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An experiment was conducted to study the effects of soil surface temperature and soil moisture on the volatilization of the herbicide clomazone. The objective of the experiment was to generate a regression equation that would model clomazone volatilization using these two variables. Radishes (Raphanus sativus) were grown to the two true-leaf stage, taken to the field, and set downwind from a clomazone-treated plot. The plants were exposed to clomazone vapors for 1.5, 3, 6, and 12 hours and then were taken to the greenhouse and grown until the third and fourth leaves were fully expanded. The third and fourth leaves were then harvested and analyzed for chlorophyll content. This procedure was repeated 21 times, each time varying the soil moisture and temperature.

The equation generated was: $LOG(Chl) = 4.037574 - 0.01732(t) + 0.002039(m) + 0.01732(h) + 0.015671(w) - 0.000041(t)(m)(w)(h)$. Wind velocity (w) and exposure time (h) data were added to the soil temperature (t) and soil moisture (m) data in order to obtain a model with an R^2 value of 21.02%. The model which included just soil surface temperature and soil moisture had an R^2 of 12.5% Chl is the chlorophyll content of the 3rd leaf expressed as a percent of control. The lower the Chl value the greater the plant response, an indication of clomazone volatilization. The model generated by these data agrees with the literature only with regard to soil temperature. Soil moisture, wind velocity, and exposure time all disagree with previous work on their effects on herbicide volatilization. The poor fit of the model and the disagreement between this model and the literature may be a result of the high variability of the radish response to clomazone vapors. The high variability could be associated with wind speed, surface drying of moist soils during repetitions done in the summer, and the size of the third and fourth leaves at time of exposure. The experimental design must be changed in order to properly evaluate the effect of soil moisture and soil temperature on clomazone volatilization. The data suggest that clomazone should be incorporated as quickly as possible after application.

The Volatility of Clomazone as Affected by Soil Moisture and Temperature

by

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INTRODUCTION

Clomazone is an effective broadleaf and grass herbicide that is in the process of being registered for use on certain horticultural crops in the Pacific Northwest. Clomazone also is a very volatile herbicide, producing vapors which are biologically active. Clomazone, if not incorporated immediately, may cause injury to non-target, sensitive crops. The purpose of this study was to determine the effects of soil moisture and soil temperature on clomazone volatilization. These parameters have been shown to affect volatilization of other herbicides. The objective of this research was to generate a regression equation that will model the effect of soil surface temperature and soil moisture on clomazone volatilization. A practical application of this research will be to determine intervals between clomazone application and incorporation that will provide safety to adjacent, sensitive crops.

CHAPTER I

LITERATURE REVIEW

INTRODUCTION

Clomazone is an effective broadleaf and grass herbicide used selectively in soybeans and peas. However, it may volatilize from soil and the biologically active vapors may damage adjacent crops. This paper reviews the literature concerning the phenomena of volatilization and off-site movement of clomazone and other volatile herbicides. The (a) relationship between chemical structure and volatility, (b) processes and interactions influencing rate of volatilization and management after field application of herbicides, and (c) phenomena associated with herbicide vapors that have escaped into the atmosphere will be discussed. Research providing specific information on clomazone also will be reviewed. Most of this research confirms that clomazone exhibits characteristics similar to other volatile herbicides.

VOLATILIZATION

Definition

Volatilization is the phase change of a liquid or solid into a gas (15). Liquids that easily evaporate or solids that easily sublime have weak intermolecular forces. As molecules move with sufficient momentum to overcome these intermolecular forces they form a vapor (the gaseous state of a substance that we would normally think of as a solid or liquid). A solid that sublimes or a liquid that evaporates easily is said to be volatile (10). This change of phase may be from the surface of the liquid or solid, from a matrix covered with a layer of the evaporating substance, or from a solution (19). Volatility is measured in terms of vapor pressure.

Vapor Pressure

Vapor pressure is the pressure of a gas in equilibrium with the liquid or solid phase and is usually recorded in millimeters of mercury (mmHg) at a certain temperature (10). Vapor pressure is an indication of the tendency of pure materials to volatilize (7). Table 1 (20) gives the vapor pressures of some common herbicides and includes clomazone.

TABLE I.1. Vapor pressure of some common herbicides.

Herbicide	mm Hg (torrs) @ 25 C
cycloate	6.2×10^{-3}
dichlobenil	5.5×10^{-4} (20 C)
propachlor	2.3×10^{-4}
clomazone	1.44×10^{-4}
triallate	1.2×10^{-4}
trifluralin	1.1×10^{-4}
alachlor	2.2×10^{-5}
metribuzin	$<1.0 \times 10^{-5}$ (20 C)
atrazine	3.0×10^{-7} (20 C)
simazine	6.1×10^{-9} (20 C)

Temperature and Vapor Pressure

The vapor pressure of a substance is dependent on temperature. As the temperature goes up, the vapor pressure goes up. Once sprayed in the field, determining the amount of herbicide volatilization or evaluating its biological consequences becomes a problem of kinetics (7,15,19). The rate of herbicide loss due to volatilization is not associated solely with equilibrium vapor pressure. There are many things such as soil type, etc. that can influence the rate of loss of a volatile herbicide from the soil.

POST-APPLICATION INFLUENCES ON VOLATILITY

Surface Area

Herbicides may have a relatively low vapor pressure when compared to highly volatile chemicals like diethyl ether. However, in a field application, a small quantity of herbicide is spread over a large surface area, and even herbicides with low vapor pressure will exhibit the characteristic of being very volatile (19). Esters of 2,4-D were shown to volatilize more as the surface area over which the chemical was applied was increased (16).

Herbicide Rates

Swann and Behrens (17) observed that as application rates (ppmw) of trifluralin increase, the rate of volatilization (shown by a decrease in shoot length of plants exposed to trifluralin vapors as opposed to untreated controls) also increases. Increasing the rate of dimethyl amine salts of dicamba applied to corn was also shown to result in an increase (shown by an increase of injury to soybean plants as rates increased) in volatilization (2).

Herbicide Concentration

As herbicide concentration in solution increases, more herbicide is lost due to vaporization (1). However, the loss of trifluralin was greater on a percentage basis, at lower concentrations (1). The vapor density above a treated area increases with concentration to a maximum level. At this point, the vapor density above the soil equals the vapor density of a matrix treated with the pure compound (19).

Soil water also affects concentration of the herbicide. As the water content decreases, the concentration of the herbicide increases (15). As shown earlier, this rise in concentration increases the amount of herbicide that is lost as vapor.

Water vs. Herbicide

Volatilization of herbicides is rapid in a moist soil. Bardsley (1) reports that the volatilization of trifluralin is largely influenced by soil water and suggests that there is competition between water and herbicide for adsorptive sites. Water is adsorbed more easily by soil surfaces than non-polar compounds such as herbicides (7). When soil moisture is increased from air dryness to field capacity, the vapor loss of trifluralin increases (8,13). As soil dries, soil surfaces become available for herbicide adsorption so vapor pressure falls (7,8). The degree of competition between herbicide and water for soil adsorption sites depends upon the structural characteristics of the herbicide. Some compounds can compete quite effectively with water for binding sites and are less sensitive to changes in soil water content (7). Trifluralin is more sensitive to changes in soil water content than metribuzin (8). This is because metribuzin is able to more effectively compete with water for adsorption sites. At normal soil moisture contents, volatilization of herbicides takes place from a dilute aqueous solution at the surface of the soil (15). Typically during the day when the humidity is low, the soil surface quickly dries and volatilization is decreased. At night, with higher humidity, adsorption of herbicides to soil surfaces is decreased and volatilization is increased (7).

Soil Properties that Affect Volatilization

Soil factors such as pH, structure, texture, CEC, and organic matter affect volatilization. When the pH of the soil is low, undissociated forms of anionic pesticides like 2,4-D can volatilize more easily than the dissociated form in a high pH soil (15).

Soil texture and structure can affect the rate of spray infiltration and the soil drying rate. Soil texture along with the herbicide structure can influence how a chemical will adsorb onto soil particles (11,15). Parochetti and Hein (13) found that the vapor loss of trifluralin decreased as soil cation exchange capacity (CEC) increased. Soil organic matter content can affect volatility with higher organic matter resulting in less evaporative loss (19). Organic matter has many sites where herbicides can adsorb or be partitioned. These sites in organic matter and clay are especially important when the soil is moist.

Movement of Herbicide to Soil Surface

Mass Transfer. Hollingsworth (8) reports that as the humidity decreases, the volatilization of trifluralin increases. In this case, as opposed to the case in the previous section, the soil surface must not dry out; if the soil surface became dry, it would provide binding sites for the herbicide as it moves to the soil surface. The rate of evaporation of herbicide is approximately equal to the rate that the herbicide is moved up to the soil surface (8). Initially, the rate of volatilization depends upon the amount of herbicide that is at the soil surface. As this is depleted, the rate then depends on rate of movement from soil depths up to the soil surface (19). As water evaporates from the soil surface, water flows through the capillaries of the soil to replace the evaporated water. Any solutes are also brought to the soil surface (15). Essentially, the solute or the herbicide is wicked to the soil surface by water that is replacing evaporating water.

The wick effect is one explanation of how water affects herbicide volatilization (7). The wick effect decreases as the soil surface dries (14). But at 100% humidity, when there is no upward movement of water, incorporated herbicides were still volatilizing (19). For many years it was thought that codistillation was responsible for the increased volatilization of herbicides from moist soil. However, Plimmer (15) states that there is no increase in volatility due to water evaporation. Vapor density or vapor pressure of herbicide does not increase in the presence of evaporating water (8). This suggests that there may be another mechanism by which herbicides can reach the soil surface.

Diffusion. Diffusion can move herbicide to the soil surface and thus can be a factor in the amount of vapor lost from the soil (7). As a herbicide volatilizes from the soil, a gradient develops that drives the diffusion of herbicide in the soil to the soil surface (15). Vapor diffusion in the soil is controlled in a similar manner as vapor pressure. Temperature, adsorption, porosity, bulk density, the tortuosity of pores in the soil, the number of blocked pores, and soil water content can all influence the rate of diffusion and thus volatilization (7). Herbicides can diffuse 104 times faster as vapor than when they are dissolved in water. The air:water partition ratio of a compound greatly influences the amount of vapor that is in the soil. Some pesticides such as DDT are not very soluble in water. DDT has a low vapor pressure but since it cannot dissolve in water very easily vapor movement can be an important mode of transportation through and out of soil (7). The same may be true for herbicides. Those that are low in water solubility may move through and out of the soil as vapor. When a compound is highly soluble, less of the herbicide is partitioned to the air and thus there may be less vapor movement (7). A compound moves much slower when it is diffusing in water rather than air. Only a small quantity of herbicide is in the vapor phase in the soil, but in that phase, the herbicide moves rapidly (15). When the herbicide moves through the soil to the surface, it may be evaporating so fast that a strong gradient is created.

This gradient, especially in dry soils, may be responsible for the loss of herbicide which has been incorporated. Movement of herbicide through the soil to the soil surface can be by mass transfer (wicking) and diffusion. In a dry soil, diffusion may play the greater role. In a moist soil, it is the wicking of the solute to the surface that is largely responsible for volatilization.

Soil Temperature

Soil temperature not only affects vapor pressure of the compound, but also can influence factors such as desorption, diffusion to the surface, rate of water loss, and establishment of temperature gradients (19). As stated in the previous section, diffusion is controlled by temperature. At higher soil temperatures, the diffusion of the compound may increase. Increasing soil temperatures increases evaporation of moderate to high volatility herbicides (14). Trifluralin volatilization at a soil temp of 40C was greater than the volatilization at 30C (13). Similar results are reported for other herbicides (13). Hollingsworth (8) reports that soil temperature is a factor only when there is a unimolecular layer of water on soil particles. Because of the higher rates of diffusion and reports of volatilization in dry soils, temperature may play a role in dry soils also. High temperatures have also been shown to slow volatilization in moist soils because high temperatures cause more rapid drying of the soil surface. This drying creates adsorption sites for herbicides attachment, thus decreasing volatilization.

Air Movement

The last factor to be discussed that affects the rate of volatilization is the movement of the herbicide from the soil surface to the air that disperses it. Diffusion is responsible for herbicide movement away from the soil surface (19). This is the diffusion of the compound through the stagnant layer of air that surrounds the soil or plant material (19). Wind currents increase the rate of volatilization. Bardsley (1) states that most vaporization experiments are done with still air. He concludes that the loss would be much greater when air movement is high. All the above variables affect the rate of herbicide volatilization from the soil.

OFF TARGET MOVEMENT

Herbicide that has escaped from the soil surface and diffused through the stagnant air layer surrounding the soil or leaf is subject to movement with atmospheric currents. These currents are responsible for the movement of herbicide away from the treated area (19). Also, topographical features, variations in air density, nature of the surface cover, and surface temperature can influence the fate of these herbicides (15). As the herbicide moves farther away from the treated area, the concentration diminishes. Behrens and Leuschen (2) show that soybeans placed farther from a test area show less symptoms than soybeans placed closer to the test area. They also report that symptoms for dicamba vapor were detected as far as sixty meters downwind from the test area. Plimmer (15) states that crop damage from growth regulator herbicides have been measured up to fifteen miles from the application area. Herbicides mainly affect the plants downwind from the sprayed field with differences being quite great between plants upwind and downwind from the source (2). Also there may be differences between various herbicides and the distance at which active herbicide vapor concentrations exist. Eagle (4) reports the iso-octyl esters of dichloprop caused crop damage at 60 meters and that mecoprop caused crop damage at 100 meters. This difference may reflect the biological activities of the two compounds.

Exposure time may play an important role in crop damage. Increasing exposure time increased dicamba vapor injury to corn in closed chamber experiments (2). In a field situation, the longer a herbicide is left unincorporated on the surface, the more potential crop damage it can cause to downwind crops. Mecoprop vapors damaged *Brassica* species that were not exposed until 30 hours after spraying. Plants set out at 54 hours did not show symptoms (4).

Damage to Plants

Foliage can intercept these vapors and thus take up enough herbicide to cause injury to the plant. It was shown that benefin vapors were absorbed by the entire foliage of a plant including the stem and the tip with a few developed leaves. The herbicide was retained by the waxy layers on the leaf. There was little movement from the expanded leaves to the stem tip (21).

CLOMAZONE

Mode of Action

Clomazone inhibits carotenoid pigment (a tetraterpenoid) synthesis which results in chlorophyll destruction. Carotenoids remove singlet oxygens from the photosynthetic system. When the carotenoids are absent, the unstable singlet oxygen atoms destroy chloroplast membranes by oxidizing them (3). The damage to plants may not be permanent. New foliage produced once the chemical is gone is green. Recovery rate from clomazone damage was variable between species (6). Clomazone may block both diterpene (e.g., phytol and gibberellic acid) and tetraterpene synthesis. This block causes a build up of sesquiterpenoids and triterpenoids, some of which act as growth inhibitors. So, besides bleaching due to lack of carotenoid, clomazone also slows growth.

Clomazone Vaporization

Off-target movement of clomazone is greatest during the first week after application (6). It has also been detected for up to thirty days after application (18).

Halstead and Harvey (6) reported that there was less movement from areas with the lowest rates applied. As rates increased, volatilization increased (6). Carrier volume did not seem to significantly affect volatilization, at least for carrier volumes within the usual range (6). Clomazone would probably need a carrier volume as high as 6000 L/ha to leach it far enough into the soil to prevent volatilization (6).

Volatilization of clomazone was 30 to 65% greater in wet soil than in dry soil (5). Incorporation of clomazone immediately after herbicide application reduced off-target movement, but didn't stop it completely (6,18). Thelen (18) found that clomazone was volatilizing up to two weeks after application both from surface applied and incorporated treatments. They also showed that clomazone volatilization increased when it was applied to a field with crop debris on the surface. It was shown that clomazone is adsorbed more by organic matter than by clay (12). Therefore, soils with high organic matter content may allow less clomazone to volatilize after incorporation.

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CHAPTER II

The Volatility of Clomazone as Affected by Soil Moisture and Temperature

Steven R. Eskelsen and Garvin D. Crabtree[1]

ABSTRACT

An experiment was done to test the effect of soil temperature, wind velocity, exposure time, and soil moisture on the volatilization of clomazone {2-[(2-chlorophenyl)methyl]-4,4-dimethyl-3-isoxalidinone} applied to a seedbed but not incorporated. The following regression equation was generated using the data from the experiment: $\mathrm{LOG(chl)} = 4.037574 - 0.01732(t) + .002039(m) + 0.01732(h) + 0.015671(w) - 0.000041(t)(m)(h)(w)$. R^2 value of the equation is 21.02%.

The lack of fit and the contradiction of some aspects of the model to literature is due the variability of plant response to clomazone vapors. Clomazone volatilizing within 1.5 hours after application can affect off-target plants and should be quickly incorporated.

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INTRODUCTION

Clomazone, a selective, premergence herbicide that controls many broadleaf and grass weeds, is in the process of being registered on certain horticulture crops in the Pacific Northwest. Clomazone has a relatively high vapor pressure of 1.44x10-4 mm Hg at 25C and therefore has a tendency to evaporate and move away from treated areas. The chlorosis caused by clomazone vapors is a concern when the vapors drift off-target and affect susceptible species. Incorporation of clomazone immediately after herbicide application reduces off-target movement, but did not eliminate it completely (4,11). The clomazone (Command) label requires that the herbicide be incorporated within 3 hours of application.

Soil moisture and temperature are among the variables that can affect the amount of clomazone that will evaporate and move away from treated soil. Volatilization of herbicides is rapid from the surface of moist soil. Bardsley (2) reports that the volatilization of trifluralin is largely influenced by soil water and suggests that there is competition between water and herbicide for adsorptive sites. Water is adsorbed more easily by soil surfaces than non-polar compounds such as herbicides (5). When soil moisture is increased from air dryness to field capacity, the volatility of trifluralin increases (6,9). As soil dries, soil surfaces become available for herbicide adsorption so vapor pressure of trifluralin falls (5,6). At normal soil moisture contents, volatilization of herbicides takes place from a dilute aqueous solution at the surface of the soil (10). Volatilization of clomazone is 30 to 65% greater in wet soil than in dry soil (3).

Soil temperature not only affects vapor pressure of the compound, but also can influence factors such as desorption, diffusion to the surface, rate of water loss, and establishment of temperature gradients (12). Trifluralin volatilization at a soil temperature of 40C is greater than the volatilization at 30C (9). Similar results are reported for other herbicides (14). Hollingsworth (6) reports that soil temperature is a factor only when there is a unimolecular layer of water on soil particles at or near the soil surface. High temperatures also slow volatilization in moist soils because high temperatures cause more rapid drying of the soil surface (5). This drying makes available adsorption sites for herbicide attachment, thus decreasing volatilization.

The purpose of this study was to determine the effects of soil moisture and soil temperature on clomazone volatilization. The objective of the research was to generate a response surface or a regression equation to model clomazone volatilization using soil temperature and soil moisture. Chlorophyll content of a test plant species was used as the measure of the presence of clomazone as influenced by soil moisture and temperature. The response surfaces could be an important source of information for determining a safe interval between application and incorporation under given soil moisture and temperature conditions.

MATERIALS AND METHODS

Plant Material

Radishes (Raphanus sativus L. cv. Everest) were planted in plastic pots (9.4 X 9.4 X 8.6 cm) containing sterilized greenhouse potting soil. The plants grew in a greenhouse (24C/20C day/night) under cool white fluorescent lights (PAR 500 $uE \cdot m^{-2} \cdot s^{-1}$) until the first true leaves were 0.5 cm long. The plants were then grown under ambient light conditions. The plants were fertilized at every watering by subirrigation with a soluble fertilizer (2.65 g of N:P:K 20:20:20/ l of water). When the plants had two well developed true leaves and the third leaf was visible, they were taken to the field and exposed to clomazone vapor. After exposure in the field, radish plants were returned to the greenhouse and grown to the fourth true leaf stage (10 d) before harvesting for chlorophyll analysis.

Field Experiment

Soil type at the experimental site is Chehalis silty clay loam (cumulic ultic haploxeroll). Soil was prepared as a seed bed. The experiment was carried out from August-December, 1988. A unicycle sprayer was used to spray an area 2.4 m wide and 12.2 m long with clomazone at

0.9 kg active ingredient per hectare with a 35 l per hectare carrier volume. The unicycle sprayer had five 8003 nozzles spaced 48 cm apart and sprays were applied at 30 psi. The length of the sprayed area was perpendicular to the prevailing wind direction for that day. After 15 min, 60 pots of radishes at the two true leave stage were set out in a line parallel to the length of the sprayed area, 1 m from the edge of the sprayed area in the downwind direction. The line of pots was placed in the center of the length of the sprayed area. The radishes were divided into 15 groups of 4 along the line. After 1.5 h of exposure to clomazone vapors, 15 pots, one taken from each group of four, were removed from the test area and taken to the greenhouse. The same procedure was used at 3, 6, and 12 h exposure times. The soil moisture at the surface of the seed bed was measured initially and at the end of the 12 h interval. Soil samples 10 cm X 10 cm and 1 cm deep were placed in metal soil cans and subsequently oven dried. Soil moisture percentage was calculated on a w/w basis. Since soil moisture was only measured in the beginning and the end of the 12 h interval, the graph of the equation

$$y=1/\log x$$

was used to estimate soil moistures for the 1.5, 3, and 6h exposure times (8). This method is used to estimate the other intervals because as soil dries, the energy required to release water molecules increases in a logarithmic fashion.

Soil surface temperature was measured with a Telatemp infrared thermometer initially and at the end of each sampling time. There were 20 repetitions on different plots during this 5 month period with different soil moistures and soil surface temperatures measured for each repetition. During August and September, some plots were moistened by sprinkler irrigation. During October, November, and December, some plots were kept dry by covering them with plastic.

A portable weather station, within 1000 meters of the test plots, was used to obtain wind speed measurements. Wind speed was recorded every 15 minutes. Wind speed was averaged for all of the exposure times.

Chlorophyll Analysis

The third and fourth true leaves of the radish were harvested, 10 leaf disks (.3077 dm^2) were cut from the widest part of the leaf and the disks from each leaf were placed in 20 ml of dimethylformamide (DMF). Absorbance was measured with a Shimadzu 260 (Shimadzu Scientific Instruments, Columbia, MD)spectrophotometer at wavelengths of 750, 664.5 and 647 nm. The amount of chlorophyll was determined using equations from Inskeep and Bloom (7). A set of control plants was grown at the beginning of the experiments and analyzed by the same procedure for chlorophyll.

Analysis of Data

The data were analyzed by regression analysis. The variables in the final model are: the LOG of the third leaf chlorophyll content (percent of the untreated control), soil moisture (percentage), soil temperature (C), wind speed (km/h), and the length of exposure (h). A log transformation was used in order to satisfy assumptions of regression analysis. In the final model, an average of all of observations that had the same length of exposure were used. This reduced the number of data points to be analyzed from 977 to 80 (There was a total of 1500 observations but some plant material was damaged and could not be used. This damage was not a result of clomazone vapors. This averaging was necessary to satisfy the assumptions of regression analysis. The regression analysis of all the observations did not satisfy the assumptions of regression analysis.

RESULTS AND DISCUSSION

In Figures II.1 and II.2, the response[2] of the bioassay radish plant is plotted against soil temperature and soil moisture, respectively. Plant response gives an indication of clomazone volatilization. There is no evident trend in either figure (Figures II.1 & II.2). Part of the reason for the lack of a trend is the fact that the variability in the plant response is quite high as shown in Figures II.3 and II.4. In Figure II.3, all of the observations[3] of plant response are plotted against soil moisture. Single observations at approximately 1 degree C in figure 3 ranges from about 1% where the third leaf was white, to 100% where the third leaf was green, showing no herbicide symptoms (standard deviation = 31.9495). The same kind of variability is evident in Figure II.4 where all observations of plant response are plotted against soil moisture. The regression equation

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[2] In Figures 1 and 2 the plant response refers to chlorophyll content as a percent of the control and is derived from the average of all the observations taken at a particular time of exposure for a particular repetition (eg. There were 15 third leaves harvested for plants exposed for 1.5 h on the second repetition or second day of experimenting.) There were 20 days and 4 time periods per day so that each point on the graph represents 10-15 observations.

[3] Data points in Figures 3 and 4 represent single observations.

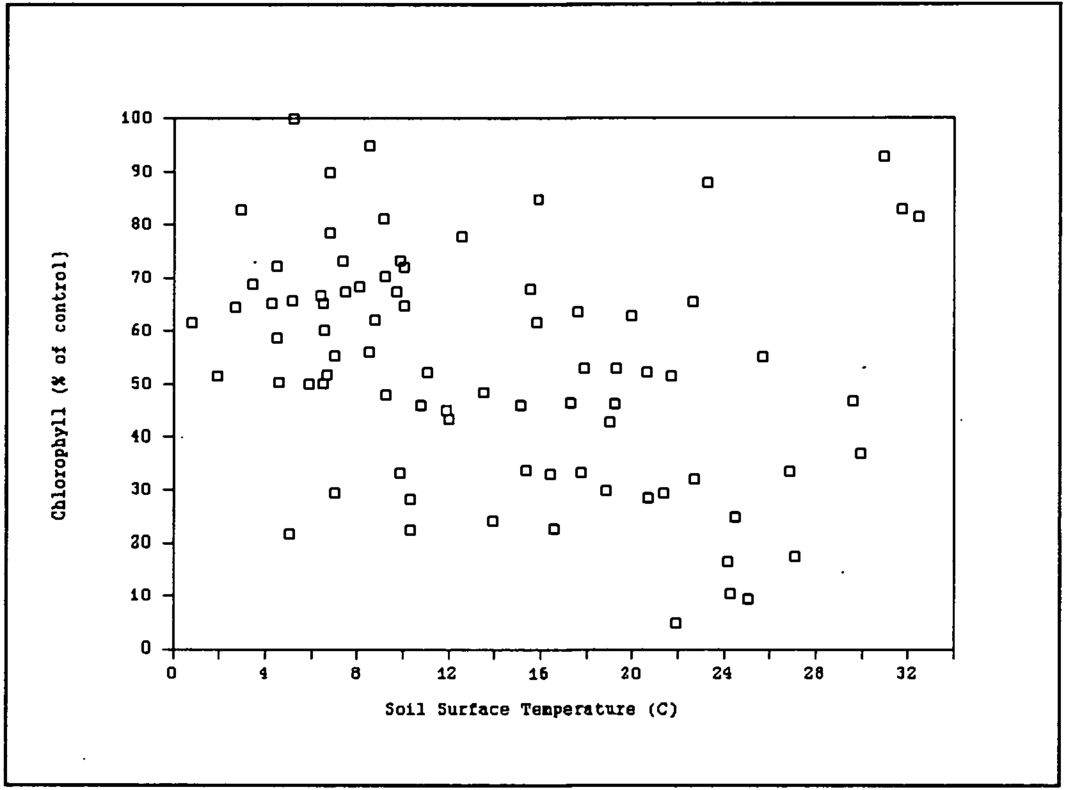

Figure II.1. Off-target plant response (chlorophyll as % of control) to clomazone as affected by soil surface temperature (C). Each point represents an average of all observations for a particular length of exposure for a particular repetition.

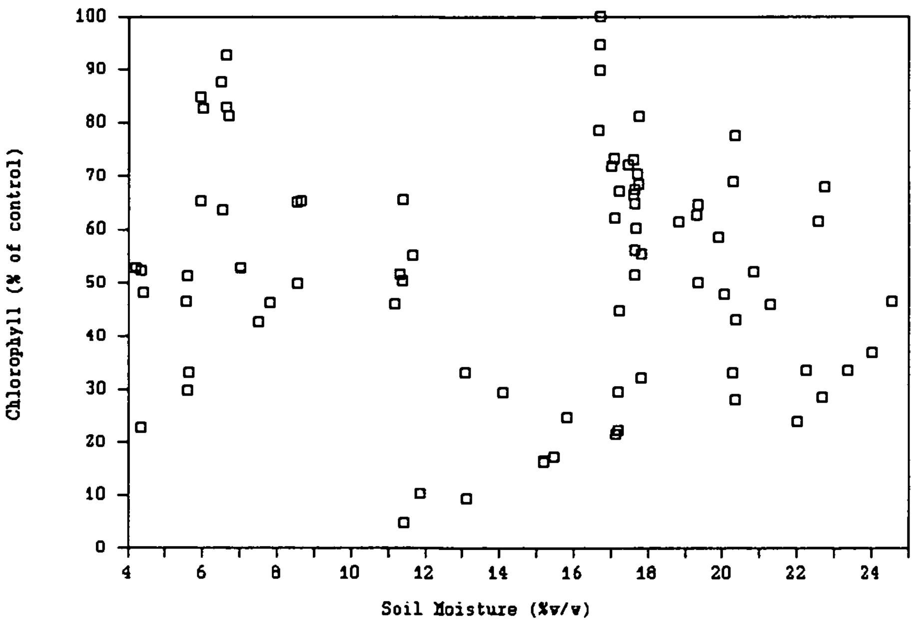

Figure II.2. Off-target plant response (chlorophyll as % of control) to clomazone as affected by soil moisture at the surface. Each point represents an average of all the observations for a particular time of exposure for a particular repetition.

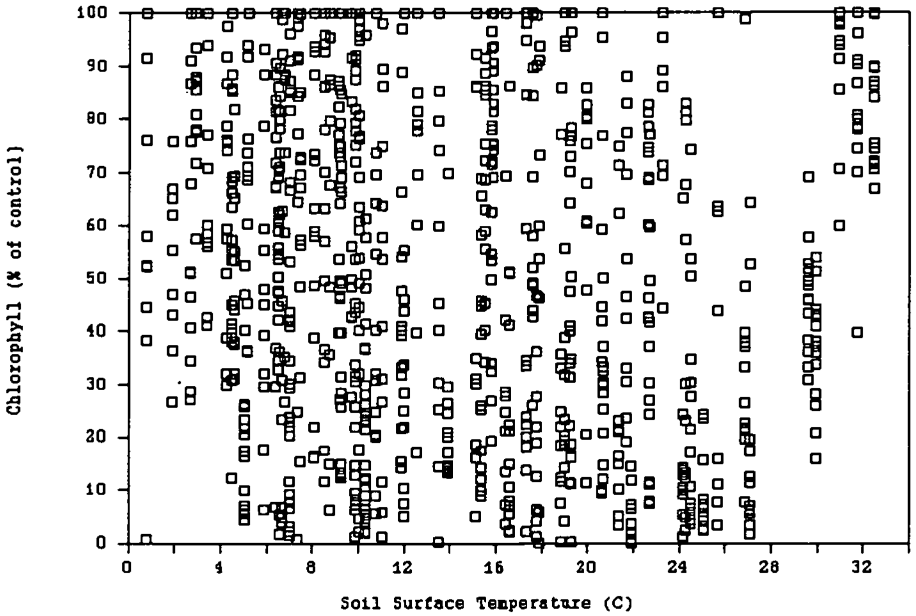

Figure II.3. Off-target plant response (chlorophyll as % of the control) to clomazone as affected by soil temperature.

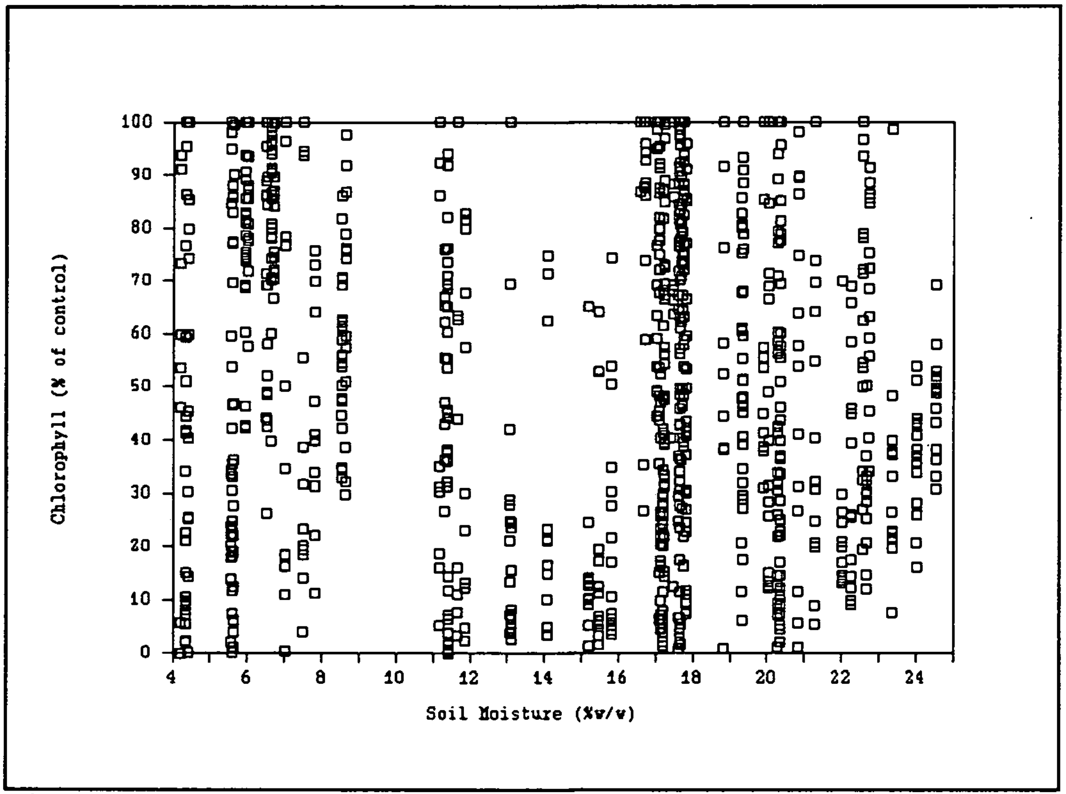

Figure II.4. Off-target plant response (chlorophyll as % of control) to clomazone as affected by soil moisture at the surface.

generated by these two variables presented in Figures II.1 and II.2 is:

$$LOG(Chl) = 3.3899369 + 0.002003(t) + 0.019837(m) - 0.001862(t)(m).$$

where Chl is a measure of herbicide damage (chlorophyll as % of control) of all plants exposed for the same period of time on a particular repetition (day)[4], t is the average temperature during the exposure period (temperature in degrees C), and m is the average soil moisture at the surface of the soil during the exposure period on a particular repetition (% moisture on a w/w basis). The R^2 value of 12.5% for the regression reflects the large variability in the response of radish plants to clomazone vapors.

To account for some of this large variability, wind velocity and exposure period were added to the model. Figures II.5 and II.6 show off-target plant response to these two variables. There is no trend present in either figure. When these variables are included in the model, the regression equation now appears as follows:

$$LOG(Chl) = 4.037574 - 0.01732(t) + 0.002039(m) + 0.01732(h) + 0.015671(w) - 0.000041(t)(m)(w)(h)$$

---

[4] See footnote 1

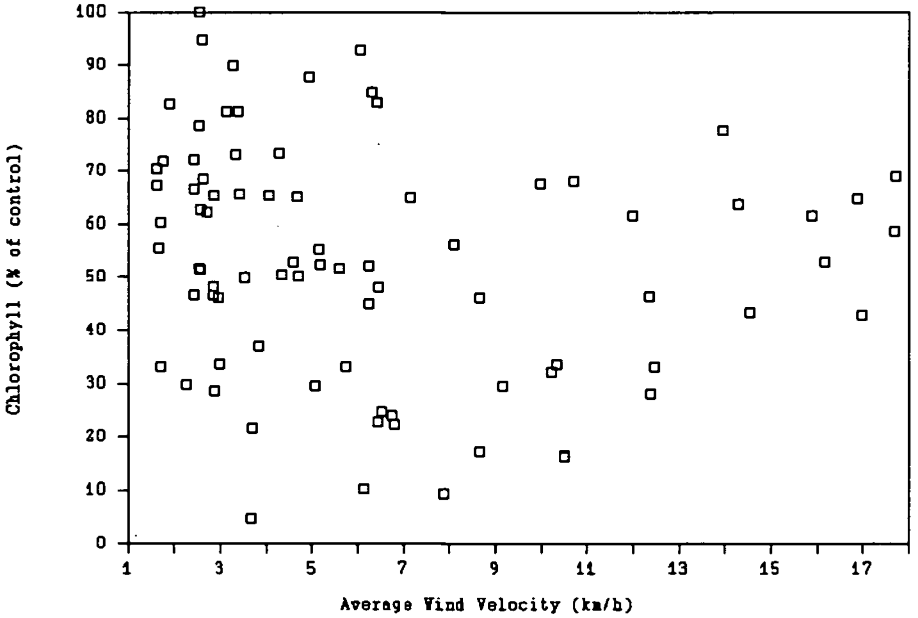

Figure II.5. Off-target plant response (chlorophyll as % of control) to clomazone as affected by average wind velocity during exposure period.

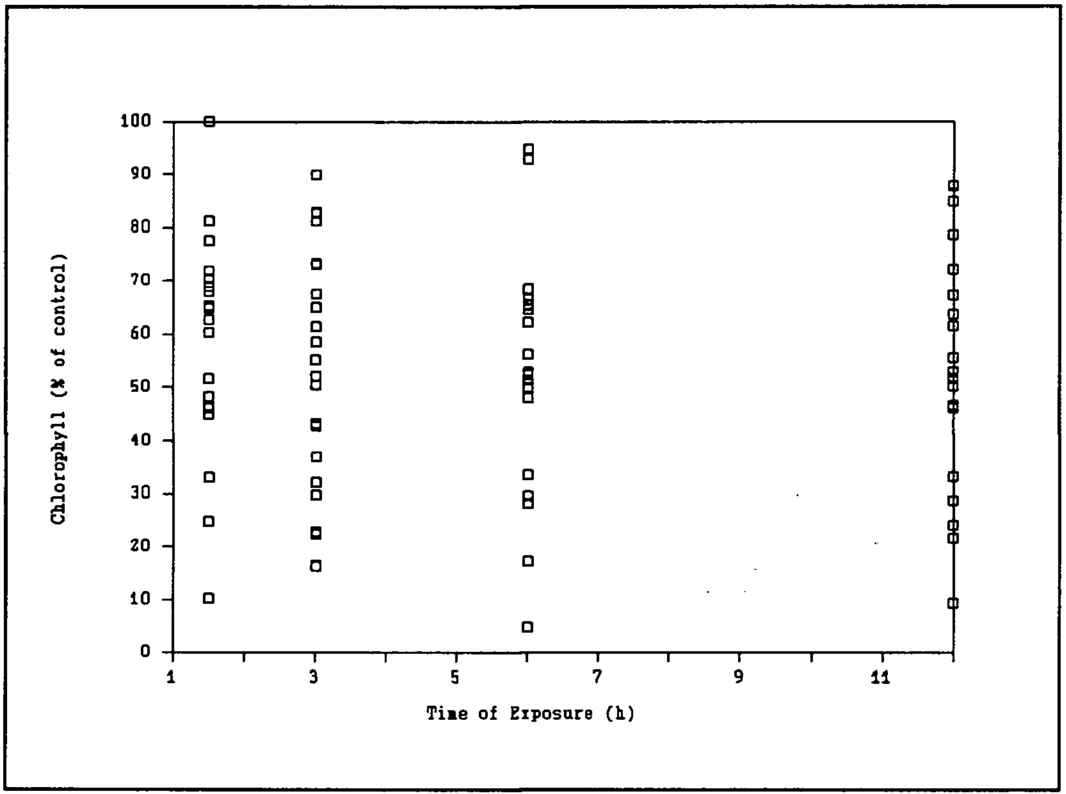

Figure II.6. Off-target plant response (chlorophyll as % of control) to clomazone as affected by length of exposure.

(km/h) during exposure time. The R^2 value for this regression equation is 21.02% which indicates that it better describes the data than the first equation.

This model does not agree with Bardley's (2) observation that soil moisture causes herbicides to volatilize faster. The model developed by the research reported here shows that increased soil moisture did not result in increased off-target plant response to clomazone vapors. One possible explanation for this result is that on repetitions done on irrigated soil in the summer, soil at the surface may have dried, and thus adsorbed clomazone molecules.

The model, which shows that as temperature increases plant injury or volatilization increases, agrees with Parochetti and Hein (9). The model shows that as wind speed increases volatilization decreases. This does not agree with information presented by Plimmer and Tinsley (10,12). Wind has a negative effect because it removes herbicide vapors from above the herbicide treated soil surface. This ensures that there is always a high clomazone concentration gradient between the soil and the air above the treated soil and the higher the gradient, the faster is the evaporation process. The wind may also disturb the thin layer of stagnant air that the herbicide must pass through just after volatilization. The diffusion of the herbicide through the stagnant air layer (12) can slow down the rate of volatilization. If the stagnant air layer is broken up, this diffusion process will not be limiting and the herbicide volatilizes at the maximum rate. The wind also may be a source in this study of some of the high variability in plant response. As wind speed increases, the rate of herbicide volatilization increases (2) until it reaches a certain maximum level with a constant rate of herbicide volatilization. Wind may then have an additional effect. As wind speed increases, the volume of air (liter/sec) that passes over the herbicide treated soil surface of the experiment increases. This results in a decrease in the concentration of clomazone vapor in the air which may consequently decrease the amount of herbicide vapor available for uptake by the test plants.

The dose of herbicide received by the tested portion of the plant also may depend upon the size of the third and fourth leaves. Clomazone is not phloem mobile (1) in plants which means that the herbicide symptoms in the third and fourth leaves were caused by the dose of herbicide they (the third and fourth leaves) received. Since there was some variation in the size of the third and fourth leaves, the amount of herbicide intercepted may reflect the size of the leaves at the time of exposure.

The small variation in the size of the leaves may have translated into a large variation in the chlorophyll content of exposed leaves.

The effect of exposure time as described by the model also fails to support findings reported in the literature. Hance (3) showed that as exposure time increases, damage to plants increases because more herbicide vapors reach the plants. This may mean that in the study reported here plants received a high enough dose to cause the maximum response in the first 1.5 hour of exposure to clomazone vapors. When all of the variables are included in an interaction term, there is a slightly negative but insignificant response.

An experimental design similar to that of Halstead and Harvey (3,4) was used to conduct this experiment. Complete emulation was not possible because the experiment was conducted over a period of 4 months. Under these circumstances, bioassay plants would not be uniform if grown in the field. In the greenhouse, fairly uniform test plants were produced.

Additional plant material would have been difficult to manage because of time constraints, but it may have been possible to decrease variability by using more plants per observation with fewer exposure times. Direct measurement of clomazone vapors by chemical methods may be another approach to avoiding the variability associated with the plant material and plant response to the herbicide in a bioassay system as used in this study.

In conclusion, using regression analysis, a model was developed to describe off-target clomazone movement from soil surfaces. Much of the variance in the experiment could not be attributed to the factors (soil moisture, temperature, wind velocity, exposure time) included in the model. A better way of decreasing the variability of the plant response is needed. Also, from the regression equation and the observations, it appears that clomazone vapors can cause the maximum response in a plant in a short time. In a practical sense, this confirms that clomazone should be incorporated as quickly as possible to avoid vapor drift to sensitive crops.

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CHAPTER III

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CHAPTER IV

APPENDIX

TABLE IV.1. Soil temperature and moisture data taken during the experiment.

	Soil Temperature (C)					Soil Moisture (% w/w)	
Date	0 hrs	1.5 hrs	3 hrs	6 hrs	12 hrs	0 hrs	12 hrs
8/24	11.3	21.1	30.9	25.6	10.7	6.2	5.8
9/1	17.4	22.5	28.1	35.8	22.0	20.6	7.8
9/13	27.9	31.3	30.6	22.2	11.9	25.0	21.0
9/16	39.8	25.1	30.2	22.8	7.2	6.9	6.1
9/20	23.8	25.2	23.6	16.8	8.6	16.4	10.9
9/27	22.2	26.3	28.4	15.0	8.0	12.0	10.6
10/3	16.9	18.6	21.0	27.1	8.0	5.7	5.3
10/14	19.8	18.6	18.7	19.3	13.7	8.1	5.5
10/18	9.5	17.6	22.8	29.6	14.5	4.6	3.8
11/4	16.3	14.7	16.3	13.3	12.1	22.9	21.4
11/11	11.4	13.7	10.8	8.7	9.5	20.4	20.1
11/18	9.5	10.5	9.1	6.9	3.4	17.7	17.6
11/28	9.8	11.7	11.5	6.4	1.4	21.7	17.8
11/28*	9.8	14.0	7.1	4.1	1.2	17.3	16.9
12/3	5.6	7.4	9.0	4.6	3.2	17.9	17.1
12/3*	6.9	3.4	9.9	8.7	4.7	16.7	16.6
12/8	8.7	9.7	9.0	6.5	5.8	17.6	18.0
12/8*	10.1	9.9	9.5	6.5	5.6	16.8	17.6
12/15	0.6	6.2	6.5	0.9	0.8	20.6	17.6
12/17	-1.1	4.8	10.0	6.6	-2.2	11.1	11.9
12/17*	0.9	7.6	10.9	7.5	-2.9	8.9	8.0

* These repetitions were done in a different field that had been covered with plastic in the fall to keep soil dry.

TABLE IV.2. Results of chlorophyll analysis of radish 3rd and 4th leaves exposed to clomazone vapors for 90 minutes.

		Observation														
Date	Leaf	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		(mg Chl/dm^2)														
9/1	3	3.65	0.91	3.78	3.56	3.54	3.0	3.53	2.11	2.7	2.67	0.5	3.33			
	4	3.71	1.71	3.95	3.41	3.96	3.19	1.72	2.95	3.42	2.45	1.56	3.75			
9/13	3	1.69	2.02	1.6	2.33	2.03	1.47	2.18	1.91	1.36	2.2	2.29	2.56	3.05	2.15	
	4	3.1	4.15	3.78	4.07	3.33	3.77	2.63	2.99	3.11	3.4	3.56	3.79	4.34	3.49	
9/16	3	2.95	4.4	3.96	3.16	4.42	3.29	3.16	3.96	3.71	3.33	3.18	3.11	3.81	3.84	
	4	3.14	4.77	4.01	3.15	5.39	4.57	3.94	3.81	4.04	3.44	4.17	3.14	3.21	4.58	
9/20	3	1.34	0.23	0.19	0.95	0.47	2.38	0.29	3.28	1.54	2.23	1.22	0.75	0.32	0.16	
	4	3.84	0.47	1.13	2.19	2.16	3.86	0.77	3.23	4.75	1.05	4.8	2.84	0.77	0.85	
9/27	3	2.99	3.65	1.33	3.59	1.02	3.52	0.58	0.1	0.54	0.21	2.53				
	4	5.86	4.5	1.86	3.94	2.4	4.3	0.5	0.02	1.54	0.49	1.81				
10/3	3	1.22	3.98	4.4	0.55	0.27	0.83	1.6	0.05	2.07	0.97	0.18				
	4	1.24	3.57	4.38	1	1.46	1.65	0.68	0.67	1.82	1.37	0.54				
10/14	3	3.35	1.81	2.09	2.84	1.38	0.5	0.97	3.09	1.5	3.22	1.76				
	4	3.32	1.56	3.09	2.38	2.71	1.13	2.19	4.23	0.79	2.64	5.46				
10/18	3	2	3.52	4.54	0.63	1.39	0	2.65	1.78	1.12	3.77	1.12	3.28			
	4	4.01	2.79	4.52	2.1	1.84	0.75	3.87	3.27	1.75	3.37	2.84	4.34			
11/4	3	2.46	3.91	3.81	3.2	2.61	3.74	4.04	1.78	3.33	2.01	1.51	2.79	3.03	3.78	
	4	3.65	3.66	4.09	3.12	4.12	2.94	3.78	3.51	4.45	2.6	3.59	3.99	2.59	3.96	
11/11	3	3.59	3.43	6.82	3.76	5.1	3.48	4.58	1.76	0.75	4.54	2.66	4.69	3.07		
	4	4.12	5.82	7.06	3.79	5.47	4.55	4.6	3.97	2.74	4.65	3.36	4.39	5.3		
11/18	3	4.22	4.66	1.78	4.45	5.73	8.18	2.69	3.38	3.57	0.1	1.42	0.2	4.28	0.78	
	4	2.86	4.14	1.92	5.84	6	8.14	2.61	2.94	4.36	1.25	4.92	2.78	4.25	1.46	

TABLE IV.2 (con't)

		Observation														
Date	Leaf	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		(mg Chl/dm^2)														
11/28	3	0.39	4.44	2.42	4.93	0.91	0.24	1.78	1.36	1.1	1.42	0.88	3.08	3.25	2.84	
	4	4.05	4.7	1.3	4.93	0.49	1.21	3.74	3.25	2.67	1.88	3.36	2.97	4.27	3.61	
11/28*	3	3.93	2.1	1.78	0.63	1.8	1.73	2.94	1.47	1.74	1.4	0.96	0.68	4.28	2.39	
	4	3.55	1.94	2.59	1.75	2.02	1.21	3.38	1.35	2.68	2.04	2.53	0.96	5.26	1.22	
12/3	3	3.59	0.07	3.26	2.75	3.96	3.14	3.46	1.6	3.52	3.72	0.24				
	4	3.25	0.03	3.6	4.26	3.09	4.33	3.82	1.29	3.54	3	3.16				
12/3*	3	5.98	6.43	6.38	4.51	6.33	5.81	5.10	7.81	4.49	5.81					
	4	6.75	6.91	6.44	6.08	6.14	7.61	7.17	8.19	3.66	6.88					
12/8	3	3.99	3.47	3.5	2.05	3.23	3.78	2.97	5.13	3.31	1.2	2.19	2.84	2.07		
	4	3.28	3.99	3.45	3.98	4.77	3.72	3.47	3.63	2.84	1.36	2.95	2.55	3.12		
12/8*	3	3.39	4.53	4.59	3.39	2.81	1.97	2.17	2.38	4.19	2.61	3.05	4.36	2.17		
	4	4.44	7.37	6.85	3.17	4.51	6.51	6.05	2.74	5.5	3.12	5.66	6.55	2.35		
12/15	3	4.15	4.55	2.48	5.21	3.13	3.41	2.66	2.59	1.88	1.82	2.51				
	4	4.37	3.75	3.97	4.33	3.15	2.79	2.93	3.39	3.55	2.42	4.11				
12/17	3	2.96	3.35	1.6	2.74	2.89	2.08	1.61	1.9	2.45	1.18					
	4	3.56	3.11	1.09	3.24	3.55	2.66	2.26	2.41	2.11	1.38					
12/17*	3	3.28	4.31	1.71	1.42	2.25	4.05	1.32	3.34	2.63	3.83	3.36	2.54	3.48		
	4	3.3	2.8	3.65	4.29	3.21	3.91	4.06	3.65	3.45	3.32	2.4	2.94	2.73		

* These repetitions were done in a different field that had been covered with plastic in the fall to keep soil dry.

TABLE IV.3. Results of chlorophyll analysis of radish 3rd and 4th leaves exposed to clomazone vapors for 3 hours.

		Observation														
Date	Leaf	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		(mg Chl/dm^2)														
8/24	3	3.57	3.45	3.86	3.78	3.17	4.43	4.13	3.88	2.55	3.78	3.85	3.43			
	4	3.72	4.01	5.07	3.66	3.63	4.11	4.14	3.84	3.17	4.22	3.7	0.61			
9/1	3	1.19	1.64	2.2	0.35	2.64	1.35	1.84	1.08	0.33	3.41	0.49	0.52			
	4	2.02	3.5	2.64	0.45	2.72	2.2	3.76	2.72	2	3.27	0.62	1.44			
9/13	3	1.24	1.64	1.15	1.59	1.68	1.95	1.8	2.38	2.26	1.9	1.9	0.71	1.49	0.92	1.9
	4	3.68	3.08	3.03	3.53	2.22	2.58	3.24	3.66	1.57	3.67	0.93	2.09	2.99	1.14	3.05
9/16	3	3.28	4.68	4.44	4.24	4.02	3.53	3.99	1.76	3.83	3.46	3.83	4.02	3.45	3.1	3.57
	4	3.84	5.24	4.48	3.92	4.98	3.39	3.67	4.98	3.8	4.77	4.09	4.11	3.85	4.36	3.63
9/20	3	0.23	0.63	0.44	0.06	0.56	0.61	0.46	0.59	0.4	2.88	1.08				
	4	0.84	0.22	0.61	0.67	1.32	1.52	1.56	1.97	0.83	3.63	1.72				
9/27	3	4.9	2.77	4.66	0.34	4.53	0.71	1.94	2.81	0.15	5.82	0.49				
	4	1.81	4.87	1.49	5.93	0.63	4.66	0.67	2.75	2.85	0.26	4.82				
10/3	3	0.01	3.4	0.52	1.58	0.97	1.46	0.81	3.79	0.55	0.33	1.1				
	4	0	3.59	2.92	2.79	2.26	2.42	1.57	3.83	0.76	0.6	0.1				
10/14	3	1.03	4.14	0.18	4.76	0.63	0.82	2.45	1.4	1.71	4.18	0.86	0.89			
	4	2.6	4.35	1.6	4.04	3.81	0.99	3.44	4.55	3.18	4.56	3.12	1.51			
10/18	3	0.1	0.46	0.24	2.25	0.31	3.81	0.66	0.36	0.99	0.1	1.82	0.93			
	4	0.55	3.55	0.78	3.34	2.96	3.9	0.28	2.08	2.19	1.04	2.79	1.83			
11/4	3	2.76	5.49	2.37	2.41	1.44	1.19	3.18	4.27	4.13	1.5	3.16	3.48	3.45	2.2	0.86
	4	4.46	5.77	3.15	4.62	2.58	2.99	2.52	4.27	5.2	2.21	2.38	2.57	2.33	3.57	1.98
11/11	3	1.26	1.93	2.03	4.79	0.46	1.26	5.44	1.48	1.1	2.45	0.33	0.97	4.79	0.22	
	4	2.97	2.74	2.84	4.87	2.91	3.93	5.54	2.25	0.91	3.34	1.51	2.94	4.42	1.52	

TABLE IV.3 con't.

		Observation														
Date	Leaf	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		(mg Chl/dm^2)														
11/18	3	2.14	1.89	5.02	4.81	4.04	1.22	1.9	2.48	5.66	3.68	2.2				
	4	3.25	3.01	5.92	3.07	3.59	2.32	3.45	3.28	5.76	4.37	3.85				
11/28	3	3.96	3.3	2.82	1.18	3.95	4.33	1.81	0.05	2.55	0.26	1.38	3.81	0.51	2.38	
	4	3.62	4.05	3.12	3.23	4.55	4.57	2.69	0.89	3.37	1.44	2.42	4.48	2.17	2.46	
11/28*	3	0.32	1.16	0.28	2.71	2.12	0.08	0.18	0.27	0.95	0.24	1.32	1.83	1.03	1.24	1.07
	4	0.99	1.61	0.15	2.68	2.96	0.03	0.16	0.39	1.77	0.22	1.43	2.96	0.76	0.93	1.08
12/3	3	3.42	4.03	2.85	4.38	4.31	3.72	4.44	1.1	0.04	4.05					
	4	3.1	4.94	2.21	4.49	3.79	4.02	4.09	3.66	0.28	3.77					
12/3*	3	2.59	6.45	5.38	6.09	6.39	3.91	3.87	3.26	6.48						
	4	6.99	7.04	6.24	5.84	5.41	4.56	5.27	5.33	5.66						
12/8	3	2.37	3.25	3.33	3.85	3.64	1.75	3.81	4.68	3.41	6.23	5.48				
	4	2.62	3.39	3.44	1.77	3.78	1.97	4.55	4.1	3.94	6.88	6.67				
12/8*	3	2.37	3.32	4.82	4.04	0.27	6.24	5.31	3.19	3.62	3.43	3.86	1.93	2		
	4	4.5	3.29	6.86	2.9	1.37	6.44	6.1	3.43	3.89	3.88	4.81	3.13	3.71		
12/15	3	1.83	1.99	4.61	2.53	2.45	1.71	1.37	1.68	4.91	3.77	2.36				
	4	1.92	3.47	3.83	3.41	2.86	3.75	2.33	2.38	4.6	5.82	2.46				
12/17	3	3.62	2.37	1.66	3.06	2.88	1.38	1.95	2.02	1.42	2.44	1.68				
	4	3.21	1.82	3.59	1.96	1.39	2.16	3.4	1.93	1.8	2.41	1.87				
12/17*	3	3.11	2.72	3.61	3.8	2.47	2.69	2.11	2.6	3.06	3.06	2.47				
	4	4.24	2.86	3.66	3	3.34	3.07	3.43	2.52	2.43	3.04	3.19				

* These repetitions were done in a different field that had been covered with plastic in the fall to keep soil dry.

TABLE IV.4. Results of the chlorophyll analysis of radish 3rd and 4th leaves exposed to clomazone vapors for 6 hours.

		Observation														
Date	Leaf	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		(mg Chl/dm^2)														
8/24	3	1.89	3.04	3.65	3.47	3.26	1.87	2.66	2.04	3.58	3.06	3.29				
	4	1.94	2.51	3.76	3.77	2.98	1.05	3.6	1.69	3.03	4.04	2.7				
9/1	3	0.76	0.5	0.28	0.08	2.33	2.84	0.25	0.27	0.55	0.86	0.3	0.15			
	4	0.82	0	0.4	0.19	2.73	2.06	0.31	0.26	1.7	0.49	0.47	1.08			
9/13	3	1	0.94	2.13	0.87	1.47	0.34	1	0.96	1.76	1.64	1.17	1.37	4.36		
	4	0.83	4.5	4.41	1.09	1.6	1.59	1.96	2.58	1.48	3.1	2	3.81	5.42		
9/16	3	4.03	4.18	3.78	4.15	4.86	5.55	4.84	2.65	5.18	3.12	4.95	5.17	4.34	4.38	4.31
	4	4.12	4.09	4.33	4.52	4.94	5.53	6.15	4.21	5.13	3.24	5.96	6.21	4.36	4.38	5.36
9/20	3	0.95	0.66	0.15	0.44	0.93	3.31	0.22	1.02	2.76	0.73	3.15				
	4	3.51	5.32	0.1	0.99	1.16	4.66	4.52	3.51	3.25	1.9	4.18				
9/27	3	0.32	0.63	0.03	0.52	0.29	0.16	0.04	0.07	0.02	0.29	0				
	4	0.29	2.01	0.1	3.04	0.36	0.42	0.61	0.1	0.23	0.9	0				
10/3	3	2.06	0.84	3.66	1.87	2.38	1.04	3.42	1.35	3.88	3.08	1.46				
	4	2.31	1.7	3.9	1.8	3.43	0.93	2.83	1.85	4.48	3.22	3.65				
10/14	3	4.82	0.49	0.01	3.45	0.72	0.82	4.23	3.39	1.53	2.22	4.63				
	4	4.2	1.41	2.74	4.27	3.1	1.48	3.75	4.35	4.5	4.63	5.33				
10/18	3	1.85	2.62	1.97	3.39	4.6	1.51	0.43	0.41	4.22						
	4	2.94	2.28	4.1	3.32	4.06	0.9	3.3	3.07	4.51						
11/4	3	2.91	0.4	0.63	1.15	0.54	0.77	0.43	3.04	1.12	2.02	2.58	1.98	1.74		
	4	4.01	0.97	0.42	0.96	1.01	0.66	0.56	4.12	0.28	0.81	3.29	1.22	1.44		
11/11	3	0.2	0.52	4.23	1.01	0.54	2.25	1.63	2.55	1.61	0.09	0.65	0.47	0.39		
	4	3.5	1.7	4.02	1.58	0.99	1.42	2.41	1.48	4.03	2.67	2.32	1.56	2.43		

TABLE IV.4 con't.

Date	Leaf	Observation														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		(mg Chl/dm^2)														
11/18	3	1.51	1.62	0.51	2.19	2.52	3.1	0.77	4.89	2.79	3.44	5.91				
	4	2.38	2.02	0.06	3.24	4.1	3.95	2.57	4.98	4.02	4.06	6.56				
11/28	3	1.25	1.76	5.3	1.13	0.66	2.17	3.05	1.39	5.28	3.74	0.59	0.54	0.56	2.93	3.15
	4	0.99	2.7	5.89	5.03	3.3	4.58	3.6	1.28	5.91	4.88	0.89	1.27	0.77	3.67	4.16
11/28*	3	3.6	0.14	0.51	0.28	3.01	1.3	1.52	0.35	1.06	0.97	3.85	0.06	0.1	0.89	1.86
	4	4.33	0.07	2.28	0.66	3.62	2.79	1.65	1.13	2.78	1.72	3.48	0.27	0.29	0.73	2.3
12/3	3	3.17	5.49	4	3.38	1.63	3.69	3.91	2.98	0.3	1.31	2.97	3.59			
	4	3.14	5.41	3.57	5.15	3.17	3.69	4.73	3.3	1.88	3.25	3.33	3.2			
12/3*	3	4.16	3.8	4.23	5.08	5.37	4.1									
	4	4.04	4.09	5.13	4.63	4.42	4.08									
12/8	3	4.14	4.65	5.97	2.6	2.8	0.72	0.96	3.19	2.56	2.15	5.32	1.71	4.09	3.24	3.9
	4	3.8	3.85	4.41	4.45	2.7	2.84	3.77	3.42	2.35	3.47	6.06	1.65	3.59	2.92	3.39
12/8*	3	0.28	3.82	4.21	1.57	3.52	4.54	2.99	2.13	0.66	3.86					
	4	0.3	5.3	3.5	2.8	4.8	4.33	2.64	3.35	3.07	5.15					
12/15	3	4.02	2.05	2.26	1.53	3.35	1.8	1.2	6.45	3	3.35	5.44	1.27	5.3		
	4	3.32	4.21	2.15	3.35	2.65	4.06	1.91	4.87	2.42	5.13	4.24	2.53	4.6		
12/17	3	1.61	1.59	3.03	3.14	4.05	4.15	2	3.07	3.37	2.67	3.25				
	4	2.04	2.28	2.81	3.22	3.64	4.35	2.89	1.8	2.47	1.82	1.72				
12/17*	3	1.52	2.38	1.45	1.86	2.77	2.09	2.22	2.41	3.12	2.68	1.97	2.74	1.53		
	4	4.86	2.72	4.5	2.33	2.59	3.17	3.22	2.36	3.04	3.48	2.96	2.3	3.16		

* These repetitions were done in a different field that had been covered with plastic in the fall to keep soil dry.

TABLE IV.5. Results of the chlorophyll analysis of radish 3rd and 4th leaves exposed to clomazone vapors for 12 hours.

		Observation														
Date	Leaf	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		(mg Chl/dm^2)														
8/24	3	4.14	3.6	3.33	3.78	4	3.66	3.06	3.94	3.32	4.42	3.28	4.46			
	4	3.78	2.89	3	3.92	4.46	4.37	3.08	5.87	3.47	4.45	4.36	3.89			
9/1	3	0.18	0.11	1.08	0.36	0.21	1.04	0.18	0.3	0.69	0.32	0.12				
	4	1.43	0.12	1.17	0.72	0.94	0.67	0.29	0.62	1.5	0.13	0.2				
9/13	3	1.47	0.65	1.34	1.63	0.53	1.32	1.12	2.22	0.91	1.43	1.25				
	4	3.12	1.16	2.68	1.13	2.09	1.22	2.26	3.5	2.37	2.58	2.5				
9/16	3	5.12	3.93	6.11	3.15	4.7	4.46	3.81	1.95	3.8	4.22	5.36	3.06	4.57		
	4	4.18	5.15	5.38	3.78	4.89	4.45	4.03	3.96	4.91	5.49	6.74	4.38	3.8		
9/20	3	1.27	0.32	3.07	1.09	0.59	0.16	1.86	5.65	1.09	1.23	0.94				
	4	2.49	1.29	5.02	4.29	1.48	0.83	2.77	5.39	3.22	3.62	3.01				
9/27	3	1.54	3.8	0.82	1.38	4.86	0.23	4.07	0.72	1.33						
	4	0.75	6.26	0.51	2.31	3.13	2.78	3.42	1.99	3.17						
10/3	3	2.63	4.56	0.61	0.09	0.99	1.48	1.52	1.05	3.73	4.33	0.89	4.19	0.79		
	4	1.8	5.08	0.76	0.18	2.59	2.09	1.96	0.65	4.6	4.64	0.85	7.31	2.3		
10/14	3	1.94	3.05	2.3	1.15	2.15	1.88	2.17	3.72	2.57	5.74	5.18	3.96			
	4	3.33	2.45	4.49	5	3.09	4.84	3.99	4.17	4.59	5.47	7.01	4.64			
10/18	3	0	2.65	4.14	2.37	4.02	2.04	0.25	3.23							
	4	0.72	4.27	3.9	2.16	4.6	3.17	1.65	3.4							
11/4	3	0.59	1.31	0.75	0.88	0.65	1.09	0.6	3.09	0.92	1.17	0.62				
	4	1.61	2.72	1.23	1.67	0.89	1.32	0.53	3.49	0.91	1.92	1.04				
11/11	3	0.32	1.49	0.65	3.5	1.35	0.05	1.4	0.37	3.94	1.14	0.41	0.97	0.56	6.28	
	4	0.98	4.41	4.16	3.3	1.76	0.68	1.11	3.81	3.72	1.2	0.18	4.58	2.5	6.57	

TABLE IV.5 con't.

		Observation														
Date	Leaf	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		(mg Chl/dm^2)														
11/18	3	1.36	2.78	0.17	4.07	1.03	2.02	4.36	4.63	0.3	0.21	4.44				
	4	4.06	4.66	3.99	6.66	3.59	2.12	4.38	3.55	0.09	0.87	4.96				
11/28	3	1.73	2.63	3.91	0.28	1.41	4.12	3.48	2.44	2	2.12	1.31	0.77	2.63		
	4	4.47	4.78	5.36	2.53	2.34	4.8	4.78	4.29	4.15	5.71	2.6	1.89	3.31		
11/28*	3	1.03	0.28	0.96	0.76	0.43	1.78	0.2	0.25	1.13	2.08	2.32	0.31	1.16	0.72	0.9
	4	1.54	1.63	1.42	0.43	0.13	2.42	0.26	0.34	1.03	1.04	3.82	1.2	2.2	1.46	1.13
12/3	3	1.78	5.51	2.81	3.9	2.93	0.55	5.32	3.02	3.05	5.39	3.79				
	4	2.22	4.13	3.94	3.84	6.89	0.49	5.53	2.04	2.99	5.86	4.08				
12/3*	3	5.71	6.71	1.18	6.25	3.88	1.56	6.99								
	4	5.7	5.13	3.96	5.36	6.69	2.02	5.13								
12/8	3	2.95	3.78	4.02	1.33	2.35	3.75	1.81	1.86	4.24	1.01	1.92	0.41			
	4	2.8	4.77	3.32	1.48	4	3.52	2.1	2.24	3.62	2.3	3.85	2.55			
12/8*	3	0.68	2.13	1.38	2.49	4.66	3.22	3.75	2.54	3.07	2.97	3.2	4.7	4.4		
	4	0.13	1.3	3.17	2.82	3.48	3.16	4.2	5.1	3.52	3.22	3.64	3.13	4.84		
12/15	3	1.69	2.57	0.04	3.36	1.97	4.42	1.7	4.04	2.31	2.32	3.83	5.48			
	4	2.19	3.53	2.76	3.74	3.14	2.82	5.27	5.1	5.44	5.49	5.18	3.36			

* These repetitions were done in a different field that had been covered with plastic in the fall to keep soil dry.

TABLE IV.6. Results of the chlorophyll analysis of radish 3rd and 4th leaves not exposed to clomazone vapors (control).

	Observation														
Leaf	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	(mg Chl/dm^2)														
3	3.85	5.39	4.6	4.26	4.53	5.39	4.08	4.01	3.73	4.33					
4	4.15	2.22	4.31	4.07	5.21	5.64	4.69	4.07	4.19	4.02					