed. A narrow band of herbicide placed just below the seed produced more injury than when an untreated layer two-thirds inch thick was interspersed between the seed and the treated layer. With the same total amount of diuron, more injury occurred from a narrow band than from a band twice as wide.

Glasshouse studies indicated that depth of planting was the most important factor studied. Injury to wheat decreased while increasing depth of planting to one and one-half inches.

No difference in diuron injury from applications in various stages of early development was observed. Stage of growth, at least up to three inches high, does not appear to be a major factor in tolerance.

An experiment using an infrared gas analyzer within a growth chamber revealed that wheat had not overcome two and three-hour exposures to a 10^{-5} M diuron solution 24 hours after treatment.

Photosynthesis was completely inhibited prior to any visual diuron symptom development. No injury symptoms were evident when the plants were harvested 16 days after treatment although foliage yields were much reduced.

On well-drained soils, diuron toxicity to wheat can be reduced by deeper plantings, lower light intensity and lower soil temperature. The results of these studies point out the need for seeding to the maximum practical depth with suitable commercial grain drills. Wheat should be planted in heavier soils which are adequately drained at a time when periods of low temperature and light intensity are likely to follow.

THE INFLUENCE OF SELECTED ENVIRONMENTAL FACTORS ON DIURON TOXICITY TO WINTER WHEAT

by

Wylie Buress Homesley

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

June 1969

APPROVED:

Redacted for Privacy

Professor of Farm Crops
in charge of major

Redacted for Privacy

Head of Department of Farm Crops

Redacted for Privacy

Dean of Graduate School

Date thesis is presented February 6, 1969

Typed by Velda D. Mullins for Wylie Buress Homesley

ACKNOWLEDGMENT

My appreciation to William R. Furtick for his practical way of handling this thesis problem and for the opportunity provided in the extensive weed research program at Oregon State University. I appreciate the allowance, the encouragement, for an individual approach to problems.

To Arnold P. Appleby, Donald W. Hedrick and Roger G. Peterson, I express thanks for personal interest in correcting this manuscript, serving on my committee and offering suggestions along the way.

My thanks to Harry J. Mack for serving on my committee as a representative for the Graduate School.

Thanks, Larry Burrill for making things go easier.

I am grateful to members of the Farm Crops staff for providing assistance, time, facilities and being co-operative.

Larry Boersma was very considerate in giving of his time and facilities.

Thanks to Warren E. Kronstad for making seed and land available for this research.

TABLE OF CONTENTS

LIST OF TABLES

Appendix
Table

LIST OF FIGURES

LIST OF PLATES

THE INFLUENCE OF SELECTED ENVIRONMENTAL FACTORS ON DIURON TOXICITY TO WINTER WHEAT

INTRODUCTION

Pre-emergence application of diuron (3-(3, 4-dichlorophenyl)-1, 1-dimethylurea) in the fall is recommended for control of annual ryegrass (Lolium multiflorium Lam.) and other weeds in winter wheat in Western Oregon and in the higher rainfall areas of Eastern Oregon (49, p. 58). The same practice is not recommended for spring-seeded wheat because of loss of selectivity and resultant injury to the crop. It has been observed by Furtick[1/] in dates of planting studies and in other trials that diuron applied in the fall pre-emergence was not excessively phytotoxic to wheat at the rates used, but when applied pre-emergence at similar rates in the spring, wheat was severely injured. This injury appeared to be progressively worse as the planting dates advanced into the spring. Burgoyne[2/] noted similar effects with linuron (3-(3, 4-dichlorophenyl)-1-methoxy-1-methylurea) on wheat. Fall-applied linuron followed by freezing winter temperatures was not toxic to wheat; however, one year when

---

1/ Furtick, W. R., Professor, Farm Crops Department, Oregon State University, Corvallis, Oregon, Personal interview. June 1967.

2/ Burgoyne, D., Technical Representative, E. I. duPont de Nemours Co., Industrial and Biochemicals Department, 701 Welch Road, Palo Alto, California. Personal interview. May 1967.

temperature did not drop below 40 F, injury to wheat was noted the following spring. This apparent difference in selectivity due to season of year has been noted with the carbamates and is of value in obtaining selectivity in grass seed crops.

Not much evidence is available which would indicate the reason for difference in selectivity of fall versus spring applied diuron in wheat. Weather conditions in Oregon's Willamette Valley are characterized by a high percentage of overcast days with resultant low light intensity, cool temperatures and generally high precipitation throughout most of the fall and winter months. Wheat planted in the fall is usually followed by these conditions; whereas, before planting spring wheat the ground must be dry enough to allow machinery to operate in the fields. By this time there are more clear days, the weather is generally warmer during the day with fluctuating humidity and there are intermittent periods in which the soil is wet and dry. The same moisture conditions are not prevalent during the winter in Eastern Oregon but the winters are colder.

Leonard (29) has related that high temperature enhances the rate of transpiration and hastens the herbicidal effect of photosynthesis-inhibiting herbicides and that crop injury is most likely to occur on sandy soils. Lee [3/] observed that growers in the Willamette Valley

3/ Lee, W. O., Research Agronomist, Agricultural Research Service, USDA, Farm Crops Department, Oregon State University, Corvallis, Oregon. Personal interview. March 1968.

experienced more injury from diuron in the fall of 1967 than in 1966 and he cited temperatures of 6 to 8 F above normal for 1967. It has been shown that light is necessary for the expression of the toxicity symptoms of monuron 3-(4-chlorophenyl)-1, 1-dimethylurea (3, 31). Montgomery and Freed (33, p. 90) have proposed that temperature is a major factor in providing safety to wheat from simazine (2-chloro-4, 6-bis(ethylamino)-s-triazine). Uptake of radioactive simazine by wheat roots was up to six times greater at 29 than 16 C. These results were offered as a partial suggestion for selectivity from fall applications of simazine. This selectivity arises from limited simazine uptake during low winter temperatures usually prevalent following seedling development. Other good evidence for the influence of environmental factors is the work by Sedgley and Boersma (41) which revealed an earlier reduction in photosynthesis at both the higher soil temperature and under the lower water stress of the two soil temperatures and moisture stresses tested. In this study diuron was used as an inhibitor of photosynthesis in wheat. The higher temperature and lower soil moisture stress resulted in higher transpiration rates than the opposite conditions. It seems likely that soil and air temperature, light, humidity and soil moisture conditions have an important bearing on the selective use of diuron in winter wheat. Knowledge of which factor or factors are important in giving diuron its selectivity in wheat would be helpful in predicting the usefulness of diuron in other crops and in other regions of the world. It would also help explain why in some seasons or areas diuron gives more crop injury than in others. It was deemed important to gain more information to determine which of these various factors postulated by research workers are responsible for diuron being selective in winter wheat.

The objectives of this study were to determine: 1) the effect of soil temperature, light intensity and soil moisture level on the expression of diuron's toxicity to winter wheat (Triticum aestivum L., var. Nugaines CI 13968); 2) the site of uptake of diuron by wheat; 3) the influence of depth of planting on diuron toxicity to wheat; 4) the influence of stage of early development at the time of diuron application on toxicity to wheat; and 5) if there is a difference between the two varieties Nugaines and (T. aestivum L., var. Druchamp CI 13723) in their sensitivity to diuron. A better understanding of the action of diuron in controlling weeds selectively in winter wheat should provide an increased margin of safety to wheat treated with diuron. Facilities were not available for studying atmospheric temperature effects.

LITERATURE REVIEW

Not much direct research has been conducted to determine the seasonal influence upon the selective use of diuron in winter wheat; however, there have been a number of studies which help give insight into the various factors which are involved. For a herbicide to be selective it must not be toxic to the crop to which it is applied, the crop must be protected from the compound, or the beneficial effect received from reduced weed competition must be such that it offsets the toxic action to the crop. Ennis (13) has stated that herbicides are selective in that they kill some plants without injury to others. They should also be selective so they will kill weeds and not injure man, domestic animals, wildlife, fish and other beneficial forms of life.

Selectivity in a crop may be obtained even when that crop has only a partial resistance to a herbicide, and the crop is planted at a depth below which the herbicide leaches (51). This crop must not be susceptible to the herbicide through uptake by the emerging plant parts.

Leonard (29) stated that photosynthesis-inhibiting herbicides exert rapid injury under conditions of rapid transpiration. These compounds are generally absorbed by the roots along with water, apparently without selective absorption. They are then transported upward through the xylem and give no indication of being phloem mobile. Leonard also states that anything which would increase the transpiration rate would hasten herbicidal effects. Under these circumstances crop injury is most likely to occur in areas which have high temperatures or on irrigated crops growing on sandy soils.

Several investigators have indicated that organic matter is the most important soil property affecting adsorption of diuron in soil (18, 19, 20, 24, 42, 48). Other studies have indicated that the mineral fraction is also important but not as important as organic matter, and that its importance varies from soil to soil (9, 24). Hilton and Yuen (24) studying the adsorptive properties of Hawaiian sugarcane soils found that the two major factors involved were the easily oxidized organic fraction and carbon which arises from the cane leaf burning and also that the soil mineral fraction was important in some soils but minor in most soils tested. In another study Coggins and Craft (9) demonstrated that bentonite clay reduced the toxicity of substituted ureas to barley. Sheets (42), in studying the phytotoxicity of diuron to oats, found a correlation between cation exchange capacity, percent organic matter and percent clay content. The organic matter appears to contribute more to reducing toxicity than the other two. Upchurch (47) in studying plant selectivity found that higher rates of diuron incorporated into the soil were required to injure cotton than Italian ryegrass. Also in this study organic matter, cation exchange capacity, and total exchangeable bases were the three factors most highly correlated with diuron toxicity. The amount of diuron adsorbed varied due to soil type. Approximately ten times as much diuron was required to produce a 50% reduction in dry shoot weight on some soils as on other soils. Upchurch also stated that the selective herbicidal properties of diuron were not found to be influenced by soil properties. Apparently, equal success can be obtained on many soils in removing a grass from a crop which is tolerant to diuron provided the amount of diuron required to give effective grass control is known. This type of selectivity would be different from the selectivity previously mentioned in that this selectivity depends upon the weed being more sensitive than the crop to diuron when both are exposed to the same amount of chemical. The amount of diuron adsorbed depended upon the kind of soil in a study reported by Harris and Sheets (20). Phytotoxicity to oats was more closely correlated with adsorption ($r = 0.88$) than with organic matter but was also highly correlated with organic matter ($r = 0.80$). Adsorption of diuron was also highly correlated with organic matter ($r = 0.89$). The phytotoxicity to oats was not significantly correlated with the percent of clay. Of the 32 soils examined in this study not one single physical or chemical property was found which would reflect the soil adsorptive capacity or soil effect on phytotoxicity. Using an aqueous slurry condition Hance (19) demonstrated there is competition between diuron and water for adsorptive sites. Water being polar is strongly adsorbed by the mineral fraction. Diuron competes more effectively at soil organic matter surfaces than at soil mineral matter surfaces so that in the presence of water organic matter is relatively more important for adsorption of diuron by soils. In another study by Hance (18) organic matter was found to be quantitatively the most important site of adsorption in the soils tested. There were indications that the adsorptive power of organic matter varies from soil to soil and that water solubility of the herbicide does not appear to be closely related to adsorption. Other indications in this study were that only a fraction of the total adsorptive sites of the soil surface were available to the herbicide molecules.

Yuen and Hilton (52) have viewed the field performance of diuron as a dynamic complex involving four principal factors: the intrinsic phytotoxicity of the chemical, the soil adsorptive characteristics, microcrystalline regions of undissolved diuron and the supply of water. Maintaining monuron at a constant concentration and increasing the soil/solution ratio resulted in more of the chemical being adsorbed. This showed that with a decreasing moisture content of the soil there was an increase in the adsorption of monuron. At a certain moisture content the solubility of the pesticide in question will be exceeded and crystallization will occur (4). Sheets (42) working with a sandy loam soil and low rates of diuron illustrated that high volumes of water were required to move the chemical measurable distances downward through soil columns. Weldon and Timmons (50) found that frequent heavy irrigations increased the rapidity of diuron penetration into the soil but did not increase the final depth of penetration over light irrigation. Hance (18) showed that water solubility of diuron does not appear to be closely related to adsorption. In these studies it appears that the adsorption of diuron is very important in determining its availability to the plant.

Hill, Belasco and Ploeg (22) using foliar applications of diuron, linuron and bromacil (5-bromo-3-sec-butyl-6-methyluracil) under simulated drought stress conditions in the greenhouse found the foliar activity of diuron at 1 lb/A with 0.3% WK against seedling crabgrass and Johnsongrass was approximately 50% less than normal greenhouse conditions. Surfactants increased water solubility of diuron but no correlation between increased phytotoxicity and increased water solubility were noted. Upchurch (46), studying the influence of soil moisture content on the response of cotton to herbicides, was able to show that diuron was more toxic under moist compared with dry soil conditions. This was assuming that cotton plants respond relatively the same to moisture variables with and without diuron. However, Knake, Appleby and Furtick (28) obtained a greater reduction in dry weight with linuron at a low rather than at a high moisture level on green foxtail (Setaria viridis (L.) Beauv.). Also with green foxtail, the site of uptake for linuron was in the shoot and not in the root. Appleby, Furtick and Fang (1) found that carbamate type herbicides exert their primary phytotoxic effects when absorbed through the coleoptiles of emerging oat seedlings; whereas, root exposure resulted in much less damage. Nishimoto (36, p. 28, 29) found diuron was effective on annual ryegrass through both root and shoot exposure. At lower concentrations a layer of diuron just below the seed was most effective. Injury to annual ryegrass increased with an increasing rate of diuron through shoot exposure with the layer just above the seed being more toxic than when a 3/4-inch buffer layer was between the seed and the treated layer. Injury to annual ryegrass was markedly reduced when a 3/4-inch untreated layer was above the treated layer and below the seed. It appears that diuron is most effective when in intimate contact with annual ryegrass seed.

Muzik, Cruzado and Loustalot (35) found entry of monuron was very rapid through the roots and that it could also enter through cuts in the stem and by dipping the leaves in a solution. Movement was primarily toward the shoot apex and experimental evidence indicated the path was through the xylem with the transpiration stream. Fang et al. (14) also working with monuron found that it was quickly absorbed and translocated throughout the entire leaf when applied to the leaf of bean plants. They also found that radioactive monuron decreased with time and that there was a corresponding increase in the concentration of a monuron complex. The adsorption and distribution of diuron was studied by Bayer and Yamaguchi (6) who found that C^{14} labeled diuron moved primarily in the apoplast with the transpiration stream and did not move with the plant assimilates of red kidney bean, soybean and barley plants. There did not appear to be a species difference in absorption, distribution and accumulation. No phloem movement and distribution was observed in the 16-day treatment time nor did the addition of a surfactant alter the translocation pattern.

It has been indicated that selectivity of crops to diuron can be obtained by planting beneath the layer of diuron. Hamilton et al. (17) making pre-plant applications of diuron in cotton demonstrated that the yield of seed cotton was reduced when planted one inch above or into the layer of diuron. Seed one inch below the diuron layer was about equal to the untreated check while yields from seed planted two inches below the diuron was better than the untreated check at this depth. When diuron injury was measured in terms of stand reduction it was found that varieties differed in their response. Planting seed in or above the diuron layer caused a higher initial concentration of diuron in the plants than planting below the diuron layer. In another depth of planting study, Culp and McWhorter (12) found that increased depth of planting gave better protection to castorbeans from diuron.

The longer that diuron persists in the soil the more opportunity it has to accumulate in the plant. Weldon and Timmons (50) found that frequent irrigation greatly increased the rate of disappearance of diuron. Diuron at 2 lbs/A disappeared in one growing season from sandy clay loam soil under frequent semi-flood irrigation but persisted two growing seasons under less frequent irrigation. Sheets (43) in a review of the disappearance of substituted ureas from the soil concluded that persistence of this type compounds is influenced by rainfall, soil properties, soil environment, microbial activity and characteristics of the herbicide such as solubility, leachability and adsorption to soil colloids. Toxicity of diuron to oats was lost more rapidly in nonautoclaved soil than in soil which was autoclaved initially. Persistence was also reduced in soil which was moist continuously as opposed to soil which dried one month between croppings (44). Soil microorganisms play a definite role and are probably the most important factor in removing substituted urea herbicides from agricultural soil. At rates of 1 to 2 lbs/A phytotoxicity disappears after 4 to 6 months in the eastern one-half of the United States. Under normal rainfall conditions leaching was not a factor in removal. It was pointed out that photodecomposition occurs and may be a factor of removal when the compound remains on the surface for some time under dry conditions (23).

Loustalot, Muzik and Cruzado (30) had experiments which illustrated that the toxicity of monuron, as measured by corn and beans, persisted longer at 10 C than at room temperature or at 45 C. There were no differences between the two warmer temperatures. Ten weeks were required for toxicity to corn and beans to disappear in treated soil stored dry while toxicity disappeared in two weeks with soil kept saturated.

Temperature is an important factor in transpiration and as such will influence the upward movement of diuron through the transpiration stream. Also adsorption processes are exothermic while desorption processes are endothermic, heat requiring, in nature. An increase in temperature would be expected to reduce adsorption and favor the desorptive process. Therefore with an increase in temperature it would be expected that there would be more diuron available to enter the soil solution. However, Upchurch and Pierce (48) studying soil temperatures from 5 to 45 C found that temperature had little influence on the amount of monuron leached from the 0 to 2-inch layer of a Lakeland sand soil. Increasing soil temperature increased the amount of monuron retained by the 2 to 4 and 4 to 8-inch soil layers. The adsorption of monuron from the percolating solution was increased by increasing soil temperature, organic matter content and the concentration of the percolating solution. Hill, Blasco and Ploeg (22) found that injury to crabgrass and Johnsongrass was 20% and 50% greater, respectively, from foliar applied diuron where the greenhouse temperature was from 5 to 7 F higher than normal. Bayer and Drever (5) found that ten days after treatment, injury to oat plants growing at 60 F was approximately 50% of that exhibited by plants growing at 72 F. Twenty days after treatment the injury in the two groups was about equal. Lowering the temperature from 72 to 60 F slowed the expression of toxicity and increased the chances of plant recovery. Power et al. (40) studying the effects of soil temperature on the growth of barley found that soil temperature had no significant effect on the net assimilation rate. Montgomery and Freed (33, p. 90) studied the effect of temperature on the uptake of radioactive simazine by wheat. After four weeks growth 84% more radioactivity was found in plants from soil sprayed with 0.5 lbs/A and 600% more in plants from soil incorporated with 0.5 ppm at 80 F than at 60 F. Work just completed by Sedgley and Boersma (41) illustrate the importance of soil temperature and soil water stress upon the inhibition by diuron of photosynthesis in wheat. Inhibition 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.

Action of phenylurea herbicides is believed to interfere with the Hill reaction of photosynthesis; however, it is possible that there are other modes of action for diuron. Moreland and Hill (34) found that sensitivity of the Hill reaction of isolated chloroplasts was inversely related to the water solubility of five phenylureas tested. Phytotoxicity measured in tests in which the herbicides were applied to the soil or in solution cultures was not correlated so precisely. Also Gentner and Hilton (16) by supplying sucrose to cut leaf tips kept barley alive and growing in the presence of lethal concentrations of diuron. Sucrose was less effective against increasing rates of diuron indicating that metabolic reactions other than photosynthesis may be sensitive to diuron. In another study Jordan et al. (27) illustrated that monuron inhibited growth of tobacco callus at 10^{-4} M which is a higher concentration than is normally used for selective weed control; however, interference by simazine, atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) and paraquat (1, 1'-dimethyl-4, 4'-bipyridinium) occurred at lower concentrations. At these lower concentrations, interference with a mechanism other than photosynthesis was responsible for inhibition of growth.

Oorschot (39) found more rapid inhibition of CO_2-uptake with simazine in maize at 28 C than at 19 C. The decrease in CO_2-uptake after exposure to simazine began later and was much slower at lower leaf temperatures. The estimated concentration of simazine in the plants at 50% inhibition of CO_2-uptake, which was based on transpiration data, was nearly the same for the plants at 19 and 28 C. This may indicate that the temperature effect on photosynthesis is mainly determined by its influence on transpiration rate. Oorschot (38) studied the inhibition of CO_2-uptake and transpiration of beans by diquat (6, 7-dihydrodipyrido (1, 2-a:2', 1'-c)pyrazidiinium) and simetone (2-methoxy-4, 6-bis (ethylamino)-s-triazine) and found that diquat applied to roots, leaves and petioles resulted in considerable decrease in CO_2-uptake and smaller effects on transpiration. Similar rates of simetone were somewhat less effective. The relative inhibition of CO_2-uptake after diquat application to the leaves was almost equal at different light intensities. These plants were not maintained at these intensities but the same plants received increasing increments of light.

Ashton (2) demonstrated that light is necessary for expression of toxicity symptoms of monuron. Increasing light from 30 to 4000 ft-c decreased fresh weights of oats as compared to the check. No toxicity symptoms were noted at 125 ft-c or below even though photosynthesis was blocked. Chlorophyll a and b are suspected to be the principal pigments involved with the action spectrum of the toxicity symptoms caused by atrazine and monuron. Minshall (31) studied bean plants growing in shade and full sunlight for two weeks before treatment and found that plants which were held at 3000 ft-c of light showed more severe symptoms from monuron than leaves grown under 10,000 ft-c. To produce extensive necrosis sun-exposed leaves required a higher internal concentration per unit weight than did shade-exposed leaves. This difference was less pronounced in leaves from four or five-week-old plants than it was in leaves from two-week-old plants. Bean plants were grown under shading slats in the greenhouse at 3000 ft-c for seven days and watered from the bottom with seven ppm monuron. Some of these plants were placed in full sunlight at 10, 000 ft-c for one day and pictures taken on the following day showed very marked injury symptoms. From this it can be seen that bright sunshine following several days of exposure under cloudy conditions can produce extensive changes to the plant. Bean leaves containing approximately 25 micrograms monuron/gram of fresh weight were placed with one-half of the leaves under 600 ft-c continuous light and the other one-half of the leaves under full sunlight in the greenhouse. Extensive necrosis developed on leaves exposed to sunlight. The light intensity during uptake did not affect the extent of subsequent symptom development in leaves which had attained equal internal concentrations under diverse conditions of light intensity during uptake. However light intensity during uptake affected the rate of absorption.

Sunlight was effective in reducing the toxicity of diuron when exposed on a surface. Comes and Timmons (10) found that exposure of diuron to sunlight resulted in reduced phytotoxicity to oats. A chemical change of the phenylureas caused by sunlight and ultraviolet light was reported by Jordan et al. (26). Decomposition products form a barrier to light and decrease the rate of decomposition of the chemical beneath them. This would suggest that once the chemical is adsorbed or incorporated into the soil photodecomposition would be of minor importance as a mechanism for herbicide loss.

Relative humidity is also suspected of being important in the expression of phytotoxicity of phenylureas. Muzik, Cruzado and Loustalot (35) found a humidity of 90 to 95% at 80.7 F resulted in less injury from monuron than a humidity of 60 to 65% at an average temperature of 86 F. Hill, Blasco and Ploeg (22) found that the surfactant duPont WK increased post-emergence activity of diuron. Increasing relative humidity also increased the activity of both diuron alone and the surfactant-diuron mixture as a post-emergence foliar spray. The activity was greatest at 100% relative humidity.

Two studies (35, 32) indicated that phenylureas are not toxic to roots at concentrations normally used for selective weed control. Minshall (32) found that monuron at greater than 32 ppm was required to suppress root extension; however, timothy and other plants tested were killed at concentrations below this level. Muzik, Cruzado and Loustalot (35) grew excised roots successfully for three months in sterile nutrient cultures containing monuron in amounts sufficient to kill intact plants in two weeks, indicating that the toxic action of monuron is primarily exerted on the aerial portion of the plant. Roots growing in a concentration of 10 ppm looked almost as good as the control.

GENERAL METHODS AND MATERIALS

Most of the experiments were carried out in the greenhouse over a period of one year from June 1967 through June 1968. The temperature control was set at 21 C but during the summer, daytime temperatures ranged as high as 34 C with nightime lows of around 21 C. The general daytime summer temperatures were about 27 C and in the winter day temperatures were 21 to 23 C with night temperature dropping as low as 18 C. Plants were grown in metal cans four inches in diameter by six inches deep and in one-quart freezer containers of similar dimensions. These pots did not have holes in the bottoms and moisture content was sustained by periodic weighing when water was added. After the results of the first moisture level experiment all pots were weighed and the moisture content equalized daily. Those plants grown in a sand culture were not always weighed daily but in each case a measured amount of water was added as needed. Also, after the first study in the summer all pots were fertilized with 46, 10, 19 ppm of N, P, K except where otherwise noted in the fertility studies. Thin clear plastic bags were placed inside the containers to reduce danger of contamination.

Soil used was a Chehalis loamy sand from the University's East Farm where the field experiment was conducted. Physical and chemical characteristics of this soil are presented in Table 1. The

Table 1. Some physical and chemical properties of the soil used.

Soil pH	P ppm	K me/100g	Ca me/100g	Mg me/100g	CEC me/100g	OM percent
5.5	15.0	0.69	8.1	3.7	13.3	0.70

2000-50 microns percent sand	50-2 microns percent silt	≤2 microns percent clay	Moisture tension 0.33 Atm	Moisture tension 15.0 Atm
70.52	16.48	13.00	13.02	7.32

soil was brought into the greenhouse, air dried and passed through an eight-mesh screen. Except as noted, one kg of oven-dry soil was placed in each container. In each experiment with soil, wheat seeds of uniform size were spaced an equal distance apart and placed with the embryo up. Following emergence the stand was thinned to a uniform number of plants per container. An overhead moving sprayer which delivered 110 gallons of water per acre was used to spray the soil surface. The depth of planting was uniformly obtained by weighing the appropriate amount of soil, seeding and then adding soil to obtain the desired amount of oven-dry soil per pot. The same procedure was followed for most experiments using washed quartz sand; however, in some instances after one kg of sand was weighed into the container the seeds were placed on top and pushed into the sand with the head of a nail. This method was unsatisfactory in that uneven emergence was caused by seed slipping past the nail head.

Plants were allowed to grow for a period of three to six weeks and harvested by cutting them approximately even with the soil surface. The plants were then put into 40x50 mm weighing bottles and placed in a forced air oven at about 90 C for periods of 22 to 30 hours. Dry weights and in some cases fresh weights were determined with an analytical balance and weights recorded to the nearest milligram. A split-plot experimental design was used in the soil temperature and light intensity studies. A randomized blocks design was used for the larger experiments on the greenhouse bench, in the field experiment and when deemed necessary on smaller experiments. When there were small numbers of containers in an experiment or the environment was thought to be uniform, a completely randomized design was employed. The data were then statistically analyzed and comparisons made by obtaining the desired sums of squares with an analysis of variance and individual degrees of freedom methods. The mean squares were then subjected to an F test. The five percent level of significance was chosen as the criterion for hypothesis testing; however, when it occurred the one percent level was indicated.

EXPERIMENT I. EFFECT OF SOIL TEMPERATURE ON TOXICITY OF DIURON TO WHEAT

Decreasing soil temperature in the fall and winter has been postulated as a reason for less diuron injury to fall-seeded wheat than to wheat planted in the spring. This experiment was designed to study diuron injury to plants growing in different soil temperatures.

Methods and Materials

In the initial experiment 12 Nugaines wheat seeds were planted one-half inch deep in soil placed in square one-quart plastic freezer containers without holes. The pots were sprayed pre-emergence with an overhead moving sprayer which delivered 110 gallons of water per acre. The soil was then brought to 20% moisture level by overhead watering and approximately maintained by daily watering and periodic weighing of the pots. This uniformity was difficult to maintain and soil at the higher temperature was usually drier than that at a lower temperature. In all cases it was seldom necessary to water plants in the 5 C tanks and drying of the soil surfaces never occurred between waterings. Rates of diuron were 0, 1, 2, 4 and 8 lbs/A with four replications of each treatment in each tank. In addition a 0.5 lb/A rate was included in the 29 C temperature tank in anticipation of more injury at the higher soil temperature.

The pots were set on a glasshouse bench and the seeds allowed to germinate; then following emergence the pots were placed in water baths (Plate I) with temperatures set at 5, 13, 21 and 29 C. The water was maintained at the soil level and was continuously circulated with small pumps. After 11 days, flooding occurred in the 5 and 13 C tanks making it necessary to discontinue the first run of the experiment. It was obvious that the 8 lb/A rate was too high as plants treated with this rate were already showing severe injury symptoms.

Plate I. Water bath tank used to control soil temperature.

In the second attempt to conduct this experiment, eight Nugaines wheat seeds were planted one-half inch deep and the pots sprayed with 0, 0.5, 1, 2 and 4 lbs/A of diuron and then irrigated by overhead watering to bring the soil to 15% moisture content which is 2% above field capacity. The same temperatures were used but only three pots per rate were used in each tank. The first date was planted July 18 and harvested August 17, the second date was planted August 14 and harvested September 14 and the final date was planted September 4 and harvested October 5, 1967. This experiment was repeated at these three dates to provide an estimate for the error term in an analysis of a split-plot design. Water temperatures were the main plots and rates were sub-plots with dates being used as blocks.

When eight tanks became available, an experiment was designed to study the effects of two soil temperatures (5 and 20 C), four rates of diuron (0, 0.5, 0.8 and 1.1 lbs/A) and three fertility levels (low: 0, 0, 0; medium: 46, 10, 19; and high: 92, 20, 38 ppm of N, P, K). A procedure similar to the one described for the temperature by rate by date study was used. A split-plot design with temperatures as the main-plots, rates of diuron as the sub-plots and rates of fertilizer as the sub-sub-plots was used. Dry weights from two pots of each sub-sub-plot were the basis for means used in determining percent of check. The experiment was seeded and treated October 23, placed in tanks October 29 and the 20 C was harvested December 4 while the 5 C was allowed to grow until December 21, 1967. The later harvest date was used because visual injury symptoms were not seen at 5 C on December 4 and because it was assumed that equivalent injury would occur at lower temperatures if given additional time for the metabolic process to function. The assumption was made that higher soil temperature hastened the herbicidal effect. Although in a glasshouse from which whitewash had not been removed, this experiment was performed at the time of the year when diuron is selective on wheat in the field.

Because rates from the three date study gave excessive injury to wheat during the summer and because results varied from date to date, a similar experiment was established, after running a rate curve to establish levels of herbicide required for winter conditions, in an effort to confirm previous results. A split-plot design with three blocks was used. Water temperatures of 5 and 20 C were the main-plots and rates of diuron, 0, 1.3 and 1.7 lbs/A, were the sub-plots. Again diuron was applied to the soil pre-emergence with the overhead sprayer and the stand was thinned to seven plants per pot. The pots were seeded January 9 and harvested February 16, 1968. In order to get a better estimate of the means used in determining percent of check, four pots of each treatment were used in each tank to estimate the mean. For expressing the injury at each temperature the total milligrams of wheat harvested from the four pots per rate was expressed as percent of its appropriate check.

Results

The dry weights expressed as percent of check and the statistical analysis of the rate by temperature experiment conducted at three dates are presented in Table 2. Dry weights from which this table was formulated are included in the appendix. The means of the dates show greater injury at the second date with the first and third dates being about equal. This is supported by contrasts which show a significant difference when date two is compared with the average of dates one and three. Also date one did not differ from date three. From these differences and noticing that there were more cloudy days on the first and third dates, light as a factor in diuron toxicity to wheat was indicated and subsequent experiments were established to study its effect. These are reported in Experiment IV of the thesis. A second factor of interest arising from these differences in dates was that fertilizer at 46, 10, 19 ppm N, P, K was applied at the second date and not on the first, but since it was also applied on the third date it could not account for the difference.

The F test for temperatures was not significant; however, the 29 C soil temperature as measured by percent of check was

Table 2. Dry weights expressed as percent of check for wheat sprayed pre-emergence with diuron at four rates and grown at four soil temperatures with the statistical analysis.

lbs/A	5 C				13 C				21 C				29 C				
	Dates				Dates				Dates				Dates				Rate
diuron	1	2	3	Avg.	1	2	3	Avg.	1	2	3	Avg.	1	2	3	Avg.	Avg.
0.5	68.1	38.0	64.1	57.6	66.8	28.8	79.9	58.5	70.3	28.6	81.8	60.2	95.0	23.8	91.7	70.2	61.4
1.0	44.1	15.8	24.8	28.2	35.6	21.3	50.8	35.9	32.7	12.2	51.2	32.0	61.6	14.0	63.5	46.4	35.6
2.0	26.5	12.1	29.2	22.6	16.9	11.8	14.4	14.4	12.1	7.9	15.4	11.8	28.9	15.3	29.4	24.5	18.3
4.0	31.1	11.1	32.1	24.8	12.8	13.3	11.4	12.5	12.1	6.2	10.9	9.7	20.4	13.6	23.8	19.3	16.6
Avg.	42.4	19.2	37.6	33.1	33.0	18.8	39.1	30.3	31.8	13.7	39.8	28.4	51.5	16.7	52.1	40.1	33.0

Date Averages

Date	1	2	3
Avg.	39.7	17.1	42.2

Analysis of variance (on a sub-plot basis)

Source	df	MS
Main-plots	11	
Dates (Blocks)	2	3,046.86**
Date 1 vs 3	1	48.51
Dates 1 + 3 vs 2	1	6,045.20**
Temperatures	3	312.33
5 vs 20 C	1	128.81
5 + 13 + 21 vs 29 C	1	806.56*
Main-plot error	6	115.16
Sub-plots		
Rates	3	5,197.51**
2.0 vs 4.0 lbs/A	1	18.55
0.5 vs 1.0 lbs/A	1	3,986.10**
0.5 + 1.0 vs 2.0 + 4.0	1	11,587.87**
Rates X Temperatures	9	77.30
Sub-plot error	24	159.92

different from the other three temperatures in this study. Visual observation of the way in which plants died would indicate that injury occurred as rapidly and as completely at 29 as 21 C, but because the 29 C checks did not grow as fast as the 21 C checks a misleading measure of toxicity is given. The same argument might be presented for slower growth which occurs at 5 C, but in this case there was not the visual symptoms of injury. Also there was increasing plant growth from 5 through 21 C soil temperatures and the growth at 29 C represents a change in the general upward growth response indicating that this high temperature was not conducive to good growth. The lower temperature, though also not conducive to maximum growth, is a part of the environment encountered by fall-seeded wheat; whereas, temperatures above 21 C are not encountered until late in the spring. Considering the data presented in Table 2 and ignoring that for 29 C the averages would indicate slightly less injury at the lower soil temperature. When one looks at individual rates within Table 2 there are seemingly no differences due to temperature at 0.5 and 1 lb/A, but the higher rates of 2 and 4 lbs/A offer evidence for less injury at 5 C. The 2 lbs/A rate did not differ from the 4 lbs/A rate, but 0.5 lb/A was found to be different from 1 lb/A. Also the two low rates were different from the two high rates indicating that a level had been reached somewhere above 1 lb/A which resulted in essentially complete kill of wheat.

This experiment was performed before soil moisture tension data were available and at each watering the soil was brought to a level below 0. 33 tension which was 2% more soil moisture than field capacity.

It should be understood when using percent of check as a measure of toxicity that after complete kill of wheat has occurred the subsequent change in percent of check is strongly influenced by difference in growth rate of the checks in each treatment. Therefore it is desirable to harvest prior to but not later than when complete chlorosis has occurred.

After observing the results of this experiment it seemed necessary to do more work on the effects of light intensity, fertility level and soil temperature. The results of the soil temperature by herbicide rate by fertility study are presented in Table 3. Perhaps of most interest is that plants growing during November at 5 C exhibited no visual injury and on a dry-weight basis were essentially equal to the check. However, during the summer an average of the three dates show dry weights which were 57. 6 and 28. 2% of check for 0. 5 and 1. 0 lbs/A diuron. In addition to this seasonal difference, those plants grown in late fall grew for a 50% longer period. A similar observation was made for 20 C soil temperature on plants grown for one month. A rate of 1. 1 lbs/A produced plants weighing 72. 3% of check while during the summer

Table 3. Dry weights as percent of check for the soil temperature by herbicide rate by fertility experiment and the analysis of variance.

Temperature	lbs/A diuron	Fertility level	Blocks 1	2	3	4	Mean
5 C	0.5	Low	118.8	101.5	103.5	95.5	104.8
		Med.	99.8	100.2	106.6	106.9	103.4
		High	82.1	90.8	106.7	100.9	95.1
		Mean	100.2	97.5	102.3	101.1	101.1
	0.8	Low	113.4	89.7	108.7	89.1	100.2
		Med.	99.8	98.5	106.1	105.0	102.4
		High	91.2	99.1	88.3	106.7	96.3
		Mean	101.5	95.8	101.0	100.3	99.6
	1.1	Low	124.2	92.3	97.4	98.2	103.0
		Med.	94.7	96.4	109.6	106.0	101.7
		High	83.7	95.6	106.5	97.8	95.9
		Mean	100.8	94.8	104.4	100.7	100.2
		Mean	100.8	96.0	103.7	100.7	100.3
20 C	0.5	Low	73.6	91.7	100.5	99.5	91.3
		Med.	101.3	103.1	98.9	99.7	100.8
		High	104.3	99.8	101.6	78.7	96.1
		Mean	93.1	98.2	100.3	92.8	96.1
	0.8	Low	58.0	86.5	92.2	80.4	79.3
		Med.	77.9	108.3	85.7	89.4	90.3
		High	69.0	77.6	92.8	73.3	78.2
		Mean	68.3	90.8	90.2	81.0	82.6
	1.1	Low	59.9	74.1	87.0	80.2	75.3
		Med.	57.4	96.3	84.8	85.4	81.0
		High	45.2	61.6	94.2	72.6	68.4
		Mean	54.2	77.3	88.7	79.4	72.3
		Mean	70.7	88.8	93.1	84.4	84.5

Temperature	Mean	Rate	Mean	Fertility	Mean
5 C	100.3	0.5	98.6	Low	92.3
20 C	84.5	0.8	91.1	Med.	96.6
		1.1	87.5	High	88.3

Continued

Table 3. Dry weights as percent of check for the soil temperature by herbicide rate by fertility experiment and the analysis by variance--Continued.

Analysis of variance (on a sub-sub plot basis)

Source	df	MS
Total	71	
Main-plots:	7	
Blocks	3	435.29
Temperatures	1	4,493.52*
Main-plot error	3	412.33
Sub-plots:		
Rates	2	761.44**
Temp. x Rates	2	622.54**
Sub-plot error	12	69.31
Sub-sub-plots:		
Fertilizer	2	407.27**
Low vs. High	1	191.24
Low + High vs Med.	1	623.33**
Temp. x Fert.	2	123.64
Rate x Fert.	4	18.92
Temp. x Rate x Fert.	4	423.75**
Sub-sub-plot error	36	66.67

Main-plots:	s = 20.31	CV = 22.0%.
Sub-plots:	s = 8.33	CV = 9.0%.
Sub-sub-plots	s = 8.17	CV = 8.8%.

0.5 lbs/A produced plants weighing 70.3, 28.6 and 81.8% of check for dates 1, 2 and 3 with an average of 60.2% of check. The 1 lb/A rate during the summer had an average value of 32.0% of check. This evidence supports previous suggestions that fall conditions are important in diuron's selective use in wheat. It also strengthens the data showing differences in dates in the three date study.

In this study a significant difference was found for soil temperatures. An average difference in percent of check of 15.8 was found with more injury at 20 than at 5 C. This difference widens to 27.9 if only 1.1 lbs/A is considered. Further support for the effect due to soil temperature is the temperature by rate and the temperature by rate by fertility interactions. Increasing the rate from 0.5 to 1.1 lbs/A failed to show an effect at 5 C but had noticeable effect at 20 C. More difficult to interpret is the temperature by rate by fertility interaction. The majority of this may be due to temperature by rate but there appears to be more effect from fertility at 20 than at 5 C. Because of the interaction there are two effects due to rates and it appears that this difference is at 20 rather than 5 C although this was not tested. Also the effect due to fertility level must be viewed carefully. The two contrasts show no difference between the high and low fertility levels but the medium level apparently had less injury than the average of the other two levels. There is some indication of the most injury having occurred at the high level. This needs further study as field observations indicate that diuron is doing a less effective job of weed control in wheat with the new short-strawed varieties which allow use of high levels of nitrogen.

Results of the final trial of the soil temperature experiment which was carried out under winter conditions in the glasshouse at 5 and

20 C are presented in Table 4. Treated plants growing at 5 C had a value which was 57.2% of their checks while those growing at 20 C had dry weights of only 33.1% of their checks. This was a difference of 24.1 units. Plants growing at 5 C had 72.8% less reduction in percent of check than those plants growing at 20 C, or stated another way, plants growing at 20 C had 42.2% more reduction in percent of check than those growing at 5 C. The hypothesis set for this experiment was that there would be no difference in toxicity resulting from different soil temperature treatments, but evidence was found to refute this hypothesis, and it was concluded that there was less injury to wheat growing at 5 than at 20 C. This work is in agreement with that of Sedgley and Boersma (41) and Montgomery and Freed (33). It is concluded that lower soil temperature in the fall and winter is an important factor in reducing diuron injury to wheat; however, this does not explain why fall-treated wheat will not be injured the following spring when the soil warms up. Partial loss of diuron residue through the winter and increased growth of tops and roots may provide the margin of safety necessary.

Table 4. Dry weights of wheat expressed as percent of check for plants grown at two soil temperatures and sprayed with two rates of diuron with the analysis of variance.

Soil temperature	lbs/A diuron	Blocks 1	2	3	Mean
5 C	1.3	48.9	72.8	70.8	64.2
	1.7	46.2	54.7	50.0	50.3
	Mean	47.6	63.8	60.4	57.2
20 C	1.3	25.8	44.0	36.4	35.4
	1.7	29.7	34.2	28.5	30.8
	Mean	27.8	39.1	32.4	33.1

Analysis of variance (on a sub-plot basis)

Source	df	MS
Total	11	
Main-plots:	5	
Blocks	2	194.50
Temperature	1	1,747.26**
Main-plot error	2	16.80
Sub-plots:		
Rates	1	255.77
Rates x Temp.	1	64.39
Sub-plot error	4	37.61

Main-plots: s = 4.1 CV = 9.1%

Sub-plots: s = 6.1 CV = 13.6%

EXPERIMENT II. THE INFLUENCE OF MOISTURE AT TIME OF SPRAYING AND FERTILITY LEVEL ON DIURON TOXICITY TO WHEAT.

Some trial studies were thought to show differences in toxicity resulting from different soil moisture levels at the time of spraying. Observations in the field often have shown increased weed control when the chemical had been applied to soils which were wet as compared to those which were dry. These observations were not from experiments designed to study these factors but were offered as suggestions in explaining differences in the amount of weed control.

The effect of soil moisture at time of spraying on diuron toxicity to wheat was studied. Moisture levels at time of spraying were added to a soil fertility study in a second experiment.

Methods and Materials

The procedure for the moisture at time of spraying study involved spraying on wet and dry surfaces followed by immediate watering and watering 24 hours later. Square four-inch plastic pots with holes in the bottom were filled with 700 g oven-dry soil. One-half of these pots were brought to 75% field capacity (9.75% moisture content) and one-half were left air dry (4.5% moisture content). Then these pots were sprayed with diuron at 0, 0.1, 0.2, 0.4, 0.6, 1.0 and 2.0 lbs/A. After spraying, one-half of the pots having a wet surface and one-half of the pots having a dry surface were brought to field capacity and then one-half inch of water was added. After 24 hours the remaining one-half of the pots were brought to field capacity, one-half inch of water was added and all pots were placed on a bench in a glasshouse. Other methods were similar to those previously described. It should be noted that those pots which were dry when sprayed and then not watered for 24 hours germinated one day later and were harvested one day later. The soil surface in those pots which were sprayed at 75% field capacity and not watered following spraying were dry on the surface at the time of watering 24 hours later. All pots which received one-half inch of water the day before were still moist on top at the time of the 24-hour treatment. Following the 24-hour treatment all pots were watered to maintain approximate field capacity. The experiment was planted and treated August 23 and harvested October 6 and 7, 1967. Because of poor seedling emergence the stand was thinned to five plants per pot on September 4. A randomized blocks design was used with four blocks.

A randomized blocks design with eight blocks was used to study two fertility levels (0, 0, 0 and 60, 13, 25 ppm N, P, K), two moisture levels at time of spraying (air dry and field capacity) and rates of diuron (0, 1.4 and 2.0 lbs/A). These plants were grown in metal cans containing 1 kg oven-dry soil on a glasshouse bench from January 10 to February 14, 1968. In this case all pots were brought to field capacity after spraying and no extra water was added. Other procedures were similar to those previously reported.

Results

Table 5 gives the milligrams of dry weight (foliage) of Nugaines wheat treated with diuron using four moisture treatments and the analysis of variance. Soils wet or dry when sprayed and soils watered immediately and 24 hours after spraying produced no apparent difference in diuron toxicity. Those rates which were not different from each other were grouped by ranking the means in decreasing order and use of a LSD. Means having the same letter, in the lower center section of the table, did not differ from each other.

The results of the fertility by moisture level at the time of spraying by herbicide rate study with the analysis of variance are presented in Table 6. All values are expressed as percent of check and the treatment averages are presented in the center of the table. The rates were found to differ from each other but moisture at time of spraying had no effect in this experiment. High fertility had an average value which was 28.7% of check while pots without added fertilizer produced plants weighing 45.5% of their

Table 5. Milligrams of dry weight of Nugaines wheat sprayed with diuron using four moisture treatments.

Treatments			Blocks					
Sprayed	Watered	Rate	1	2	3	4	Avg.	
Wet	Initially	CK	910	1099	1066	1071	1036	
		0.1	1105	1078	1021	959	1041	
		0.2	959	1021	1032	1015	1007	
		0.4	837	791	986	914	882	
		0.6	654	876	781	787	777	
		1.0	194	417	258	187	264	
		2.0	122	127	151	202	150	736
	24 hrs.	CK	918	996	1217	987	1030	
		0.1	979	960	1015	1036	998	
		0.2	941	874	940	1076	958	
		0.4	801	847	820	402	718	
		0.6	593	852	752	793	748	
		1.0	237	430	251	139	264	
		2.0	133	87	69	23	78	685
Dry	Initially	CK	805	1034	922	1079	960	
		0.1	927	1060	1020	1038	1011	
		0.2	818	904	1038	879	910	
		0.4	791	814	868	871	836	
		0.6	715	675	767	766	731	
		1.0	492	453	283	165	348	
		2.0	205	124	116	104	137	705
	24 hrs.	CK	899	1071	1113	1089	1043	
		0.1	933	971	1071	1110	1021	
		0.2	950	1000	1038	1049	1009	
		0.4	749	707	890	852	800	
		0.6	571	676	677	807	683	
		1.0	406	320	329	132	296	
		2.0	103	115	92	85	99	707

Continued

Table 5. Milligrams of dry weight of Nugaines wheat sprayed with diuron using four moisture treatments--Continued.

Rate	Mean
CK	1017[a]
0.1	1018[a]
0.2	971[a]
0.4	809[b]
0.6	734[b]
1.0	293[c]
2.0	116[d]

$LSD_{.05}$ = 78.4 for rates

Analysis of variance

Source	df	MS
Total	111	
Blocks	3	24,841*
Treatments	27	476,179**
Rates	6	2,116,657**
Moistures	3	12,766
Rates x Moistures	18	6,583
Blocks x Treatment	81	8,141

$\bar{\bar{y}}$ = 708.3 s = 90.22 CV = 12.7%

Table 6. Milligrams of wheat expressed as percent of check from the fertility by moisture level at time of spraying by rate study and the analysis of variance.

Fertility	Moisture	Rate	Blocks 1	2	3	4	5	6	7	8	Avg.
Low	Dry	1.4	33.9	55.4	53.7	63.7	48.8	67.6	44.4	43.4	51.4
		2.0	31.8	43.3	44.8	40.4	37.0	37.6	31.4	38.7	38.1
	Wet	1.4	53.0	39.1	57.1	54.0	48.4	50.0	58.0	46.8	50.8
		2.0	45.4	39.7	43.5	29.9	47.5	42.7	32.7	52.2	41.7
High	Dry	1.4	25.2	30.4	39.0	42.9	26.7	42.7	24.2	25.4	32.1
		2.0	18.9	14.9	30.1	27.4	22.4	37.3	19.3	17.2	23.4
	Wet	1.4	38.2	28.8	38.5	34.1	22.0	44.0	29.4	20.1	31.9
		2.0	26.9	24.3	34.4	29.9	34.3	28.4	19.4	20.7	26.0

Rate	Avg.	Moisture	Avg.	Fertility	Avg.
1.4	41.5	Dry	36.2	Low	45.5
2.0	32.6	Wet	37.9	High	28.7

Continued

Table 6. Milligrams of wheat expressed as percent of check from the fertility by moisture level at time of spraying by rate study and the analysis of variance--Continued.

Analysis of variance

Source	df	MS
Total	63	
Blocks	7	161.52**
Treatments	7	855.79**
Rates	1	1,264.69**
Moisture	1	44.72
Fertility	1	4,530.97**
Rate x Moisture	1	66.63
Rate x Fertility	1	83.04
Moisture x Fertility	1	0.44
R x M x F	1	0.01
Blocks x Treatment	49	43.32

$\bar{\bar{y}} = 37.1$ $s = 6.58$ CV = 17.7%

check. This was an average difference of 16.8 units as compared to a difference of 8.9 units between 1.4 and 2.0 lbs/A rates. In this study increasing the fertility level increased injury to wheat as measured by percent of check. This needs more study as different fertility practices could influence the toxicity of diuron to wheat. It is doubtful if it matters whether diuron is sprayed on wet or dry soil at least when moisture is received within 24 hours.

EXPERIMENT III. THE EFFECT OF DIFFERENT SOIL MOISTURE LEVELS ON THE TOXICITY OF DIURON TO WHEAT

The soil is very wet in the Willamette Valley during the fall and winter, thus soil moisture was considered as a factor in the selective use of diuron. The two studies described in this section were designed to study the influence of soil moisture on diuron toxicity to Nugaines wheat.

Methods and Materials

In one study four rates of diuron, 0, 2, 3 and 4 ppmw, were added to batches of soil by spraying the diuron mixed with enough water to bring the soil to field capacity through a stationary nozzle in a soil tumbler. The same rates were added to another batch of soil with enough water to bring the soil to 80% field capacity which was 10.4% moisture content. Metal cans were filled with an equivalent of 1 kg oven-dry soil from the appropriate batches and were seeded to a depth of one-half inch. The cans were then covered with inverted clear pastic bags 6 in wide, 4 in deep and 16 in long which were secured to the cans with rubber bands. The bags were held open by three eight-inch pot labels placed inside the can wall and bags were not removed until harvest except for a few minutes when the stand was thinned. Moisture which condensed on the inside surface of the bags was returned to the soil daily by shaking the bags. The 80% field-capacity treatment had an expected moisture content of 10.4% at time of harvest but measured values showed it to vary from 8.2 to 8.5%. The 100% field-capacity treatment had an expected moisture content of 13.0% at harvest but actual measured content was 10.2 to 11.0%. The pots were treated and seeded November 13, grown on a glasshouse bench and harvested December 15, 1967. A randomized blocks design with eight blocks was used.

A second study was designed to see if the same results could be obtained where water was added daily and without the use of plastic bags. Moisture levels of 70, 85 and 100% field capacity were chosen. Soil was placed in metal cans, seeded to a depth of one-half inch and sprayed with diuron at rates of 0, 1.3, 1.8 and 2.3 lbs/A. Water was applied by overhead flooding to obtain the desired moisture content. Other procedures followed those described in the general methods section. A randomized blocks design with ten blocks was used. The pots were seeded and treated January 13, grown on a glasshouse bench and harvested February 15, 1968.

Results

The results of the experiment comparing two moisture levels and three rates are presented in Table 7 along with the statistical

Table 7. Milligrams of oven-dry weight expressed as percent of check from wheat grown at two soil moisture levels under plastic bags and the analysis of variance.

Field capacity	ppmw diuron	Blocks								Mean
		1	2	3	4	5	6	7	8	
100%	2	38.8	39.8	65.4	55.6	74.8	47.1	77.5	58.8	57.2
	3	22.9	24.9	10.8	13.2	13.3	11.8	12.1	11.3	15.0
	4	6.6	13.3	8.8	7.6	12.8	11.8	5.8	8.8	9.4
80%	2	89.2	86.0	104.6	88.0	103.9	110.6	90.8	79.4	94.1
	3	67.0	70.4	86.2	42.1	55.9	108.7	33.0	50.5	64.2
	4	79.5	48.9	71.3	47.0	46.4	73.1	37.4	58.0	57.7

ppmw	Mean	Field capacity	Mean
2	75.6	100%	27.2
3	39.6	80%	72.0
4	33.6		

Analysis of variance

Source	df	MS
Total	47	
Blocks	7	277.40
Treatments	5	8,195.43**
Moisture	1	24,044.18**
Rates	2	8,277.22**
Moisture x Rates	2	189.27
B x T	35	187.43

$\bar{\bar{y}} = 49.6$ $s = 13.69$ CV = 27.6%

analysis. Wheat was better able to survive in this soil when grown at 80% field capacity than at field capacity. Those plants grown at 80% field capacity weighed 72.0% of check compared to those grown at field capacity which weighed 27.2% of check.

Differences occurring between herbicide rates expressed as percent of check are the result of variation between rates of applied herbicide because each rate of a particular treatment level is compared to the same check. They are not compared in the analysis to plots which do not have a chemical application except each rate of chemical has reference to the particular check in its replication. At rates of 3 and 4 ppmw, wheat was almost completely deteriorated at harvest time when grown in soil maintained at field capacity; whereas, it weighed over 50% of check when grown in soil maintained at 80% field capacity. At 2 ppmw wheat weighed 94.1% of check from soil kept at 80% field capacity and was 57.2% of check from soil kept at field capacity. From this study it can be seen that soil moisture content has a very important effect on toxicity of diuron to wheat.

In order to support information gained in the first study and to determine if plastic bags influenced toxicity, a second study was performed with results presented in Table 8. The differences between means of moisture levels were not as wide as when grown under bags but the same trend was present. More injury occurred

Table 8. Dry weight expressed as percent of check from wheat grown at three soil moisture levels and the analysis of variance.

Field Capacity	lbs/A diuron	1	2	3	4	5	6	7	8	9	10	Mean
100%	1.3	28.3	19.2	19.4	14.4	17.9	17.4	19.2	17.1	18.9	16.7	18.8
	1.8	8.6	20.4	18.9	15.0	18.5	22.9	23.6	20.4	21.8	17.2	18.7
	2.3	12.0	21.7	18.0	20.9	18.0	22.9	16.8	24.4	14.1	16.7	18.6
85%	1.3	42.2	34.4	29.0	27.1	36.0	27.7	29.9	37.7	40.3	19.6	32.4
	1.8	27.9	29.4	34.6	26.3	20.2	28.1	24.3	30.0	32.4	20.2	27.3
	2.3	34.1	26.7	22.3	25.3	21.6	32.8	24.6	48.0	32.2	22.5	29.0
70%	1.3	39.4	18.9	30.3	29.0	30.2	28.0	50.6	26.2	24.4	26.8	30.4
	1.8	20.4	22.7	36.3	32.3	31.6	31.8	36.1	25.2	19.3	26.6	28.2
	2.3	30.9	28.3	28.8	32.1	13.3	22.6	23.1	17.3	32.5	28.3	25.7

Rate	Mean
1.3	27.2
1.8	24.8
2.3	24.4

Field Capacity	Mean
100%	18.7
85%	29.6
70%	28.1

Analysis of variance

Source	df	MS
Total	89	
Blocks	9	34.40
Treatments	8	291.05**
Moisture Levels	2	1,043.39**
70 vs 85%	1	32.41
70 + 85 vs 100%	1	2,054.36**
Rates	2	68.99
1.3 vs 1.8	1	89.30
M L X Rates	4	25.91
B X T	72	38.60

$\bar{\bar{y}}$ = 25.5 s = 6.21 CV = 24.4%

at field capacity than at 70 or 85% field capacity. There was no difference between the 70 and 85% levels. These differences may have been greater had the experiment been harvested earlier or the rates involved been lower as there were not any differences due to rates. However there appeared to be somewhat more difference between rates at 70 than 100% field capacity. It was concluded from these studies that increased soil moisture increases injury to wheat. These findings fail to give support for any hypothesis as to why diuron is selective in the fall. On the contrary it would work against selectivity in that the soil is usually at field capacity or higher through the winter and after spring seeding there would be more intermittent periods in which the soil would be drier. Two explanations are offered for more injury occurring at field capacity than at 70 or 85% field capacity. Water being a better competitor for adsorption sites than diuron would free more diuron which would then be available to go into the soil solution. Another suggestion which could work alone or in addition to the first is that as the soil becomes drier the salt concentration of the soil solution is higher forcing diuron out of solution to where it would become adsorbed to a surface or exist as an undissolved particle in the soil.

These results help explain why diuron injury occurs on low spots of the poorly drained soils in the area. In these situations wheat may be almost completely eliminated except for small skips made during diuron application. This would indicate that diuron should be used with care at a reduced rate, if at all, on these areas.

EXPERIMENT IV. STUDIES DESIGNED TO INDICATE THE EFFECT OF LIGHT ON DIURON TOXICITY TO WHEAT

Several previous observations have indicated that light has an influence in the expression of diuron injury to wheat. At similar rates more injury occurred during summer months than during the fall. Atmospheric temperature also changes between these two seasons, but this is a function of light intensity. Therefore the following studies were designed to ascertain what the role of light intensity might be.

Methods and Materials

Controlled-environment chambers were not available so a plywood box with eight chambers (Plate II) was built on a glasshouse bench with chamber dimensions of 2 by 2 by 2 feet. The chambers were open at the top and wide-spectrum gro-lux tubes with 10% incandescence were the light source. An area above the chambers was enclosed with black polyethylene and fans were provided for cooling of the lamps and ballasts. The design was a split-plot with four blocks using light intensity as the main-plots and rates as subplots. Because all of the high light was in chambers on one side with the low light in chambers on the opposite side true randomization of main-plots within blocks was not achieved. This should be

Plate II. Chambers used in light intensity studies.

considered when looking at the analysis since calculations were made as if all main-plots were random. The insides of the chambers were lined with aluminum foil and light readings at the soil surface were 1600 ft-c under high light and 500 ft-c under low light. The temperature inside the chamber was primarily controlled by the environment inside the glasshouse room. On bright days the temperature went as high as 28 C with the high-light chambers being as much as 2 C above the low-light chambers. The majority of the days were cloudy and on these days temperature was 25 C with no more than 1 C variation between high and low light. Plants were grown under 12 hours of light. Seeds were planted one-half inch deep and sprayed with diuron at 0, 0.6, 1.1 and 1.6 lbs/A. The stand was thinned to seven plants per pot and three pots of each treatment were used to give a better estimate of the means used in calculating percent of check. The pots were placed in water baths and seeds germinated at 20 C, then placed in the light chambers after emergence and rotated daily within each chamber. The study was seeded and treated January 9 and harvested February 10, 1968.

A second study planted May 31, treated June 14 and harvested June 24, 1968 was designed similar to the first except seeds were planted in 30-mesh washed quartz sand. The plants were watered with a nutrient solution twice weekly and a measured amount of water was added daily with the moisture content being equalized by weighing at least once a week. The lights used were the same as above but the intensity was 1100 ft-c on the high side, 400 ft-c on the low side and day length was 13 hours with 11 hours night. Four pots per treatment were used in blocks 2 and 4 but poor emergence left only three pots per treatment in blocks 1 and 3. In the analysis it was assumed that three pots was as good an estimate of the mean as four pots which in reality is not true. Plants were germinated in the chambers and treated with 0, 10 and 15 ppbw diuron. Temperatures were much more difficult to maintain at this season and were dominated by the water cooler within the glasshouse room. Chamber temperatures were lower when the cooler was running than when it was off. Chamber temperature differences were constant except for short periods when the cooler was off, then it was as much as 3 C higher under high light. During the last four days of the experiment temperatures in the chambers climbed to 31 C under low light and 34 C under high light for three to four hours per day even when the cooler was operating. On cloudy days the temperature was 27 C, and all night temperatures were 20 C.

Results

The results of the light by diuron-rate experiment with plants grown in soil are presented in Table 9. Plants grown under 1600 ft-c of light produced injury symptoms earlier than those growing under 500 ft-c and as measured by percent of check had more injury at the time of harvest. Dry weights of plants grown under high light were 23.7% of check while those grown under low light were 30.3% of check for a difference of 6.6 units. There was a difference in rates with the most injury occurring at 1.6 lbs/A, but the mean of 1.1 showed less injury than the mean of 0.6 lbs/A; however, these two were not different from each other. Differences due to light may have been greater had the experiment been harvested prior to the time that marked visual injury occurred to plants under low light.

The soil dried faster under high than low light so the second study was grown in a sand culture to minimize effects of soil

Table 9. Dry weights as percent of check from wheat grown in soil under two light intensities with the analysis of variance.

Ft.-candles light	lbs/A diuron	Blocks 1	2	3	4	Avg.
1600	0.6	28.0	20.8	27.5	30.1	26.6
	1.1	28.3	25.8	26.2	21.4	25.4
	1.6	19.3	16.8	19.6	20.5	19.0
500	0.6	39.5	27.9	28.0	28.1	30.9
	1.1	41.7	28.1	37.2	29.9	34.2
	1.6	29.0	23.6	24.5	25.7	25.7

Light intensity	Mean	lbs/A diuron	Mean
1600 ft-c	23.7	0.6	28.7
500	30.3	1.1	29.8
		1.6	22.4

Analysis of variance (on a sub-plot basis)

Source	df	MS
Total	23	
Main-plots:		
Blocks	3	53.78
Light	1	259.38*
B x L	3	17.17
Sub-plots:		
Rates	2	129.56**
R x L	2	10.25
(error)	12	8.78

Main-plots: s = 4.14 CV = 15.3%

Sub-plots: s = 2.96 CV = 11.0%

moisture tension. The results of this study are presented in Table 10 with the analysis of variance. In this study both light intensities were lower than in the first study. The ratio of the difference was approximately 3.2:1 in the first and 2.75:1 in the second study for high vs low light intensity. Plants weighed 43.3% of check under high light and 56.4% of check under low light for a difference of 13.1 units. It is possible that because plants were grown in sand, more injury between light levels was noted indicating more moisture availability under high light. Less difference in light intensity with lower total intensity would make it reasonable to assume that less difference should occur than in the first study but the opposite occurred. In this study plants were harvested when dry weights averaged about 50 instead of 27% of check and atmospheric temperatures were more variable and higher than in the first. It is not known why more injury occurred in blocks 1 and 2 than in 3 and 4; however, 3 and 4 were closer to the cooler and temperature was recorded in block 2. Periodic checks did not reveal differences of more than 2 C between blocks. There was not any difference between 10 and 15 ppb. Evidently at these rates the herbicide was present in large enough quantities that 50% more diuron had only a small added effect. No definite conclusions can be drawn from these studies because of the limited control of temperature and other environmental factors. It is probable that in a controlled-environment chamber differences

Table 10. Milligrams of dry weight as percent of check from wheat grown in 30-mesh sand under two light intensities with the analysis of variance.

Ft. -candles light	ppbw diuron	Blocks 1	2	3	4	Avg.
1100	10	33.8	33.6	57.1	54.7	44.8
	15	33.0	37.1	46.1	50.8	41.8
400	10	55.3	46.9	68.1	68.2	59.6
	15	50.7	45.5	52.9	63.7	53.2
Block avg.		43.2	40.8	56.0	59.4	49.8

Ft -c light	Mean	ppbw diuron	Mean
1100	43.3	10	52.2
400	56.4	15	47.5

Analysis of variance (on a sub-plot basis)

Source	df	MS
Total	15	
Main-plots:		
Blocks	3	340.36*
Light	1	690.37*
B x L	3	21.66
Sub-plots:		
Rates	1	89.75
R x L	1	11.42
(error)	6	18.43

Main-plots: s = 4.65 CV = 9.3%
Sub-plots: s = 4.29 CV = 8.6%

in injury due to light intensity would be obtained. Visual symptoms of the second study showed a complete whitening of patches on the leaves of plants growing under high light while on plants under low light the whitening was not present but the leaf edges were curled. Certainly more study on the effect of light intensity is required to explain its effect on diuron toxicity in fall-planted wheat.

EXPERIMENT V. THE EFFECT OF FULL SUNLIGHT ON WHEAT AFTER 12 DAYS EXPOSURE TO DIURON UNDER LOW LIGHT CONDITIONS

The influence of light noted in Experiment IV may result from an effect on transpiration and the rate of upward movement of diuron to the site of action. It would be desirable to know if light has an influence other than on transpiration. Light has been shown to be necessary for the expression of toxicity symptoms of monuron (31) and indications in these studies show that it also is important for the expression of diuron symptoms. This study was designed to show the effect of one day exposure to full sunlight following growth for several days under low light intensity. It was assumed that equal uptake between pots would occur under these conditions and that exposure of one-half of the pots to full sun would show the effect of high light intensities. This would necessitate disregarding any additional uptake that would occur under high light because of increased transpiration during the one day exposure.

Methods and Materials

Nugaines wheat was planted one-half inch deep in 16 pots May 30, sprayed with diuron at rates of 0 and 1 lb/A and placed in a growth chamber after emergence June 3, 1968. The cans were divided into four treatments with 0 and 1 lb/A (1000 Ck and 1000 1 lb) rates remaining under low light on the day of exposure while 0 and 1 lb/A (Sun Ck and Sun 1 lb) rates were exposed to full sunlight for one day. The environmental conditions within the chamber were a 12-hour day and night with 20 C day and 15 C night temperature. The light measured three inches above the soil surface was 1000 ft-c. On June 15, 1968 when visual symptoms were beginning to occur the sun treatments were set outside in full sunlight (12, 000+ ft-c) for an eight-hour period. They were then taken inside, pictures taken and harvested at 7 pm. A randomized blocks design was used with four blocks.

Results

The fresh weights and analysis of variance are presented in Table 11. The differences due to treatments may be mainly attributed to the effect of adding 1 lb/A diuron, as can be seen in the contrast comparing checks with diuron treated pots. Comparing the 1 lb/A rate of those plants left in the growth chamber with the same rate exposed to full sun did now show a statistical difference. The F value with 1 and 9 degrees of freedom of 4. 23 was less than the expected F at the 5% level of 5. 12. This was the case even though the mean of those plants treated with diuron and left in the growth chamber was almost 50% greater than the mean of diuron-treated plants exposed to full sun. From the dry weights presented

Table 11. Milligrams of fresh weight and the analysis of variance from the experiment to determine the effect of exposing wheat to eight hours full sunlight following diuron uptake under low light.

	Blocks				
Treatment	1	2	3	4	Avg.
1000 CK	1286	1341	1326	1348	1325
1000 1 lb	1010	784	979	837	902
Sun CK	1239	1154	1120	1340	1213
Sun 1 lb	846	503	964	273	646

Analysis of variance

Source	df	MS
Total	15	
Blocks	3	29, 515.42
Treatments	3	378, 423.42**
1000 1 lb vs Sun 1 lb	1	131, 072.00
1000 CK vs Sun CK	1	25, 088.00
Cks vs 1 lb/A	1	979, 110.25**
B x T	9	31, 015.25

$\bar{\bar{y}}$ = 1021.9 s = 176.1 CV = 17.2%

in Table 12 it can be seen that in this sample the Sun 1 lb weighed more than the 1000 1 lb which means that fresh weights for the Sun 1 lb were in part heavier due to greater dry weight. The same relationship is true for the checks indicating that exposure to the outdoor environment reduced fresh weight of plants not receiving diuron although these differences were not significant. The visual ratings in Table 12 show that there was 50% injury in block three of the Sun

Table 12. Milligrams dry weight and percent visual injury from the experiment to determine the effect of exposing wheat to eight hours full sunlight following diuron uptake under low light.

Treatment	Blocks 1	2	3	4	Avg.
1000 CK	173	183	182	179	179
1000 1 lb	107	60	111	90	92
Sun CK	189	176	175	202	186
Sun 1 lb	128	92	155	67	110
		Percent visual injury			
1000 CK	0	0	0	0	0
1000 1 lb	30	20	10	10	17.5
Sun CK	0	0	0	0	0
Sun 1 lb	80	90	50	95	78.8

1 lb pot. This pot had a fresh weight almost equivalent to the 1000 1 lb pot and this helps explain why significant differences were not noted. There was a wider range in fresh weights of treated plants receiving full sun than of treated plants remaining in the growth chamber indicating that light intensity has a strong influence in the death of wheat. In other studies it was noted that treated plants died at various rates during the stage of greatest herbicide activity. Sometimes there would be a single green plant left in a pot.

Based on the assumption that these pots had obtained equal uptake of diuron, it can be seen (Plate III) that plants growing under cloudy conditions in the fall then receiving one or more days of full sunlight can develop injury symptoms almost overnight. The checks which went into the sun for one day were broken over by the wind. It is concluded that light plays a definite role in the expression of toxicity symptoms and that it has a role in the action of diuron other than its effect on transpiration.

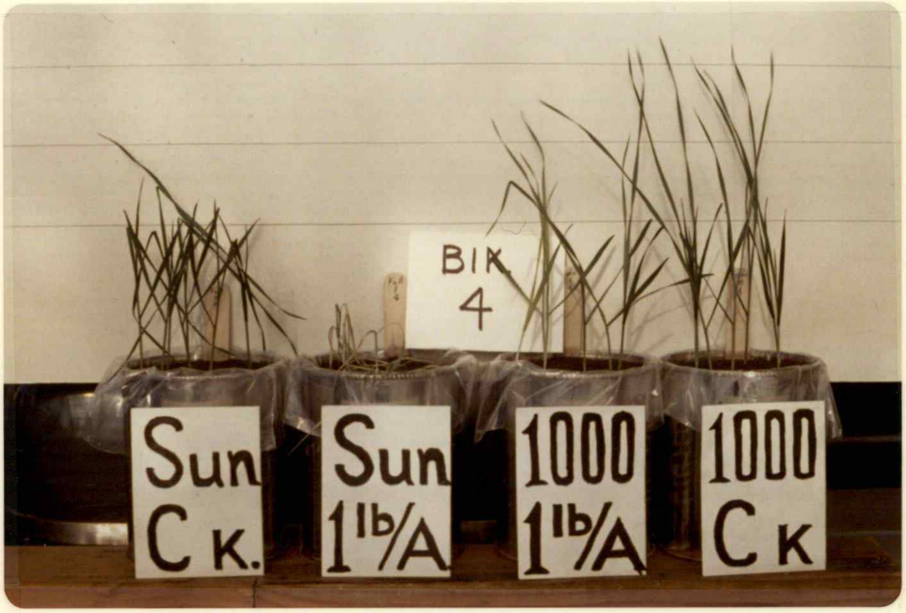

Plate III. Effect of full sunlight on wheat after 12 days exposure to diuron under low-light conditions.

EXPERIMENT VI. THE INFLUENCE OF PLANTING DATE ON DIURON TOXICITY TO WHEAT

This experiment was planned to compare planting dates in the late summer with those in late fall. This would provide more information concerning variation of toxicity in the fall as compared to the original concept that diuron is selective only in the fall. Establishing a date to begin spraying in the fall may be as important as not applying diuron in the spring. The plantings were started in August to provide summer climatic influence.

Methods and Materials

An area was chosen one mile east of Corvallis on the University's East Farm. The soil was a Chehalis loamy sand with characteristics given in Table 1. Nugaines wheat was planted with a Planet Jr. at approximately three-week intervals on the dates given in Table 13. An application of 52 lbs N and 86 lbs P per acre was watered into the soil at the beginning of the experiment. The area was irrigated (Table 13) prior to the first seeding and after each herbicide application as needed until sufficient moisture was available from fall rains. Plots 8 by 25 feet with 8 rows spaced 12 inches apart were sprayed pre-emergence with diuron at rates of 0, 1.5, 3.0 and 6.0 lbs/A. A randomized blocks design having four blocks was used. Plots were placed into blocks based on terrain

Table 13. Seeding, emergence, sampling and irrigation information.

	Dates					
No.	Seeded	Emerged	First sample	Second sample	Irrigation	Inches
1	8/19/67	8/23/67	9/12/67	10/3/67	8/16/67	3.0
2	9/11	9/16	10/7	10/30	8/19	2.5
3	9/30	10/7	10/30	11/23	8/26	2.5
4	10/20	10/28	11/25	12/20	9/4	2.5
5	11/11	11/22	12/23	1/19/68	9/11	2.5
6	12/1	12/28	1/24/68	2/20	9/15	1.5
					9/16	1.5
					9/30	1.5

with lower elevation plots being grouped into block three. Serious flooding during the later dates made it necessary to eliminate block three from the analysis; however, it is included in the visual observations. We planned to take samples three and six weeks after emergence but the actual days of growth following emergence to the time of sampling are presented with the results. In the later planting dates more time elapsed prior to sampling so more growth could occur. The center six rows were the basis for drawing the sample with two rows being randomly selected per plot per sampling date. Rows sampled the first date were not subject to sampling on the second date. Eight one-foot sections (sampling units) were taken from two rows with the centers of the sampling units being 5, 10, 15 and 20 feet along the row. Green and dying plants were clipped at ground level with total forage harvested from each plot pooled to give the total grams collected per plot on each sampling date. The number of green plants in the eight one-foot sampling units were recorded for the first sampling date. Soil temperature at two locations about ten feet apart in the center of the area was recorded at depths of 1, 3 and 6 inches.

Results

Table 14 gives the dry weights as percent of check from the first sampling date and the age of plants in days from emergence to harvest. The data show less injury at the last three compared with the first three planting dates. This can be seen in the contrasts which show that date four differs from the first three dates and from date five. More injury occurred in date five after 31 days growth than in date six with 27 days growth. Also included in this table is a comparison of date means by use of a LSD where those means which do not have the same letter are different. The analysis fails to reveal any differences due to the rate of herbicide but in all cases injury appeared slower at 1.5 with negligible difference in rate of symptom development between 3.0 and 6.0 lbs/A diuron. Visual measurements of wheat injury at the time of the first sampling are presented in Table 15. These observations indicated the same trend as weight measurements except no decrease in injury was noted for date four over the first three dates.

Table 14. Dry weights as percent of check from the first sampling of the field experiment and the analysis of variance.

Planting date	Days old when harvested	lbs/A diuron	Blocks 1	Blocks 2	Blocks 4	Avg.	Date	Mean	Rate	Mean
1 8/19/67	21	1.5	40.7	8.9	12.4	20.7	1	9.6[a] 1/	1.5	45.5
		3.0	4.4	5.1	4.1	4.5	2	9.9[a]	3.0	41.2
		6.0	4.9	2.5	3.0	3.5	3	8.6[a]	6.0	28.2
							4	32.6[b]		
2 9/11	21	1.5	28.9	17.0	29.3	25.1	5	69.5[c]		
		3.0	1.2	1.1	10.7	4.3	6	99.7[d]		
		6.0	1.2	0.0	0.0	0.4	Avg.	38.3		
3 9/30	23	1.5	10.3	17.2	19.0	15.5				
		3.0	6.9	6.9	2.4	5.4				
		6.0	3.4	6.9	4.8	5.0				
4 10/20	28	1.5	23.3	50.0	60.0	44.4				
		3.0	23.3	35.0	30.0	29.4				
		6.0	16.7	25.0	30.0	23.9				
5 11/11	31	1.5	71.2	61.9	47.6	60.2				
		3.0	73.8	77.8	121.4	91.0				
		6.0	47.5	81.0	42.9	57.1				
6 12/1	27	1.5	100.0	132.0	88.9	107.0				
		3.0	77.3	72.0	188.9	112.7				
		6.0	109.1	68.0	61.1	79.4				

Continued

Table 14. Dry weights as percent of check from the first sampling of the field experiment and the analysis of variance--Continued.

Analysis of variance

Source	df	MS
Total	53	
Blocks	2	194.43
Treatments	17	4,238.82**
Dates	5	13,110.49**
1 + 2 + 3 vs 4	1	3,636.60**
4 vs 5 2/	1	6,116.18**
5 vs 6 2/	1	4,116.27**
Rates	2	1,455.46*
1.5 vs 3.0	1	161.93
3.0 vs 6.0	1	1,524.90
D x R	10	359.65
B x T	34	439.12

s = 20.96 Avg. = 38.3 CV = 54.6%

1/ Means with same letters are not different.

2/ Not orthogonal.

Table 15. Percent injury to Nugaines wheat as measured by visual observation at the time of the first sampling of the field experiment.

Planting date	lbs/A diuron	Blocks 1	2	3	4	Mean
1	CK	0	0	0	0	0
(21 days	1.5	40	99	90	60	72
old)	3.0	95	100	100	99	98
	6.0	99	100	99	100	100
2	CK	0	0	0	0	0
(21 days	1.5	60	60	70	50	60
old)	3.0	99	99	90	90	94
	6.0	99	99	99	99	99
3	CK	0	0	0	0	0
(23 days	1.5	90	90	80	60	80
old)	3.0	99	90	95	95	95
	6.0	99	95	99	99	98
4	CK	0	0	0	0	0
(28 days	1.5	70	70	70	60	68
old)	3.0	90	90	80	90	88
	6.0	95	95	95	95	95
5	CK	0	0	60 1/	0	15
(31 days	1.5	10	20	10	10	12
old)	3.0	20	20	40	20	25
	6.0	40	30	40	30	35
6	CK	0	0	0	0	0
(27 days	1.5	10	10	10 1/	10	10
old)	3.0	10	10	10 1/	10	10
	6.0	20	20	20	10	18

1/ Flooded.

At the time of the second sampling the situation was somewhat different as can be shown by the data presented in Table 16. This change was not as great for the first three dates as for the last three. Date four had serious injury but not as marked as the first three dates, when first sampled. When sampled the second time it was not distinguishable from the first three dates. Both dates five and six decreased as percent of check but the largest decrease occurred in date six. This was almost equivalent to the check when first sampled but with the second sampling showed more injury than date five. Date six was extremely slow in emerging during the cold weather and was subjected to high amounts of rainfall. This date does not appear to be a favorable time to plant wheat because the checks did not produce satisfactory growth. Comparisons in the analysis of variance show the first four differed from the last two dates and that date five differed from date six. Also by the time of the second sampling a difference was obtained in rates showing less injury at 1.5 than 3.0 with no difference between 3.0 and 6.0 lbs/A. Also included in Table 16 is a LSD test where means with different letters are considered different populations. Both sampling dates had very large coefficients of variation. Percent injury by visual observation of the second sampling is given in Table 17. These observations also include block three which had serious flooding of plots in date five. The observations made show the same results

Table 16. Dry weights as percent of check from the second sampling of the field experiment and the analysis of variance.

Planting date	Days old when harvested	lbs/A diuron	Blocks 1	2	4	Avg.
1	42	1.5	42.0	0.0	25.6	22.5
8/19/67		3.0	0.0	0.0	0.0	0.0
		6.0	0.0	0.0	0.0	0.0
2	45	1.5	11.5	9.4	45.4	21.9
9/11		3.0	0.0	0.0	2.5	0.8
		6.0	0.0	0.0	0.0	0.0
3	47	1.5	3.6	0.9	21.4	8.6
9/30		3.0	0.0	0.9	1.4	0.8
		6.0	0.0	0.0	0.0	0.0
4	53	1.5	9.1	30.3	33.3	24.2
10/20		3.0	0.0	0.0	3.7	1.2
		6.0	0.0	0.0	0.0	0.0
5	58	1.5	40.1	69.6	145.3	85.0
11/11		3.0	27.4	43.5	83.0	51.3
		6.0	19.1	47.0	37.7	34.6
6	53	1.5	85.4	45.4	60.3	63.7
12/1		3.0	27.1	6.2	20.6	18.0
		6.0	1.0	3.1	0.0	1.4

Date	Mean
1.	7.5[a] 1/
2	7.6[a]
3	3.1[a]
4	8.5[a]
5	57.0[b]
6	27.7[c]
Avg.	18.6

Rate	Mean
1.5	37.7
3.0	12.0
6.0	6.0

Continued

Table 16. Dry weights as percent of check from the second sampling of the field experiment and the analysis of variance--Continued.

Analysis of variance

Source	df	MS
Total	53	
Blocks	2	890.64
Treatments	17	1,921.47**
Dates	5	3,852.11**
5 vs 6	1	3,860.28**
1 + 2 + 3 + 4 vs 5 + 6 2/	1	15,243.94**
Rates	2	5,093.87**
1.5 vs 3.0	1	5,923.27**
3.0 vs 6.0	1	326.40
D x R	10	321.68
B x T	34	280.40

Avg. = 18.6   s = 16.74   CV = 90%

1/ Means with same letters are not different.
2/ Not orthogonal.

Table 17. Percent injury to wheat as measured by visual observation at the second sampling of the field experiment.

Planting date	lbs/A diuron	Block 1	Block 2	Block 3	Block 4	Mean
1	CK	0	0	0	0	0
	1.5	50	99	90	70	77
	3.0	100	100	100	100	100
	6.0	100	100	99	100	100
2	CK	0	0	0	0	0
	1.5	80	70	70	50	68
	3.0	100	100	99	99	99
	6.0	100	100	100	100	100
3	CK	0	0	0	0	0
	1.5	99	95	90	90	94
	3.0	100	99	99	99	99
	6.0	100	100	100	100	100
4	CK	0	0	0	0	0
	1.5	99	80	90	50	80
	3.0	100	100	99	95	98
	6.0	100	100	100	99	100
5	CK	0	0	80 1/	0	20
	1.5	40	50	50	40	45
	3.0	60	60	80 1/	60	65
	6.0	70	60	60	80	68
6	CK	0	0	0	0	0
	1.5	50	30	90	40	52
	3.0	99	95	99	90	96
	6.0	99	95	100	100	98

1/ Flooded.

obtained by taking plant weights.

Table 18 records the number of green plants expressed as percent of check. The means follow the same trend as weights from the first sampling date. There were more green plants per sampling unit as compared to the check at the last two dates than the first four. Also the fourth date would appear to have more plants than the first three dates but these differences were not subjected to a statistical test.

The maximum and minimum soil temperatures from the 1, 3 and 6 inch depth are illustrated in Figure 1. Arrows at the bottom of the figure indicate the date on which the various plantings emerged and data are available for those days which are connected by solid lines. As would be expected there was more variation between maximum and minimum at the one-inch depth with the least variation occurring at the six-inch depth. The same general downward trend appeared at all three depths as the season progressed. Dates of planting comparisons to influence of soil temperature show that maximums for the one-inch layer had dropped below 20 C by emergence of date four. Also maximums were below 15 C by emergence of date five and through date six. The maximum in the three-inch depth was generally below 15 C after emergence of date four and 10 C after emergence of date five. The minimum follows the same general trend and differed less from the maximum later in the season.

Table 18. Number of green plants expressed as percent of check.

Planting date	lbs/A diuron	Blocks 1	2	3	4	Mean
1	1.5	57.2	9.9	16.7	67.1	37.7
	3.0	7.8	16.9	8.9	23.3	14.2
	6.0	2.4	0.0	2.6	0.0	1.2
2	1.5	81.7	39.8	47.5	48.4	54.4
	3.0	3.7	4.8	22.0	24.2	13.7
	6.0	6.1	2.4	11.9	0.0	5.1
3	1.5	19.4	25.9	54.0	28.9	32.0
	3.0	26.9	22.4	19.0	6.0	18.6
	6.0	6.0	15.5	12.7	13.3	11.9
4	1.5	76.3	83.8	56.5	114.5	82.8
	3.0	63.6	62.5	38.3	59.2	55.9
	6.0	50.8	28.8	49.6	51.3	45.1
5	1.5	101.0	75.3	181.2	64.7	105.6
	3.0	100.0	98.9	100.0	135.3	108.6
	6.0	74.5	105.6	133.3	67.6	95.2
6	1.5	103.4	120.9	70.6	71.4	91.6
	3.0	94.9	65.1	52.9	239.3	113.0
	6.0	149.2	100.0	58.8	117.9	106.5

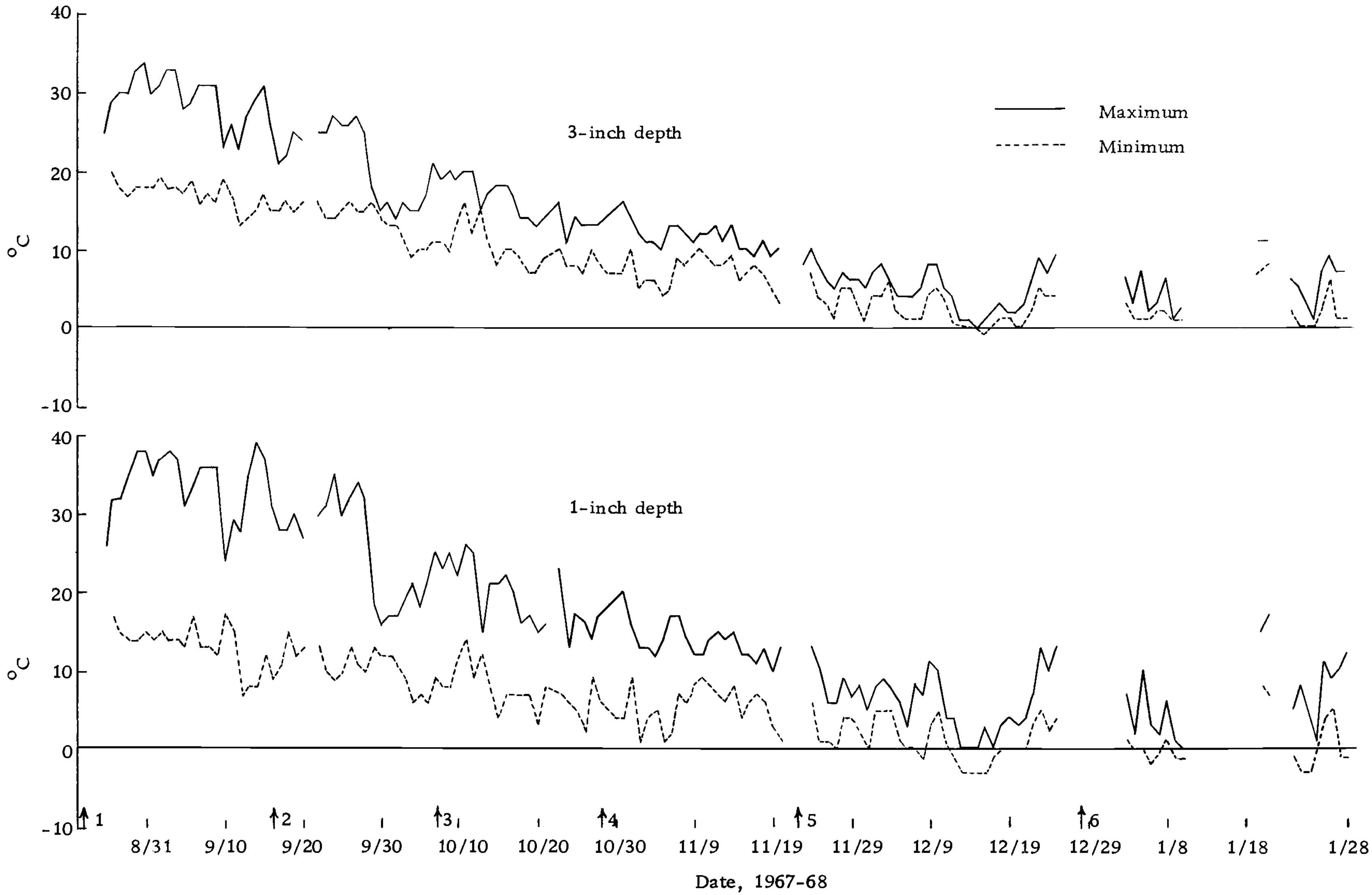

Figure 1. Maximum and minimum soil temperatures from 1, 3 and 6-inch soil depths.

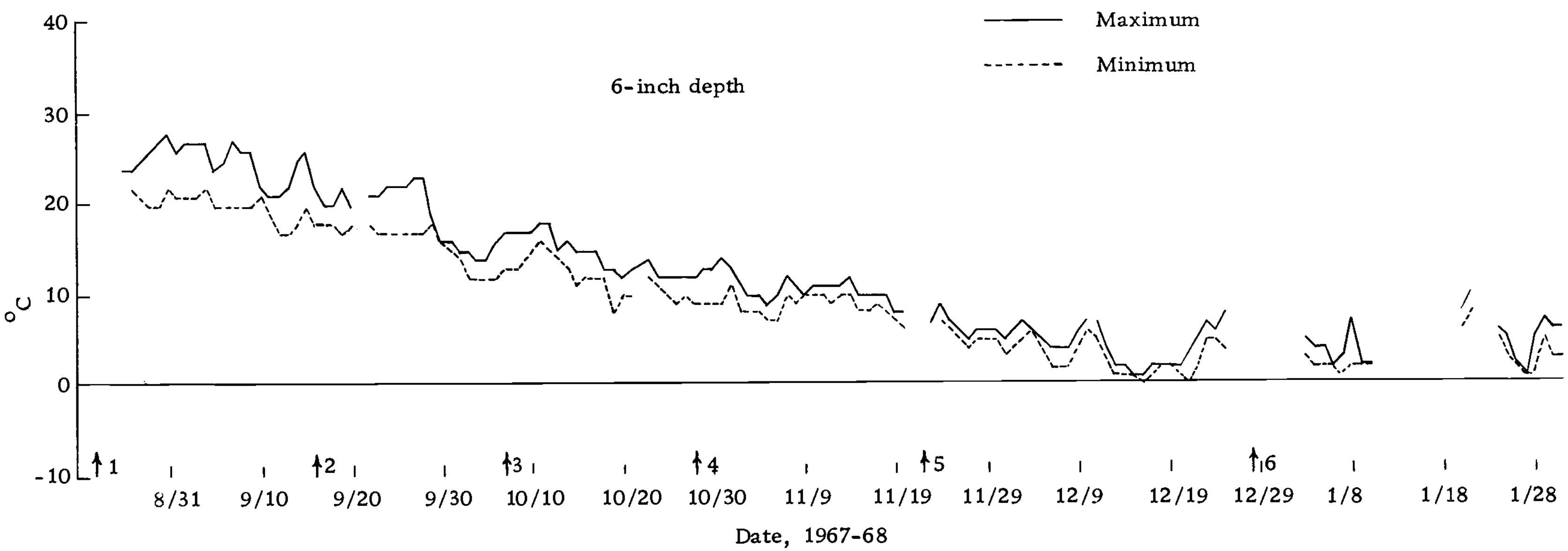

Figure 1 (continued). Maximum and minimum soil temperatures from 1, 3 and 6-inch soil depths.

Temperatures 0 C or below were recorded two days at the six-inch depth, ten days at the three-inch depth and 28 days at the one-inch depth.

Injury from the rate used was much higher than expected; as 1.6 lbs/A is the commercial recommendation in the Willamette Valley. Part of the reason for higher injury may be because this soil has a high sand and low organic matter content. The later dates were not planted over 3/4-inch deep because the Planet Jr. did not penetrate the firmer seedbed. When the soil was wet adequate coverage of seed was not uniformly obtained. Two of the 1.5 lbs/A plots from the first date had about a 40% stand, while other sprayed plots were almost bare the following spring. These may have escaped due to deeper planting in the soft soil of the first planting date. Less injury noted, when the second samples were taken, for date five and six over the first four dates had disappeared by spring.

One conclusion of this experiment is that differences in wheat injury occurs as a result of the time of year in which wheat is planted and sprayed pre-emergence. Injury can occur in any season at excessive rates, but at the same rate injury from late summer or early fall planting is more likely to occur than when planted in late fall or early winter. Later planting dates seemed to slow herbicidal action. It appeared likely that at lower rates there would be a point where wheat planted and sprayed later would escape while that with earlier treatment would show injury.

It was suspected from this study that Nugaines may be more sensitive to diuron than Druchamp and that the reason some of the plots had partial escape from injury was because of variation in depth of planting. Nugaines is a new introduction and is receiving its first commercial use in Oregon. Records are not available, but it is strongly suspected that the reason wheat did not become established in late planted plots sprayed with diuron was due to shallow planting. These two factors are considered further in Experiments VII and IX.

EXPERIMENT VII. COMPARATIVE TOXICITY OF DIURON TO NUGAINES AND DRUCHAMP WHEAT

Injury in the field experiment (VI) was greater than expected and raised the question whether Nugaines was more sensitive to diuron than Druchamp, which is a commonly used variety in the Willamette Valley. Nugaines was introduced to Oregon in 1967 from Washington without herbicide research or commercial experience. The two studies in this section were designed to determine if Nugaines and Druchamp differ in their sensitivity to diuron.

Methods and Materials

Seven seeds per pot were planted on December 4, 1967 in plastic pots having holes in the bottom and containing 800 grams oven-dry soil. The plants were thinned to five per pot except some of the Druchamp pots had three or four plants resulting from poor germination. The pots were sprayed with 0, 0.75, 1.00, 1.25 and 1.50 lbs/A diuron. Plants were grown on a glasshouse bench, supplemented with fluorescent light during the day and harvested January 10, 1968. A randomized blocks design with five blocks was used.

A similar study using ten seeds per pot with the resulting stand thinned to seven plants following emergence was conducted. The experiment was seeded and sprayed with diuron at rates of 0, 1.5

2.0 lbs/A on January 18 and harvested February 17, 1968. Plants were grown on a glasshouse bench without supplemental light and a randomized blocks design with eight blocks was used.

Results

The means in Table 19 show that Nugaines averaged 53.2 while Druchamp averaged 64.5% of check indicating that Nugaines is more sensitive to diuron. The same relationship was true at all rates of herbicide; except, they were almost equal as measured by percent of check at 1.25 lbs/A diuron. Definite conclusions cannot be drawn from this study because of poor emergence of Druchamp, and because the checks in some blocks weighed less than expected.

The second study was performed to help decide if the injury differences noted in the first study were actually varietal differences. There was not any difference in the means of 1.5 and 2.0 lbs/A diuron as can be seen in Table 20; however, Druchamp again had less injury as measured by percent of check than Nugaines. It is concluded from these two studies that Druchamp and Nugaines differ in their sensitivity to diuron. It certainly requires further investigation because with the narrow margin of safety in using diuron selectively in wheat a change in variety could produce drastic results, especially on sandy soils.

Table 19. Milligrams of dry weight expressed as percent of check from the first variety study and the analysis of variance.

Variety	Rate	Blocks 1	2	3	4	5	Mean
Nugaines	0.75	51.2	59.5	58.9	83.0	80.4	66.5
	1.00	40.1	49.1	58.0	54.8	59.3	52.3
	1.25	56.0	48.8	50.7	34.4	51.2	48.2
	1.50	46.4	53.3	46.4	46.4	35.5	45.6
Druchamp	0.75	62.0	63.7	107.6	100.3	93.0	85.4
	1.00	39.1	46.3	98.6	61.8	95.5	68.2
	1.25	44.3	38.2	72.5	31.6	63.1	50.1
	1.50	45.1	36.3	61.6	64.2	64.3	54.2

Variety	Mean	Rate	Mean
Nugaines	53.2	0.75	76.0
Druchamp	64.5	1.00	60.3
		1.25	49.1
		1.50	50.0

Analysis of variance

Source	df	MS
Total	39	
Blocks	4	791.61**
Treatments	7	915.24**
Varieties	1	1,273.51*
Rates	3	1,564.66**
V x R	3	146.40
B x T	28	178.31

Table 20. Milligrams of dry weight expressed as percent of check from the second variety study with the analysis of variance.

Variety	lbs/A diuron	Blocks 1	2	3	4	5	6	7	8	Avg.
Nugaines	1.5	38.9	33.4	30.4	23.7	36.8	52.6	40.6	31.9	36.0
	2.0	20.1	39.7	26.1	33.1	27.1	39.7	26.2	38.0	31.2
Druchamp	1.5	48.0	41.8	45.1	44.7	56.1	55.6	37.6	41.2	46.3
	2.0	33.1	26.9	43.4	33.6	39.0	39.8	61.3	43.1	40.0

Variety	Mean	Rate	Mean
Nugaines	33.6	1.5	41.2
Druchamp	43.1	2.0	35.6

Analysis of variance

Source	df	MS
Total	31	
Blocks	7	74.16
Treatments	3	323.10*
Varieties	1	722.00**
Rates	1	243.10
V x R	1	4.21
B x T	21	67.89

s = 8.24 CV = 21.5%

EXPERIMENT VIII. TOXICITY TO WHEAT IN RELATION TO DIURON PLACEMENT AND SITE OF UPTAKE.

Species differ in their site of herbicide uptake and herbicide placement can be very important in gaining selectivity. It is therefore necessary to know the principal site of absorption of diuron by wheat. The objective of this study was to determine if diuron is taken up through the roots or the emerging cleoptile and to study the importance of proximity of the herbicide to the seed. Two levels of herbicide were included to study the influence of a narrow concentrated layer versus a wider dilute layer.

Methods and Materials

The methods used were similar to those described by Nishimoto (36, p. 22). The soil was sprayed with water and herbicide plus water as it was being mixed in a soil tumbler. This produced three batches of field-capacity soil containing 0, 4 and 8 ppm diuron which were the stock soil used to make the desired treatment layering in metal cans. Twelve treatments which were combinations of two rates (4 and 8 ppm) and four layers (A-D in descending order with A being the top layer) are shown in Table 21. The layers contained 100 g oven-dry soil which at field capacity weighed 113 g and were approximately 2/3-inch thick. Seeds were planted between layers B and C at a depth of 1.3 inches. Cans were then covered with clear plastic bags held open with three pot labels placed on the inside edge of the cans. No additional moisture was applied. It was assumed that little or no movement between layers would occur from herbicide diffusion. The seed did not have a buffer of untreated soil when layers B or C or both were treated. A randomized blocks design having six blocks was chosen and the pots were placed on a bench November 10 and harvested December 7, 1967. The plants received supplemental flourescent light during the day.

Results

A summary of the results and the analysis of variance are presented in Table 21. Those comparisons of primary interest are presented as individual degrees of freedom comparisons in the table. Also comparisons, obtained by ranking treatment means in decreasing order and separating into similar groups by use of a $LSD_{.05}$, are presented in the table with those means having the same letter belonging to the same group. A comparison of treatment means exposed to shoot uptake versus root uptake show that much more injury occurred where only the roots were exposed to diuron. In addition, a comparison of all treatments having only shoot exposure with the check failed to offer evidence for shoot uptake. Therefore it is concluded that little or no diuron is taken up through

Table 21. Dry weights from diuron placement and site of uptake study with the analysis of variance.

Treatment number	ppmw diuron	Layer(s)	Blocks 1	2	3	4	5	6	Mean
1	8	A	215	205	199	201	175	157	192[a] 1/
2		B	200	172	174	195	188	166	182[a]
3		C	67	37	20	47	30	42	40[e]
4		D	186	162	146	176	172	153	166[b]
5		A+B	192	165	166	185	175	145	171[a]
6		C+D	41	22	37	35	34	33	34[e]
7		A+D	184	169	163	183	170	162	172[a]
8	4	A+B	208	183	176	182	184	177	185[a]
9		C+D	48	62	153	48	96	96	84[d]
10		B+C	158	133	137	162	139	100	138[c]
11		A+B+C+D	33	32	64	31	43	81	47[e]
12	0	Check	192	197	207	179	162	202	190[a]

Continued

Table 21. Dry weights from diuron placement and site of uptake study with the analysis of variance--Continued.

Analysis of variance

Source	df	MS
Total	71	
Blocks	5	497.20
Treatments	11	24,067.73**
Root vs Shoot	1	124,236.75**
Treatment 3 vs 9	1	5,633.33**
Treatment 2 vs 8	1	18.75
Treatment 7 vs 10	1	3,400.33**
Check vs Shoot 2/	1	243.68
B x T	55	364.60

$\bar{\bar{y}}$ = 133.5 s = 19.09 CV = 14.3%

1/ Means with the same letter are not different as measured by ranking the averages in increasing order and use of $LSD_{.05}$. Notice analysis for meaningful comparisons designed in the experiment.

2/ Not orthogonal with four contrasts above.

the emerging coleoptile. A close observation of the means and visual observations would indicate some reduction due to coleoptile uptake; however,this experiment was not sensitive enough to detect it.

Comparisons of treatments 2 and 8 which is a concentrated narrow band (B) versus a dilute wider band (A+B) above the seed where both treatments have the same total amount of herbicide were not different. Again this would indicate that diuron is not being taken up from these layers as these two treatments were a part of the comparison with the check. Other studies have shown more injury from plants having coleoptile uptake when the herbicide was placed close to the seed. Contrasts comparing treatments 3 and 9 which is a concentrated layer just below the seed (C) with a dilute wider layer (C+D) show more injury occurring when a concentrated layer is placed just below the seed. Again this is a comparison of the same total amount of herbicide. A dilute layer surrounding the seed (B+C) caused more injury than two concentrated layers (A+D) above and below the seed with a buffer layer in between. Much more injury occurred in a concentrated band just below the seed (C) than when a buffer layer was included between the seed and an equivalent concentrated layer (D).

These findings would support the concept that diuron is absorbed through the roots where it enters the transpiration stream and then is moved upward with water. The fact that diuron is absorbed through the roots of wheat would explain in part why it is selective in removing annual ryegrass from wheat. Ryegrass germinates close to the soil surface and would be in a more concentrated layer of herbicide because diuron is tightly adsorbed and not readily leached. Since ryegrass absorbs diuron through both roots and shoots it would be more susceptible from the standpoint of physical herbicide placement. Root uptake by wheat would favor a concept of physical selectivity with wheat being protected from diuron by soil placement. Increased safety would result from deeper planting. This was studied and the results reported in Experiment IX.

It is not known why more injury occurred when a concentrated layer was placed just below the seed than when the same amount of herbicide diluted with twice the amount of soil was also below the seed or when layer D only was treated. More dilution would result in more diuron being adsorbed to the soil. It was also noted that when the soil was dumped from the pots the two top layers came off exposing the roots in several of the pots. These roots ran horizontally from one to two inches prior to turning downward. It is not known whether this occurred because of the way the layers were placed in the cans or whether this is a natural phenomenon for wheat. Neither of these observations were explored experimentally. If this was the general case then more roots would be exposed for a longer period in layer C than in layer D while the roots were still small. When the roots turn downward to grow straight through layer D only a section of roots 2/3-inch in depth would be exposed. With further development of roots they extend and fill the can beneath the seeds having uptake from total available soil. However, larger amounts of diuron would be taken up in layer C if roots grow horizontally as suggested as there would be a larger percentage of the total root system in the treated layer. This would be especially true when the plants were small. A buffer zone in the region of horizontal root growth (layer C) with layer D being treated would result in a smaller percentage of the total plant roots being exposed to the chemical. Placement of seed so the root system would be below the leached layer of diuron would minimize injury to wheat.

EXPERIMENT IX. PLANTING DEPTH AS A MEANS OF REDUCING DIURON INJURY

Wheat primarily absorbs diuron through the roots and it seemed reasonable that deeper planting should give more protection from diuron exposure. Therefore this experiment was designed to determine the effects of different depths of planting on the toxicity of diuron to Nugaines wheat.

Methods and Materials

Wheat was seeded at depths of 0, 0.5, 1.0, 1.5 and 2.0 inches in metal cans. Depths were established by weighing the amount of soil necessary to give the desired soil covering. Air-dry soil weighing 150 g was considered to be equal to a layer 0.5-inch thick. Seeds placed on the surface and at the other depths were pressed into the soil with a board, prior to covering. The seeds from the zero depth were still visible. After seeding, all pots received 1.3 lbs/A diuron from an overhead sprayer and then water was added to bring the soil to field capacity. Six replications of each planting depth in a completely randomized design was used. Pots were treated December 25, 1967, and emergence occurred 2 and 3, 3 and 4, 4 and 5, 5 and 6, and 6, 7 and 8 days after seeding for 0, 0.5, 1.0, 1.5 and 2.0-inch planting depths, respectively. All plants failed to emerge evenly from the same planting depth as can be seen when two or more dates are given for each depth. The plants were harvested in the sequence 0 and 0.5 on January 6, 1.0 on February 7, 1.5 on February 8 and 2.0 on February 9, 1968.

Results

The appearance of visual injury was slower with increased depth of planting. Seeds planted on the surface germinated and appeared to become established after which visual diuron injury symptoms appeared rapidly and by harvest these plants were almost completely deteriorated. In this soil and with this method of planting, plants emerged from the 2.0 inch depth with difficulty. Nugaines wheat characteristically has difficulty emerging if the soil is somewhat crusted. A summary of the results is presented in Table 22. There was a difference between all planting depths except 1.5 and 2.0 inches. Those plants from the one-inch depth were about 50% of an equivalent check growing in an adjacent experiment and some injury was evident in plants from 1.5 and 2.0-inch planting depths. The 1.5-inch depth produced plants weighing 86% more than 0.5-inch depth. In this soil and with this rate, increased depth of planting appears to be more important in protecting wheat from diuron than any other factor studied in this series of experiments. It would also seem likely that deeper-planted wheat would have a better opportunity for overcoming diuron because other environmental

Table 22. Milligrams dry weight from depth of planting study and the analysis of variance.

Planting depth inches	Replications						Avg.
	1	2	3	4	5	6	
0.0	38	34	32	43	38	42	38[a]
0.5	178	199	212	207	193	196	198[b]
1.0	222	215	237	244	295	297	252[c]
1.5	380	384	336	372	361	375	368[d]
2.0	365	414	360	332	352	352	362[d]

Analysis of variance

Source	df	MS
Total	29	
Treatments	4	111, 214.0**
Error	25	503.3

$\bar{\bar{y}} = 243.5$ $s = 22.43$ $CV = 9.2\%$ $LSD_{.05} = 26.7$

factors prevalent in late fall should have a more marked influence on diuron uptake from a region in the soil which contains less diuron. When only a small amount of diuron is available for uptake, the reductions in uptake and toxicity caused by lower light, lower temperature and other factors may provide the extra margin of safety required for selectivity.

When using diuron as a selective herbicide in wheat the seeds should be planted deep enough to provide protection from diuron in the root zone. This depth should be the maximum which would still produce the desired stand of plants and would be influenced by soil type. This should work well as satisfactory emergence occurs from deeper levels in a sandy soil than in a clay soil and more sand than clay is required to provide equivalent adsorption sites.

EXPERIMENT X. STAGE OF EARLY DEVELOPMENT AT TIME OF SPRAYING AS A FACTOR IN DIURON TOXICITY TO WHEAT

Results from a diuron placement study indicated little or no shoot uptake of diuron by wheat; however, when the area just below the seed was treated there was considerable injury. When a buffer of 2/3 inch was left below the seed and the next 2/3-inch layer was treated there was still injury, but not nearly as intense. Some leaching might be expected in this sandy soil. It was considered a possibility that if wheat was sprayed or the chemical reaches the root zone after the young roots have reached an inch or more in length a reduction in injury to wheat might occur. This experiment was designed to compare the toxicity of diuron to Nugaines wheat when applied at various stages of early development.

Methods and Materials

Wheat was seeded 0.75-inch deep and all pots except checks were sprayed with 1.3 lbs/A diuron. Extra pots were planted to provide samples for determining stage of development. Each time before spraying all pots were brought to field capacity. The treatments were: check - not sprayed; A - sprayed just after seeding; B - sprayed when wheat just started to germinate; C - sprayed when about one-half the plants were breaking the soil surface; and D - sprayed when a majority of plants were three inches high. The treatment schedule was: A - 4:30 pm, December 25; B - 9:30 pm, December 27; C - 6:00 pm, December 29, 1967; and D - noon, January 1, 1968. All plants were harvested February 6, 1968.

Results

The results obtained are presented in Table 23 with the analysis of variance. Diuron at 1. 3 lbs/A caused a reduction of about 50% in dry weight for all treatments but there were no difference between treatments receiving diuron. No evidence was found which would indicate any difference in wheat susceptibility to diuron due to time of application between seeding and the time the plants were three inches high.

Table 23. Milligrams dry weight from stage of early development study and the analysis of variance.

	Replications								
	1	2	3	4	5	6	7	8	Avg.
CK	615	561	589	529	523	523	494	532	546^{a}
A	247	257	299	273	285	271	356	299	286^{b}
B	225	275	213	254	294	325	295	230	264^{b}
C	242	274	252	272	202	296	311	247	262^{b}
D	274	252	314	237	296	232	293	291	274^{b}

Analysis of variance

Source	df	MS
Total	39	
Treatments	4	121, 197.0**
CK vs Applications	1	481, 912.3**
Among applications	3	958.6
Error	35	1, 275.2

$\bar{\bar{y}} = 326.2$ $s = 35.71$ $CV = 10.9\%$

$LSD_{.05} = 36.2$

EXPERIMENT XI. ABILITY OF WHEAT TO OVERCOME EXPOSURE TO DIURON

Some plants are able to metabolize certain herbicides thereby obtaining a margin of safety from that herbicide. The objective of this experiment was to determine if Nugaines wheat could overcome two rates of exposure to diuron as measured by CO_2-uptake.

Methods and Materials

Thirteen 18-day-old wheat plants were removed from a sand culture and placed in a nutrient solution with their tops supported by one-inch thick styrofoam plugs and their roots in 150 ml beakers containing 100 ml nutrient solution. This was done one day prior to starting measurements. All plants had been grown in a controlled environment chamber under a 12-hour day with 2000 ft-c light measured midway up the plants and 20 C day and 15 C night temperatures. A randomized blocks design with four blocks made up of three treatments each was used. Treatments were intended to be 0, 25 and 50% reduction in CO_2-uptake resulting from root exposure to a 1×10^{-5} M diuron plus nutrient solution. But because one hour was required to take a complete set of readings and once CO_2-uptake began to fall it fell rapidly, the treatments were actually a three and four-hour exposure to diuron solution which gave readings close to the intended reductions. The plants were brought to the recording room at the end of a dark period from the growth chamber. Measurements were made with a Beckman IR 215 Infrared Gas Analyzer. The units of measurements were ppm CO_2 taken up or given off during a four-minute period. After CO_2-uptake in light was recorded a black plastic bag was placed over the plexiglass chamber and dark respiration rates were obtained at the beginning and again at the end of the experiment. These are indicated by short horizontal dashes on the figure and are a negative value determined by calculating the ppm CO_2 given off in four minutes as a percent of the initial reading for each pot. The initial readings were recorded after a two-hour exposure to light and the roots were exposed to diuron immediately after this reading. After a three-hour exposure when a little over 25% reduction in CO_2-uptake had occurred the roots were removed from the diuron solution, rinsed and placed in nutrient solution. After a four-hour exposure it appeared that over 50% reduction had occurred and roots from this treatment were washed and changed back to a regular nutrient solution. Temperature in the recording room was 20 C with continuous light, except for an unknown dark period of approximately eight hours occurring about 16 hours after the start of the experiment. Light intensity in the room was 2000 ft-c one-half way up the plant and 1600 ft-c at the leaf surface in the plexiglass chamber. A reading was taken 24 hours after treatment and then plants were transferred to a controlled environment chamber having a 10-hour day and 14-hour night with 20 C day and 15 C night temperatures. Mechanical failure of the gas analyzer did not allow any subsequent readings. Plants were harvested 16 days after treatment.

Results

The results of the CO_2-uptake measurements are illustrated in Figure 2 which gives the CO_2-uptake as percent of the initial reading and is the average of four blocks. The average after a three-hour exposure was a value of 66% of the initial but the blocks ranged from values of 54 to 78% of their initial readings. For the four-hour exposure the interpolated average at time of diuron removal was 58% of the initial value. Eight hours after the initial exposure, treated plants were giving off more CO_2 than they were taking up and at the end of the measurements, 24 hours later, the values obtained under light were almost equal to the dark respiration values indicating almost a complete inhibition of photosynthesis by diuron. Under these experimental conditions this rate produced very rapid inhibition of CO_2-uptake with little difference occurring between a three or four-hour exposure. Dark respiration was taken only at the beginning and end of the experiment and is expressed as a percent of the initial (2-hour) reading but given a negative value. These readings were only for four minutes and followed a light exposure so

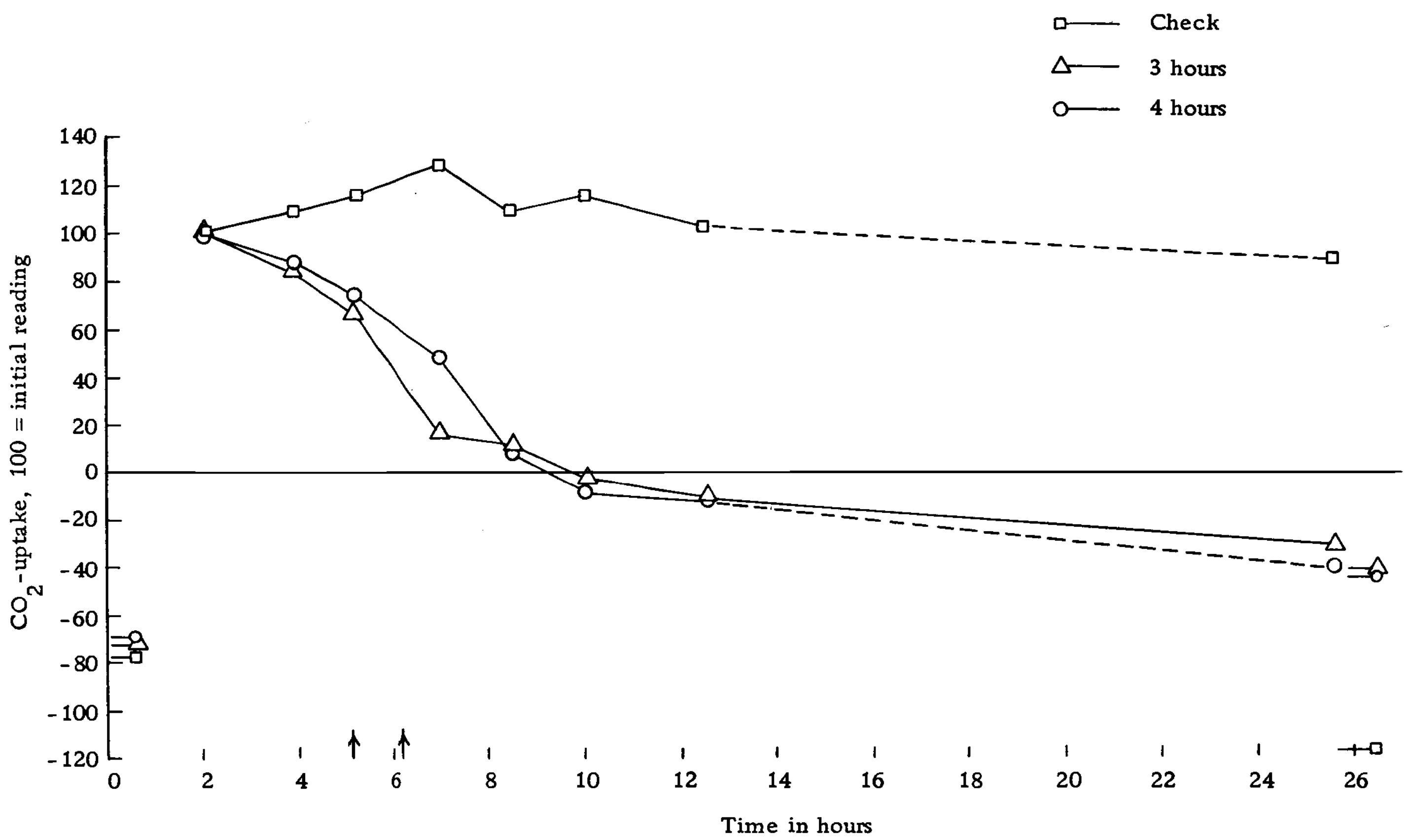

Figure 2. CO_2-uptake as percent of each pot's initial reading after a temporary exposure to 1×10^{-5}M diuron. At ↑ the diuron was removed.

the respiration rate was not stabilized. The readings are only included for indications. There was an increase in respiration for the check from -77 to -116% of the initial reading under light while those treated with diuron showed a decrease in respiration.

Because the check increased in its rate of CO_2-uptake after the initial reading, indicating that stabilization had not been obtained after a two-hour exposure to light, the readings were adjusted as shown in Figure 3 by multiplying each of the readings at each time by a factor which puts the check on a basis of 100. Assuming the two sets of plants receiving diuron would have a CO_2-uptake adjustment similar to the check, had they not received diuron, would mean that diuron was removed from the three-hour treatment when it had an average 57% of the initial reading instead of the intended 75%. With the four-hour treatment the corrected interpolated value shows diuron to be removed when a value 46% of the initial was attained. The factor adjusts the first readings downward and the last reading upward.

Visual injury symptoms had not occurred after 24 hours although there may have been a slight wilting. After returning to the growth chamber, treated plants developed a yellow color and fell over but did not exhibit any of the more advanced diuron symptoms. Dry weights are given in Table 24 which shows that diuron treatments produced plants weighing just over 40% of check with no difference

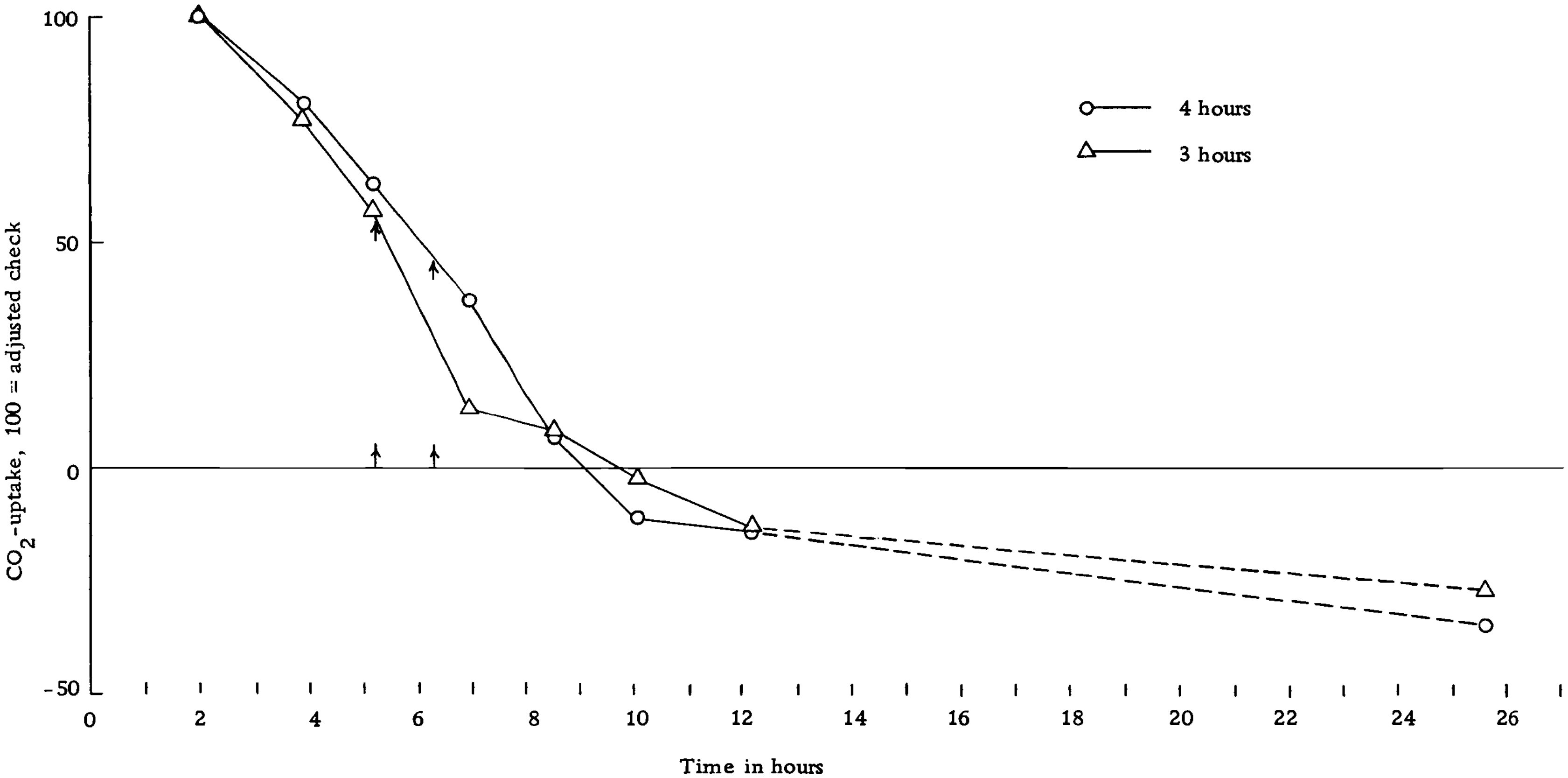

Figure 3. CO_2-uptake as percent of each pots initial reading corrected to make the check shown in Figure 2 equal 100. At ↑ the diuron was removed.

Table 24. Milligrams dry weights from study of wheat's ability to overcome exposure to diuron and the analysis of variance.

Treatment	Blocks 1	2	3	4	Mean
CK	2160	1849	1765	2253	2007[a]
3-hour	770	788	809	1113	870[b]
4-hour	791	756	741	916	801[b]

Analysis of variance

Source	df	MS
Total	11	
Blocks	3	64,406.7*
Treatments	2	1,833,863.0**
B x T	6	12,112.8

$\bar{\bar{y}} = 1226$ s = 110.06 CV = 9.2%

$LSD_{.05} = 191$

between the three and four-hour exposure. When these plants were harvested it appeared that they had lost their yellow color and it was thought that growth had resumed.

An extra pot was carried through this experiment and it received 100 ml of a 1×10^{-7} M diuron solution which was not removed but volume was maintained by the addition of nutrient solution. The majority of the diuron would have been taken up after four days because of the amount of water used. CO_2-uptake for this pot fluctuated above and below its initial value and at harvest the dry weight was 2226 mg. This pot was not distinguishable from the check and it appears that wheat is capable of overcoming smaller amounts of diuron although this was only a single observation. No positive evidence was found to indicate that wheat can actively detoxify diuron but an indication worthy of further study is that wheat appears capable of overcoming small dosages. Further study with a more dilute solution and with Nugaines and Druchamp varieties which differ in their sensitivity may reveal wheat is able to detoxify smaller dosages. Small dosages in the plant under field conditions would result when the environmental conditions which occur during the late fall favor movement of smaller quantities into the plant.

DISCUSSION AND CONCLUSIONS

Wheat can be injured or killed in a sand culture when diuron is applied at low concentrations. However, diuron has been a significant factor in improving yields from wheat grown in ryegrass infested fields in Western Oregon. These studies were conducted in an effort to obtain a better understanding of why diuron can successfully be used as a selective pre-emergence herbicide in fall-planted wheat.

In glasshouse studies, soil temperature was a major consideration and appeared to have a definite influence on diuron toxicity. As measured by percent of check, wheat grown at 20 C soil temperature had more injury than at 5 C. Lower soil temperatures common in the Willamette Valley during the late fall could contribute to decreased injury to winter wheat. Experiments conducted on three dates during the summer produced different levels of injury between dates. These results indicated that light and atmospheric temperature might be implicated as important factors in toxicity and worthy of further study.

Studies designed to examine the effect of light intensity in the range from 400-1600 ft-c provided evidence that increased injury from diuron occurred with increased light intensity. Injury symptoms occurred earlier and were more severe under the higher intensities. Conclusive statements cannot be made because other environmental parameters were not adequately controlled. Future studies should be conducted in controlled-environment chambers where light interactions with atmospheric temperature and soil moisture levels can be clarified. It was possible that increased injury under higher light intensities was due to increased transpiration and more diuron uptake. Therefore an experiment was performed to observe the effect of light under approximately equal amounts of diuron uptake. Plants were kept under 1000 ft-c light until minor symptom development occurred and then one-half of the plants were exposed to eight hours of full sunlight. Almost complete whitening of the leaves occurred on diuron-treated plants exposed to sunlight. Those left in the growth chamber exhibited only the early symptoms of injury. This would indicate that sunlight has an injurious effect other than its influence on transpiration rate, as transpiration rates were assumed equal prior to exposure to sunlight. Further work is needed in controlled-environment chambers to learn more about the influence of light intensity on phytotoxicity. A curve needs to be worked out which would show the change in plant injury over the range of light intensities which occur naturally.

Soil moisture studies at the time of diuron application indicated no differences in toxicity to wheat. Plants on wet soil when sprayed were not different from those on dry soil when sprayed and then watered.

Fertility experiments yielded conflicting results. Increased fertility caused more injury in one experiment. In another, plants receiving one rate of complete fertilizer showed less injury than plants receiving twice this rate or those receiving no added fertilizer. Fertility differences should be studied further because of the increasing amounts of commercial fertilizer being applied to wheat. When toxic responses are evaluated as percent of check, one should be careful to distinguish between toxicity and differences due to growth rate from the environmental parameter being studied. Measured differences as percent of check are the result of the environmental parameter after diuron-treated plants have stopped photosynthesis because from this time on dry weight as percent of check becomes smaller as the check continues growth.

Wheat grown in soil maintained at field capacity was injured more by diuron than when the soil was maintained below field capacity. There was no difference in injury found between plants grown in soil maintained at 70 or 85% of field capacity. It appears that diuron is not as available for uptake and it would be expected that less water would be transpired from the drier soil. This helps explain why wheat is severely injured in those fields with saturated soil conditions, a condition which is widespread during the winter on some heavier soil types in Western Oregon.

Because Nugaines was a new variety and no information on effect of diuron was available it was compared to Druchamp, which is a common commercial variety. In two experiments in a glass-house it was found that Nugaines was injured more by diuron than was Druchamp although the differences were not large. It was not determined if this was because of differences in root systems and amount of uptake or if Druchamp is able to metabolize more diuron than Nugaines. Variety testing should provide some check on these questions and a sounder basis for using diuron.

In a diuron placement study this herbicide was found to be taken up through the roots with little or no uptake occurring through the emerging coleoptile. A narrow band of herbicide just below the seed produced serious injury. Less injury occurred when an untreated layer, 2/3-inch thick, was just below the seed and the next 2/3-inch layer was treated. Movement between treated and untreated layers apparently was not a problem in this study. In future studies movement between layers might be prevented by spraying activated charcoal between layers. Care must be taken to avoid drying of the soil when making treatments in order to maintain uniform moisture levels among layers. A narrow band produced more injury than a band twice as wide having the same amount of diuron. This would indicate the herbicide was diluted and more of it adsorbed in the wider layer.

Depth of planting was considered to be the most important factor studied. Increased depth of planting provided more safety to wheat and it is suggested that when diuron is used as a selective herbicide in wheat that seeds be planted as deep as is agronomically practical.

Diuron was applied to wheat in various stages of early development from seeding to three inches high. No difference was noted in diuron injury in any of these applications. Stage of growth, therefore, does not appear to be a major factor in tolerance.

An experiment designed to study the ability of wheat to overcome short exposures to diuron failed to provide conclusive evidence for rapid recovery from the rates used. When wheat roots were removed from a 10^{-5} M diuron solution after approximately a 25 and 50% reduction in CO_2-uptake had occurred the plants failed to show any recovery in CO_2-uptake 24 hours later. Photosynthesis was completely inhibited and this was prior to any visual diuron symptom development except for a slight wilting. When returned to the growth chamber some diuron symptoms developed but at harvest, 16 days after treatment, the plants appeared to be actively growing. It appears that very small doses would be rendered harmless to the plants. It is suggested that more information be obtained using lower rates of diuron to see if wheat is able to overcome smaller doses than were used here. Druchamp should be better able to overcome exposure to diuron than Nugaines in a nutrient solution if the observed differences in degree of toxicity between these two varieties is metabolic.

A field experiment was conducted to see what effect date of planting would have on pre-emergence applications of diuron to Nugaines wheat. Rates were chosen based on past usage of diuron, but on the sandy soil of this site and under the conditions of this experiment much more injury occurred than was expected. As measured by percent of check less injury occurred after six to eight weeks to those plants from November 11 and December 1, 1967 plantings than to plantings made August 19, September 11, September 30 and October 20, 1967. Plants from the October 20 seeding had less injury than earlier plantings after three weeks growth but in another three weeks this advantage was not evident. All treated plants were dead the following spring except those few which escaped the low rate in the first seeding date. It is thought these plants escaped and became established because earlier plantings made with a Planet Jr. would have been seeded deeper in soft soil than later when the seedbed was firmer. The observed phytotoxicity was much greater than expected and may in part be explained by the sandy soil with low organic matter content, use of Nugaines instead of Druchamp and that seeding was done with equipment which failed to place the seed as deep as is commonly done with commercial grain drills.

The following is offered as a suggestion as to why diuron is not as toxic to late fall-planted wheat compared with plantings made in the spring. When seeds are planted at the maximum depth which still gives good emergence there should only be small amounts of diuron in the root zone. Lower light intensity, shorter days, lower soil and atmospheric temperatures and higher humidity are probably important factors in reducing diuron uptake and injury. These conditions are usually present in late fall and winter in the Willamette Valley. However, also common in the fall ànd winter is high soil moisture levels which cause increased injury. More study needs to be done on the interaction of these factors. The question remains as to why the fall-seeded plants are not killed the following spring when the opposite of fall conditions begin to occur. A possible explanation for this is that root growth would place a larger percentage of the roots outside the diuron zone, the plant would be somewhat larger giving a growth dilution effect or more plant area for metabolism in relation to amount of diuron and some microbial breakdown could occur leaving less herbicide in the soil. Also the soil would not be as wet having intermittent periods of drying occurring especially on the surface when the sun comes out and temperatures go up. If it can be shown that wheat metabolizes small amounts of diuron then this would help explain and perhaps determine what is actually happening.

The results of these studies indicate a need for further work on light intensity, atmospheric temperatures, humidity and interactions of these factors. Further work to establish the level of diuron exposure which will not reduce wheat growth should be performed and wheat's ability to overcome larger dosages received for short periods, as during short intervals of increased sunlight, should be studied. It is also suggested that influence of increased fertility levels be examined closer.

The information gained from these studies should be helpful in predicting diuron use in other climatic areas. These results point out the need for deep seeding with suitable commercial grain drills. Wheat should be grown in heavier soils which are adequately drained and which afford some protection due to increased adsorptive capacity. Wheat should be planted when it is expected that periods of low temperature and light intensities will follow or if seeded earlier in the fall, diuron treatment should be delayed until these conditions would be expected following spraying. It was shown that no difference in injury occurred when diuron was applied between seeding and the time the plants were three inches high. However, other studies have shown diuron to have some foliar activity and this should be considered when spraying plants. When new varieties are introduced into an area they should be indexed as to the effect current commercial herbicide practices may have on them.

BIBLIOGRAPHY

1. Appleby, A. P., W. R. Furtick and S. C. Fang. Soil placement studies with EPTC and other carbamate herbicides on Avena sativa. Weed Research 5:115-122. 1965.

2. Ashton, F. M. Relationship between light and toxicity symptoms caused by atrazine and monuron. Weeds 13:164-168. 1966.

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

4. Bailey, G. W. and J. L. White. Soil-pesticide relationships. Review of adsorption and desorption of organic pesticides by soil colloids, with implications concerning pesticide bioactivity. Journal of Agricultural and Food Chemistry 12:324-332. 1964.

5. Bayer, D. E. and H. R. Drever. The effects of surfactants on efficiency of foliar-applied diuron. Weeds 13:222-226. 1965.

6. Bayer, D. E. and S. Yamaguchi. Absorption and distribution of diuron-C^{14}. Weeds 13:232-235. 1965.

7. Bingham, S. W. and R. P. Upchurch. Some interactions between nutrient level (N, P, K, Ca) and diuron in the growth of cotton and Italian ryegrass. Weeds 7:167-177. 1959.

8. Cochran, W. G. and G. M. Cox. Experimental Designs. 2d ed. New York, John Wiley, 1957. 611 p.

9. Coggins, C. W., Jr. and A. S. Crafts. Substituted urea herbicides: Their electrophoretic behavior and the influence of clay colloid in nutrient solution on their phytotoxicity. Weeds 7:349-358. 1959.

10. Comes, R. D. and F. L. Timmons. Effect of sunlight on the phytotoxicity of some phenylurea and trizine herbicides on a soil surface. Weeds 13:81. 1966.

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

12. Culp, T. W. and C. G. McWhorter. Amiben and diuron preemergence in castorbeans. Weeds 14:171-173. 1966.

13. Ennis, W. B., Jr. Selective toxicity in herbicides. Weed Research 4:93-104. 1964.

14. Fang, S. C. et al. Herbicide action-adsorption, translocation and metabolism of radioactive 3-(4-chlorophenyl)-1, 1-dimethylurea (CMU) by bean plants. Journal of Agricultural and Food Chemistry 3:400. 1965.

15. Freed, V. H. and R. O. Morris (eds.). Environmental and other factors in the response of plants to herbicides. Corvallis, 1967. 128 p. (Oregon, Agricultural Experiment Station. Technical Bulletin 100)

16. Gentner, W. A. and J. L. Hilton. Effect of sucrose on the toxicity of several phenylurea herbicides to barley. Weeds 8:413-417. 1960.

17. Hamilton, K. C. et al. Preplanting applications of diuron in cotton. Weeds 14:145-148. 1966.

18. Hance, R. J. The adsorption of urea and some of its derivatives by a variety of soils. Weed Research 5:98-107. 1965.

19. Hance, R. J. Observations on the relationships between the adsorption of diuron and the nature of the adsorbent. Weed Research 5:108-114. 1965.

20. Harris, C. I. and T. J. Sheets. Influence of soil properties on adsorption and phytotoxicity of CIPC, diuron and simzaine. Weeds 13:215-219. 1965.

21. Helson, V. A. Comparison of Gro-lux and cool-white fluorescent lamps with and without incandescent as light sources used in plant growth rooms for growth and development of tomato plants. Canadian Jounral of Plant Science 45:461-466. 1965.

22. Hill, G. D., Jr., I. J. Belasco and H. L. Ploeg. Influence of surfactants on the activity of diuron, linuron and bromacil as foliar sprays on weeds. Weeds 13:103-106. 1965

23. Hill, G. D., et al. The fate of substituted urea herbicides in agricultural soils. Agronomy Journal 47:93-104. 1955.

24. Hilton, H. W. and Q. H. Yuen. Adsoprtion of several pre-emergence herbicides by Hawaiian sugar cane soils. Journal of Agricultural and Food Chemistry 11:230-234. 1963.

25. Hoagland, D. R. and D. I. Arnon. The water-culture method for growing plants without soil. Berkeley, 1938. 39 p. (California. Agricultural Experiment Station. Circular 347)

26. Jordan, L. S. et al. Photodecomposition of substituted phenylureas. Weeds 12:1-4. 1964.

27. Jordan, L. S. et al. Effect of photosynthesis-inhibiting herbicides on non-photosynthetic tobacco callus tissue. Weeds 14: 134-136. 1966.

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

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

30. Loustalot, A. J., T. J. Muzik and J. H. Cruzado. Persistence of CMU in soil. Agricultural Chemicals 8:52-53. Nov. 1953.

31. Minshall, W. H. Influence of light on the effect of 3-(4-chlorophenyl)-1, 1-dimethylurea on plants. Weeds 5:29-33. 1957.

32. Minshall, W. H. Primary place of action and symptoms induced in plants by 3-(4-chlorophenyl)-1, 1-dimethylurea. Canadian Journal of Plant Science 37:157-166. 1957.

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

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

35. Muzik, T. J., H. J. Cruzado and A. J. Loustalot. Studies on the adsorption, translocation and action of CMU. Botanical Gazette 116:65-73. 1954.

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

37. Oorschot, J. L. P. van. An assembly for the continuous recording of CO_2 exchange and transpiration of whole plants. Weed Research 1:245-257. 1961.

38. Oorschot, J. L. P. van. The inhibition of CO_2-uptake and transpiration of beans by diquat and simeton. In: Jaarboek der Instituut voor Biologisch en Scheikundig Onderzoek van Landbouwgewassen (Wageningen), 1966. p. 41-50.

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

40. Power, J. F. et al. Effect of soil temperature, phosphorous and plant age on growth analysis of barley. Agronomy Journal 59:231-234. 1967.

41. Sedgley, R. H. and L. Boersma. 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, 1968. 15 numb. leaves. (In preparation)

42. Sheets, T. J. The comparative toxicities of four phenylurea herbicides in several soil types. Weeds 6:413-424. 1958.

43. Sheets, T. J. Review of disappearance of substituted urea herbicides from soil. Journal of Agricultural and Food Chemistry 12:30-33. 1964.

44. Sheets, T. J. and A. S. Crafts. The phytotoxicity of four phenylurea herbicides in soil. Weeds 5:93-101. 1957.

45. Snedecor, G. W. Statistical methods. 5th ed. Ames, Iowa State University, 1956. 534 p.

46. Upchurch, R. P. The influence of soil moisture content on response of cotton to herbicides. Weeds 5:112-120. 1957.

47. Upchurch, R. P. The influence of soil factors on the phytotoxicity and plant selectivity of diuron. Weeds 6:161-171. 1958.

48. Upchurch, R. P. and W. C. Pierce. The leaching of monuron from lakeland sand soil. Part II. The effect of soil temperature, organic matter, soil moisture and amount of herbicide. Weeds 6:24-33. 1958.

49. Warren, R. (comp.). Oregon weed control handbook. Corvallis, Oregon, Cooperative Extension Service, 1967. 236 p.

50. Weldon, L. W. and F. L. Timmons. Penetration and persistence of diuron in soil. Weeds 9:195-203. 1961.

51. Woodford, E. K., K. Holly and C. C. McCready. Herbicides. Annual review of plant physiology 9:311-358. 1958.

52. Yuen, Q. H. and H. W. Hilton. The adsorption of monuron and diuron by Hawaiian sugarcane soils. Journal of Agricultural and Food Chemistry 10:386-392. 1962.

APPENDIX

Table 1. Milligrams dry weight of Nugaines wheat grown on three dates at four soil temperatures and sprayed pre-emergence with diuron.

Diuron	5 C Dates				13 C Dates				21 C Dates				29 C Dates				
	1	2	3	Avg.	1	2	3	Avg.	1	2	3	Avg.	1	2	3	Avg.	Rate Avg.
CK	238	595	315	383	587	652	561	600	612	737	680	676	357	450	411	406	516
0.5	162	226	202	197	392	188	448	343	430	211	556	399	339	107	377	274	303
1.0	105	94	78	92	209	139	285	211	200	90	348	213	220	63	261	181	174
2.0	63	72	92	76	99	77	81	86	74	58	105	79	103	69	121	98	84
4.0	74	66	101	80	75	87	64	75	74	46	74	65	73	61	98	77	74
Avg.	128	211	157	166	272	228	288	263	278	228	353	286	218	150	253	207	192

Table 2. Milligrams dry weights from soil temperature by fertility by diuron rate experiment.

Temperature	Lbs/A diuron	Fertility level	r	I	II	III	IV
5 C	CK	Low	1	341	509	393	447
			2	402	535	461	433
		Medium	1	493	589	452	434
			2	445	507	460	439
		High	1	453	582	477	443
			2	662	549	511	458
	0.5	Low	1	420	492	434	418
			2	464	567	449	422
		Medium	1	465	503	469	488
			2	472	595	502	444
		High	1	482	540	547	411
			2	433	489	507	496
	0.8	Low	1	472	473	507	410
			2	371	463	420	373
		Medium	1	488	552	445	445
			2	448	527	522	470
		High	1	512	592	460	452
			2	506	530	413	509
	1.1	Low	1	489	469	378	444
			2	435	496	453	421
		Medium	1	395	500	492	443
			2	494	555	507	482
		High	1	470	535	504	459
			2	461	547	549	420
20 C	CK	Low	1	1070	617	393	620
			2	767	609	376	504

Continued

Table 2. Milligrams dry weights from soil temperature by fertility by diuron rate experiment. -- Continued

Temperature	Lbs/A diuron	Fertility level	r	I	II	III	IV
20 C	CK	Medium	1	514	507	477	645
			2	976	534	457	560
		High	1	595	644	372	600
			2	1080	764	490	717
	0.5	Low	1	712	575	403	582
			2	640	548	368	536
		Medium	1	546	551	474	540
			2	964	522	449	660
		High	1	762	726	497	540
			2	988	677	378	495
20 C	0.8	Low	1	538	525	359	427
			2	526	535	348	477
		Medium	1	614	612	423	574
			2	546	514	378	502
		High	1	628	573	374	420
			2	527	520	425	544
	1.1	Low	1	700	509	314	424
			2	400	399	354	478
		Medium	1	467	536	386	520
			2	390	466	405	509
		High	1	304	532	355	521
			2	454	336	457	434

Table 3. Dry weights of wheat for plants grown at two soil temperatures and sprayed pre-emergence with diuron.

Temperature	Rate	r	Blocks I	II	III
5 C	CK	1	401	447	386
		2	389	371	372
		3	483	465	391
		4	495	394	400
	Total		1768	1677	1549
	1.3	1	194	342	228
		2	193	310	315
		3	225	299	288
		4	253	270	265
	Total		865	1221	1096
	1.7	1	158	289	204
		2	232	209	172
		3	198	217	225
		4	228	201	174
	Total		816	916	775
20 C	CK	1	504	822	635
		2	728	730	682
		3	654	733	809
		4	564	725	810
	Total		2450	3010	2936
	1.3	1	169	392	180
		2	127	416	401
		3	151	317	232
		4	195	197	253
	Sum		632	1322	1066
	1.7	1	200	199	206
		2	184	374	190
		3	160	240	263
		4	185	216	177
	Sum		729	1029	836

Table 4. Milligrams dry weight of wheat from diuron rate by fertility level by surface moisture at time of spraying study.

lbs/A. diuron	Surface moisture	Fertility level	Blocks 1	2	3	4	5	6	7	8
CK	Dry	Low	327	305	268	270	322	287	315	318
		High	628	690	615	634	602	475	710	733
	Wet	Low	313	320	308	311	337	330	312	316
		High	744	692	564	592	559	552	701	705
1.4	Dry	Low	111	169	144	172	157	194	140	138
		High	158	210	240	272	161	203	172	186
	Wet	Low	166	125	176	168	163	165	181	148
		High	284	199	217	202	123	243	206	142
2.0	Dry	Low	104	132	120	109	119	108	99	123
		High	119	103	185	174	135	177	137	126
	Wet	Low	142	127	134	93	160	141	102	165
		High	200	168	194	177	192	157	136	146

Table 5. Milligrams dry weight from wheat grown under plastic bags at two moisture levels.

Field capacity	ppm diuron	Blocks 1	2	3	4	5	6	7	8
100%	CK	227	241	240	250	226	221	240	238
	2	88	96	157	139	169	104	186	140
	3	52	60	26	33	30	26	29	27
	4	15	32	21	19	29	26	14	21
80%	CK	185	186	174	183	179	160	206	214
	2	165	160	182	161	186	177	187	170
	3	124	131	150	77	100	174	68	108
	4	147	91	124	86	83	117	77	124

Table 6. Milligrams dry weight from wheat grown at three soil moisture levels.

Field capacity	lbs/A diuron	Blocks 1	2	3	4	5	6	7	8	9	10
70%	CK	388	449	479	427	450	465	385	428	483	466
	1.3	153	85	145	124	136	130	195	112	118	125
	1.8	79	102	174	138	142	148	139	108	93	124
	2.3	120	127	138	137	60	105	89	74	157	132
85%	CK	616	540	538	506	583	545	568	273	534	560
	1.3	260	186	156	137	210	151	170	103	215	110
	1.8	172	159	186	133	118	153	138	82	173	113
	2.3	210	144	120	128	126	179	140	131	172	126
100%	CK	798	636	700	640	699	659	665	550	729	676
	1.3	226	122	136	92	125	115	128	94	138	113
	1.8	69	130	132	96	129	151	157	112	159	116
	2.3	96	138	126	134	126	151	112	134	103	113

Table 7. Milligrams dry weight from wheat grown under two light intensities and sprayed pre-emergence with diuron.

Light	lbs/A diuron	r	Blocks 1	2	3	4
High	CK	1	1086	1095	1052	942
		2	1037	1125	1087	975
		3	1076	1169	1132	921
		Sum	3199	3389	3271	2838
	0.6	1	372	281	300	243
		2	256	223	353	327
		3	268	200	245	285
		Sum	896	704	898	855
	1.1	1	204	298	270	217
		2	396	304	312	200
		3	305	272	276	190
		Sum	905	874	858	607
	1.6	1	178	186	261	176
		2	231	156	183	139
		3	209	228	198	268
		Sum	618	570	642	583
Low	CK	1	591	777	619	668
		2	602	690	668	706
		3	625	705	743	638
		Sum	1818	2172	2030	2012
	0.6	1	258	169	203	153
		2	270	211	185	182
		3	190	227	181	230
		Sum	718	607	569	565
	1.1	1	210	128	224	229
		2	277	215	303	176
		3	271	267	229	196
		Sum	758	610	756	601
	1.6	1	192	150	188	150
		2	184	180	131	192
		3	152	182	178	175
		Sum	528	512	497	517

Table 8. Milligrams dry weight from wheat grown in sand culture under two light intensities and treated with diuron.

Light intensity	ppb diuron	r	Blocks 1	2	3	4
High	CK	1	256	242	193	165
		2	214	274	195	236
		3	279	247	295	162
		4		202		143
		Sum	749	965	683	706
	10	1	88	88	132	72
		2	84	77	124	124
		3	81	90	134	115
		4		69		75
		Sum	253	324	390	386
	15	1	90	79	110	94
		2	81	103	115	105
		3	76	108	90	77
		4		68		83
		Sum	247	358	315	359
Low	CK	1	139	175	189	130
		2	144	163	127	151
		3	151	180	164	104
		4		170		103
		Sum	434	688	480	488
	10	1	81	76	124	87
		2	77	80	96	86
		3	82	85	107	96
		4		82		64
		Sum	240	323	327	333
	15	1	79	89	102	83
		2	63	78	76	76
		3	78	77	76	84
		4		69		68
		Sum	220	313	254	311

Table 9. Dry weights in grams of Nugaines wheat from the first sampling of the field experiment.

Planting date	lbs/A diuron	1	2	3	4	Total	Mean
1	CK	18.2	15.8	14.7	16.9	65.6	16.4
	1.5	7.4	1.4	2.8	2.1	13.7	3.4
	3.0	0.8	0.8	0.7	0.7	3.0	0.8
	6.0	0.9	0.4	0.5	0.5	2.3	0.6
2	CK	8.3	8.8	7.1	7.5	31.7	7.9
	1.5	2.4	1.5	1.9	2.2	8.0	2.0
	3.0	0.1	0.1	0.6	0.8	1.6	0.4
	6.0	0.1	0.0	0.2	0.0	0.3	0.1
3	CK	2.9	2.9	4.0	4.2	14.0	3.5
	1.5	0.3	0.5	0.8	0.8	2.4	0.6
	3.0	0.2	0.2	0.3	0.1	0.8	0.2
	6.0	0.1	0.2	0.2	0.2	0.7	0.2
4	CK	3.0	2.0	2.6	2.0	9.6	2.4
	1.5	0.7	1.0	0.7	1.2	3.6	0.9
	3.0	0.7	0.7	0.5	0.6	2.5	0.6
	6.0	0.5	0.5	0.4	0.6	2.0	0.5
5	CK	0.80	0.63	0.27*	0.42	2.12	0.53
	1.5	0.57	0.39	0.47	0.20	1.63	0.41
	3.0	0.59	0.49	0.23	0.51	1.82	0.46
	6.0	0.38	0.51	0.33	0.18	1.40	0.35
6	CK	0.44	0.25	0.23	0.18	1.10	0.28
	1.5	0.44	0.33	0.09*	0.16	1.02	0.26
	3.0	0.34	0.18	0.11*	0.34	0.97	0.24
	6.0	0.48	0.17	0.09	0.11	0.85	0.21

*Plot flooded.

Table 10. Dry weight in grams of Nugaines wheat from the second sampling of the field experiment

Planting date	lbs/A diuron	Blocks 1	2	3	4	Total	Mean
1	CK	119	108	205	164	596	149
	1.5	50	0	18	42	110	28
	3.0	0	0	0	0	0	0
	6.0	0	0	0	0	0	0
2	CK	56.6	94.4	78.6	44.7	274.3	68.6
	1.5	6.2	8.9	8.5	20.3	43.9	11.0
	3.0	0.0	0.0	0.8	1.1	1.9	0.5
	6.0	0.0	0.0	0.0	0.0	0.0	0.0
3	CK	14.0	11.3	13.9	14.5	53.7	13.4
	1.5	0.5	0.1	0.4	3.1	4.1	1.0
	3.0	0.0	0.1	0.0	0.2	0.2	0.1
	6.0	0.0	0.0	0.0	0.0	0.0	0.0
4	CK	2.2	3.3	1.7	2.7	9.9	2.5
	1.5	0.2	1.0	0.0	0.9	2.1	0.5
	3.0	0.0	0.0	0.0	0.1	0.1	0.0
	6.0	0.0	0.0	0.0	0.0	0.0	0.0
5	CK	1.57	1.15	0.20[1/]	0.53	3.45	0.86
	1.5	0.63	0.80	0.90	0.77	3.10	0.78
	3.0	0.43	0.50	0.07[1/]	0.44	1.44	0.36
	6.0	0.30	0.54	0.35	0.20	1.39	0.35
6	CK	0.96	0.97	0.43[1/]	0.68	3.04	0.76
	1.5	0.82	0.44	0.29	0.41	1.96	0.49
	3.0	0.26	0.06	0.46	0.14	0.92	0.23
	6.0	0.01	0.03	0.00	0.00	0.04	0.01

1/ Plot flooded.

Table 11. Number of green plants from each of six planting dates at the time of the first sampling.

Planting date	lbs/A diuron	Blocks 1	2	3	4	Total	Mean
1	CK	166	71	78	73	388	97
	1.5	95	7	13	49	164	41
	3.0	13	12	7	17	49	12
	6.0	4	0	2	0	6	2
2	CK	82	83	59	62	286	72
	1.5	67	33	28	30	158	40
	3.0	3	4	13	15	35	9
	6.0	5	2	7	0	14	4
3	CK	67	58	63	83	271	68
	1.5	13	15	34	24	86	22
	3.0	18	13	12	5	48	12
	6.0	4	9	8	11	32	8
4	CK	118	80	115	76	389	97
	1.5	90	67	65	87	309	77
	3.0	75	50	44	45	214	54
	6.0	60	23	57	39	179	45
5	CK	98	89	48	68	303	76
	1.5	99	67	87	44	297	74
	3.0	99	88	48	92	327	82
	6.0	73	94	64	46	277	69
6	CK	59	43	34	28	164	41
	1.5	61	52	24	20	157	39
	3.0	56	28	18	67	169	42
	6.0	88	43	20	33	184	46

Table 12. Milligrams dry weight from first diuron rate by wheat variety study.

Variety	lbs/A diuron	Blocks 1	2	3	4	5
Nugaines	CK	334	336	343	323	332
	0.75	171	200	202	268	267
	1.00	134	165	199	177	197
	1.25	187	164	174	111	170
	1.50	155	179	159	150	118
Druchamp	CK	379	361	211	288	244
	0.75	235	230	227	289	227
	1.00	148	167	208	178	233
	1.25	168	138	153	91	154
	1.50	171	131	130	185	157

Table 13. Milligrams dry weight from second diuron rate by wheat variety study.

Variety	lbs/A diuron	Blocks 1	2	3	4	5	6	7	8
Nugaines	CK	591	527	560	541	549	443	549	445
	1.5	230	176	170	128	202	233	223	142
	2.0	119	209	146	179	149	176	144	169
Dru-champ	CK	723	661	687	743	729	651	636	657
	1.5	347	276	310	332	409	362	239	271
	2.0	239	178	298	250	284	259	390	283