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The persistence of DCPA, trifluralin, diphenamid, diuron, and prometryne was studied in three soils which were located at the Kula, Poamoho, and Waimanalo Experiment Stations. The order of decreasing persistency was diuron, prometryne, trifluralin, DCPA, and diphenamid.

Diuron and prometryne activities were recorded for at least six months and diuron phytotoxicity was noted in the Poamoho plot, one year after application.

Degradation was faster when the herbicides were applied the second time in the same plots. For example, DCPA was inactivated between 60-80 days after application in the Poamoho soil. In the second application, inactivation took place in 40-60 days. This indicated that herbicide accumulation or build up was not an important factor in successive croppings. Tilling the soil did not seem to affect

inactivation with the exception of prometryne. The bio-assay plants in the prometryne plots showed less phytotoxic symptoms than those grown in soils from untilled areas.

Inactivation was most evident in the Waimanalo soil which has montmorillonite as one of the predominant clays. Adsorption and micro-degradation appeared to be the dominant factors in degradation. Inactivation was not related to herbicide solubility, even under high rainfall conditions. Photo-decomposition and volatilization were minimized by rainy periods soon after application.

The data indicated that sensitive crops like lettuce could be resown in soil treated with diphenamid, DCPA, and trifluralin at 20 to 40, 20 to 60, and 40 to 80 days, respectively.

A phytotoxicity study at Poamoho and Waimanalo indicated that more variations existed in toxicity symptoms between lettuce and cucumber than between soil types of the two locations.

Subjective rating of the bio-assay crops (lettuce and cucumber) appeared to be a satisfactory method of evaluating phytotoxicity.

# The Persistence of Five Herbicides in Hawaiian Soil

by

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# THE PERSISTENCE OF FIVE HERBICIDES IN HAWAIIAN SOIL

## INTRODUCTION

Farming in Hawaii is a 12-month operation where limited farm lands are extensively cultivated. Mono-culture is principally restricted to sugar cane and pineapple. Most crops are grown in rotation with several other crops. These crops are grown in a variety of soil types and under different climatic conditions. It is difficult to typify the production of an average vegetable producer. Four to seven different crops can be produced on an acre in a year.

Vegetable production is generally restricted to farms of small acreages, operated by the family. The average farm size is between eight-nine acres. The use of herbicides to improve the farm's productivity and to relieve the economic pressure in labor costs is increasing. Many herbicides are available for vegetable production but the type and extent of use is generally restricted because of persistence in the soil and the effect on the subsequent crop. The period from one crop to another may be as short as one month. The usual practice is to disc or till the soil after each crop in preparation for the next planting. Methods of irrigation may differ but the amount of water applied is about 1/2 acre inch per irrigation. Knapsack sprayers are used to apply herbicides on most farms.

Trifluralin, DCPA, benefin, diphenamid, CDEC, CDAA, DNBP, nitrofen, and EPTC are commonly used for vegetable production in Hawaii. Weed control from these herbicides has been satisfactory. Some farmers have insisted that the constant use of such herbicides has caused crop failure and have not used herbicides for the next one or two crops. On the other hand, other farmers growing the same crop on the same soil type using the same herbicide concentration and the same type of irrigation have not experienced crop failures. An explanation of the reasons for such inconsistency may contribute to the proper increased usage of herbicides.

The objectives of this thesis were:

a. to determine the soil persistence of DCPA, diphenamid, trifluralin, prometryne, and diuron under field conditions,

b. to develop standard disappearance curves for each of the herbicides, and

c. to estimate the extent of herbicide accumulation.

# LITERATURE REVIEW

Many factors influence a herbicide applied to the soil and these factors will eventually destroy the effectiveness of the herbicide. Inherent characteristics of chemicals have direct bearing on soil persistence. Soil and climatic variations complicate the study of herbicide persistence.

Six processes affect the persistence of a herbicide in the soil: 1) volatilization, 2) photo-decomposition, 3) leaching, 4) adsorption on the soil colloids, 5) chemical decomposition, and 6) micro-organism decomposition (32).

## Volatility

A chemical may evaporate and be lost to the atmosphere as a gas soon after spraying. Menges and Hubbard (38) reported that poor performance of soil surface applications of volatile herbicides can result from rapid loss into the atmosphere. The resulting losses were from high temperatures and failure of the soil particles to trap the herbicide vapors. This agrees with the work of Parochetti and Warren (42) who found that CIPC volatility increased as the soil temperature increased in fields with soil moisture at field capacities. Volatilization may be appreciably greater from moist than from dry soil because of a process akin to steam distillation (28). Dry soils can attain high temperatures on the surface and this can lead to serious increase of loss by evaporation. A chemical in solution below the soil surface can be lost through the process of evaporation. After rain, water evaporation from the soil surface continues by upward capillary flow, which then exposes the chemical solution to evaporation (26).

Co-distillation with water evaporating from the surface is another means by which a herbicide may be lost (32). Under some circumstances, the volatility response to temperature was reversed, to give a decreasing loss with increasing temperature. Deming (13) found that the volatility-temperature relationship was strongly influenced by the amount of water present in the soil colloids. CDAA volatility loss was accelerated by increasing the amount of water. The mechanism for this reaction appears to involve a competition between water and CDAA for adsorption sites. Deming found a correlation between organic matter content of the soil and resistance of CDAA to evaporation; that is, the higher the organic matter content, the smaller the loss of CDAA. Parochetti and Warren (42) also found that losses of IPC and CIPC from moist quartz sand and soil decreased with an increase in the percentage of clay, organic matter, or both. Fang, Theisen, and Freed (18) found that there was a positive correlation with the rate of EPTC loss to the rate of moisture evaporation from the soil.

## Photo-Decomposition

A chemical is frequently lost if it remains on a soil surface for an extended period under a dry condition. A chemical with low vapor pressure can be lost from photo-decomposition if exposed to constant high light intensities over an extended period. Monuron is known to degrade after a period of time when exposed to sunlight (28). Ultra-violet rays have been suggested to be responsible for most of the photo-chemical decomposition.

## Leaching

Counteracting the upward capillary flow is a downward movement of water called leaching. The properties of the chemical and soil and the amount of water moving through the soil play important roles in leaching. Holly (28) suggests that leaching depends primarily on the water solubility of herbicides. Schweizer and Holstun (46) found that water solubility played an important role in the leaching of DCPA, trifluralin, diuron, prometryne, and norea. Norea, being the most soluble, leached the most. Factors other than water solubility may play important roles. Klingman (32) postulates that the strength of "adsorption bonds" is as important as water solubility in determining leaching. In one study, trifluralin did not leach out from the surface of a silty clay loam even with ten inches of water (43). Leaching was observed to a depth of 16 inches in fine sand and only about four inches in silty clay loam. This indicates that adsorption may be very important. Another study found no relationship between the water solubility of the herbicides and their adsorption (21). Day, Jordon, and Hendrixson (12) observed that the leaching rate of amitrole relative to the movement of water varied with soil types. Diphenamid, considered intermediate in leaching, showed higher losses in sandy soil and is known to be highly adsorbed to organic soils (53). Harris (22) found that adsorption gave a better indication of herbicide movement in soil than did solubility. Prometryne, nearly ten times more soluble than simazine, moved less readily in the soil than simazine. Harris (24) also categorizes aromatic acid herbicides as more mobile and insoluble toluidines as less mobile. As an example, he lists trifluralin, prometryne, diuron, and diphenamid in order of increasing mobility. This order may vary, however, in different soils.

Leaching of herbicides into the subsoil or lower strata is another consideration in persistence. A herbicide under this condition is exposed to low $O_2$ and high $CO_2$. In many cases, the subsoil is heavy and poorly drained. These conditions all contribute to a slow breakdown of the chemical (9).

## Adsorption

Herbicide adsorption on soil colloids is closely related to leaching. Adsorption is the phenomenon of the binding of molecules or ions on surfaces of solids (37). Adsorption occurs primarily with inorganic colloids, principally clay, and with organic colloids which includes the humus of the soil. Many factors are involved in adsorption: type of clay, chemical make-up of the herbicide, percentage of soil colloids, soil pH, soil temperature, and soil moisture.

Harris (21, 22) found that the adsorption of s-triazines increased as the pH was lowered. Diuron tended to be more toxic as the pH increased according to Selman and Upchurch (47). In general, decreasing the pH increases the adsorption of most herbicides. McGlamery and Slife (37) found the pH effect to be greater than the effect of temperature on adsorption. Since adsorption processes are exothermic, an increase in temperature should reduce adsorption. They also found that atrazine adsorption appears reversible and that desorption was nearly complete at a pH greater than 6. 0 and a temperature above 30° C.

EPTC was found to be more persistent in soil of high organic matter content (11). Upchurch and Mason (54) found that increasing the soil organic matter by a given percentage required a certain percent increase in herbicide content for equal biological toxicity. They also found that the toxicity indices of 12 soil-incorporated herbicides to cotton were highly and positively correlated with soil organic matter, cation exchange capacity, exchangeable calcium, moisture equivalent, free drainage value, and total exchangeable bases. A number of investigators are in agreement that inactivation of some herbicides are greater in heavier and/or high organic matter soils. Substituted urea studies showed $ED_{50}$ values to be correlated to cation exchange capacity, percent organic matter, and clay (17). In the same study, the $ED_{50}$ of diphenamid was correlated to organic matter, cation exchange capacity, and exchangeable magnesium; however, organic matter was more important. Diphenamid toxicity had no relationship with clay content which is in agreement with other studies (53).

In studies with simazine and atrazine, increasing amounts of organic matter and/or clay in soil generally led to increased adsorption, but the type of clay or organic matter was important (51). Kaolinite clay did not seem to adsorb simazine or atrazine. Harris and Sheets (25) found soils high in clay relative to organic matter adsorbed more simazine than CIPC and diuron. Those soils which adsorbed the most simazine contained montmorillonite clay. CIPC and diuron $ED_{50}$ values correlated with percent organic matter better than simazine. Grover (20) found simazine available to plants, regardless of the concentration of clay in the soil under relatively high soil moisture conditions.

Obien, Suehisa, and Younge (40) found neburon adsorption was positively correlated with total soil nitrogen and organic matter. Herr, Stroube, and Ray (27) concluded that the persistence of picloram is strongly influenced by the organic matter content in the soil.

## Chemical Decomposition

Chemical decomposition destroys some herbicides and activates others by processes as oxidation, reduction, hydrolysis, and hydration (32). Slow hydrolysis is a common reaction. The amide (-CO-NH-) grouping of the phenyl ureas and the -C-Cl, $-C-O-CH_3$, and $-C-S-CH_3$ groupings of the substituted triazines are subject to hydrolysis in sterile solution (26). Dacthal, at soil temperatures below 90° F is lost mainly by chemical deterioration while above this temperature, loss occurs through a combination of chemical deterioration and volatilization (6). Burnside (8) in studying amiben, atrazine, and 2, 3, 6-TBA found atrazine to be the most liable to microbial and/or chemical breakdown.

## Microbial Degradation

Sometimes it is difficult to differentiate between losses from chemical or microbial degradation. But microbial degradation is probably more influential under field conditions. Temperature, moisture, pH, and aeration are some of the factors which can affect the rate of microbial degradation. The structural make-up of a herbicide has direct bearing on microbial degradation. Methoxy s-triazines were more toxic to the fifth successive oat crop than were the corresponding chloro s-triazines although the latter had the greatest initial toxicity (51). Certain methylmercapto derivatives also showed moderate persistence in soil.

Simazine and atrazine were partially inactivated in soil stored for eight weeks at 30° and for two weeks at 45° C (7). Field trials indicated that simazine, atrazine, and ipazine were inactivated in less than seven weeks during the summer but not in the winter or spring when the temperatures were below 30° C. Donaldson and Foy (15) found that high rates of herbicides decomposed very little under ideal conditions of microbial decomposition. They speculated that soil micro-organisms were apparently unable to adapt themselves to the utilization of the herbicides or the rates used were toxic to the organisms. Fields, Der, and Hemphill (19) found that continuous application of recommended rates of DCPA showed no accumulating or adverse effects on molds, bacteria, and actinomycetes. In another study, decomposition of atrazine and diuron was accelerated by the addition of vetch (36). Evidence is that certain herbicides show inhibitory effects to certain soil fungi more than to others (3). This indicates that the rate of breakdown of a herbicide may depend on the kind of organisms in the soil.

# MATERIALS AND METHODS

## General Materials and Methods

The field experiments were conducted at Poamoho, Waimanalo, and Kula Experiment Stations. The edaphic and environmental factors are contained in Table 1. The three areas represented soil types on which vegetables are grown in Hawaii. Crops like beans, cucumber, and leafy lettuce are grown in the Wahiawa and Waimanalo silty clay soils, and head lettuce, celery, and head cabbage in the Waimea (Kula) loam soils. The differences in climate fairly well dictate the types of crops grown.

Table 1. Description of the test locations.

| Experiment Station | Island | Elevation (feet) | Medium Annual Rainfall (inches) | Soil Type | Percent O. M. | C.E.C. (meq/100g) |
|---|---|---|---|---|---|---|
| Kula | Maui | 3,200 | 28 | Waimea (Kula) loam | 6-9 | 70 |
| Poamoho | Oahu | 870 | 45 | Wahiawa silty clay | 2-3 | 14 |
| Waimanalo | Oahu | 70 | 45 | Waimanalo silty clay | 4-5 | 45 |

The greenhouse where the bio-assay studies were conducted was located about five miles from the Poamoho Experiment Station. Although it was at a higher elevation than the experiment station, the climatical conditions were similar. The greenhouse was a simple construction in the back yard, without a fan or air conditioner.

Commercial formulations of the herbicides were used in the experiments. The chemicals were dissolved or suspended in water and applied at a volume of 40 gallons per acre. Prometryne, diuron, diphenamid, and DCPA were applied to the soil surface. Trifluralin was incorporated into the topsoil with a hand-operated motor-driven tillivator.

The chemicals used were selected on the basis of their present or potential use for weed control in vegetable crops in Hawaii. Herbicides and rates used were:

1. Trifluralin (a, a, a-trifluoro-2, 4-dinitro-N, N-dipropyl-p-toluidine) at 4 lb active per acre
2. Diphenamid (N, N-dimethyl-2, 2-diphenylacetamide) at 6 lb active per acre
3. Prometryne (2, 4-bis(isopropylamino)-6-methylmercapto-s-triazine) at 4 lb active per acre
4. Diuron (3(3, 4-dichlorophenyl)-1, 1-dimethylurea) at 4 lb active per acre
5. DCPA (dimethyl 2, 3, 5, 6-tetrachloroterephthalate) at 10.5 lb active per acre.

The plots were sprinkler irrigated soon after application. Thereafter at least 1/2 acre inch of water was applied every week, unless received by rain. This is similar to the general irrigation practices in vegetable production. Adequate soil moisture was always present to sustain plant growth.

Weed growth in the plots was suppressed as needed with overall applications of paraquat at the rate of one pound active ingredient per acre. The plots at all three locations were treated at about the same time.

A common method of determining phytotoxicity is to compare dry weights. Schweizer and Holstun (46) and Dowler (16) found that interpretation of phytotoxic expressions could be measured by visual symptoms on the plants. For this experiment, subjective visual ratings were used to interpret phytotoxic expressions. The following numerical rating system was used (44):

1 - no injury (commercially acceptable)

2 - slight injury

3 - moderate injury

4 - severe injury

5 - dead

The procedure for the subjective rating was to study all check plots or pots before the evaluations were made; subsequently, the plots or pots were rated without knowledge of the treatment. This unbiased method sometimes resulted in check ratings greater than "1".

## Soil Persistence Study

In this study, the herbicides were applied in main plots of 20' x 40' and each treatment was replicated three times in a randomized complete block design. The area was tilled to a depth of 8 to 12 inches one day prior to herbicide application. This is the normal procedure used by vegetable farmers in preparing their fields. Soil samples were taken to a depth of two inches. This depth was selected because it is important in seed germination. Also, most of the short-term crops have a concentration of roots within two inches from the soil surface in the early stages of growth.

The experiment was divided into two phases.

### Phase I

The main plots were divided into four equal sub-plots. Each sub-plot was designated a date when soil samples were to be taken for greenhouse bio-assay tests. These dates represented 0, 20, 40, and 60 days from the herbicide application date. Samples were taken from nine locations within a sub-plot and combined into one sample. These samples were taken on or about the designated day and assayed the same day. In case of a delay, the samples were refrigerated at 40°F to minimize degradation. The samples from Kula were air freighted to minimize any delay from sampling to seeding.

Each sample was divided and placed into three 9-ounce cups, each cup representing a replicate. Each cup was seeded with green Mignonette lettuce (Lactuca sativa). It was difficult to maintain the desired moisture content in the 9-ounce cups. To correct this situation in Phase II, the soil samples were placed in 4" x 6" x 4" aluminum baking pans.

The seedlings were harvested 20 days after seeding by clipping them off at the soil level. They were immediately weighed and placed in the oven at 115° F for over 16 hours. Prior to harvesting, the seedlings were subjectively rated, based on visible symptoms of injury.

The bio-assay plants in Phase I indicated low soil fertility levels at all three locations; therefore, fertilizer was disced into the soil one week prior to treatment in Phase II.

## Phase II

After Phase I, the soil was tilled and the original plots were identified in preparation for Phase II. The same treatments in Phase I were applied to the same plots and the procedures were repeated. The only difference in procedure was that aluminum pans were used in the bio-assay. One pan was used for one soil sample in which three rows of lettuce were seeded to obtain a representative sample.

On the 60th day of Phase II, a strip of soil was tilled across the main plots. Green Mignonette lettuce and Straight-8 cucumber (_Cucumis sativus_) were seeded in the tilled area to assay any chemical residue in the soil. Cucumber was used for the first time as a bio-assay crop and it was more sensitive to all herbicides than lettuce. Dowler (16) also found the cucumber to be a good test plant for certain herbicides.

## Phytotoxicity Study

A second study was added to help interpret the data of the persistence study. This test was conducted at Poamoho and Waimanalo Experiment Stations. The same herbicides and basic procedures used in the persistence study were used. But in this study, the chemicals were applied with a logarithmic sprayer on main plots of 5' x 52', replicated four times in a randomized complete block design. As in the persistence study, all herbicides except trifluralin were applied on the soil surface. The logarithmic sprayer reduced the herbicide concentration by 50% every 13 feet. The test was designed to study the toxic effects on the bio-assay plants at five levels of herbicide concentration. Lettuce and cucumber were seeded the length of the main plots before the herbicides were applied. After application, soil samples were taken from each of the five concentration areas for greenhouse bio-assay using lettuce. The greenhouse and field bio-assay plants were rated 20 days after seeding, at which time the study was terminated.

# RESULTS AND DISCUSSION

## Soil Persistence Study

The results of the soil persistence study showed that several herbicides persisted longer than 80 days; however, a second application did not lead to increased herbicide accumulation (Figure 1). The bio-assay plants showed less injury in Phase II than in Phase I. This could be attributed to several reasons. Fertilizer was added to the plots in Phase II because of poor plant growth in Phase I. Good plant growth may have counteracted some of the phytotoxic effects. Better plant growth also made it easier to rate the injury symptoms. It is conceivable that the mechanism of soil "enrichment" occurred causing a faster breakdown of the herbicides applied in Phase II (1). Particular micro-organisms multiplied or became adapted to the herbicide after the first application. This increase in number would cause rapid degradation.

The upswing in phytotoxicity of diuron at Waimanalo and trifluralin at Poamoho from the 40th day is hard to explain (Figure 1). It is probably due to an experimental error in soil sampling or rating. In examining the sampling data, the ratings for one replicate at each location were consistently low. Results in Table 2, which show the toxicity of the herbicides 60 days after application, agree with the greenhouse bio-assay ratings of the two herbicides in question.

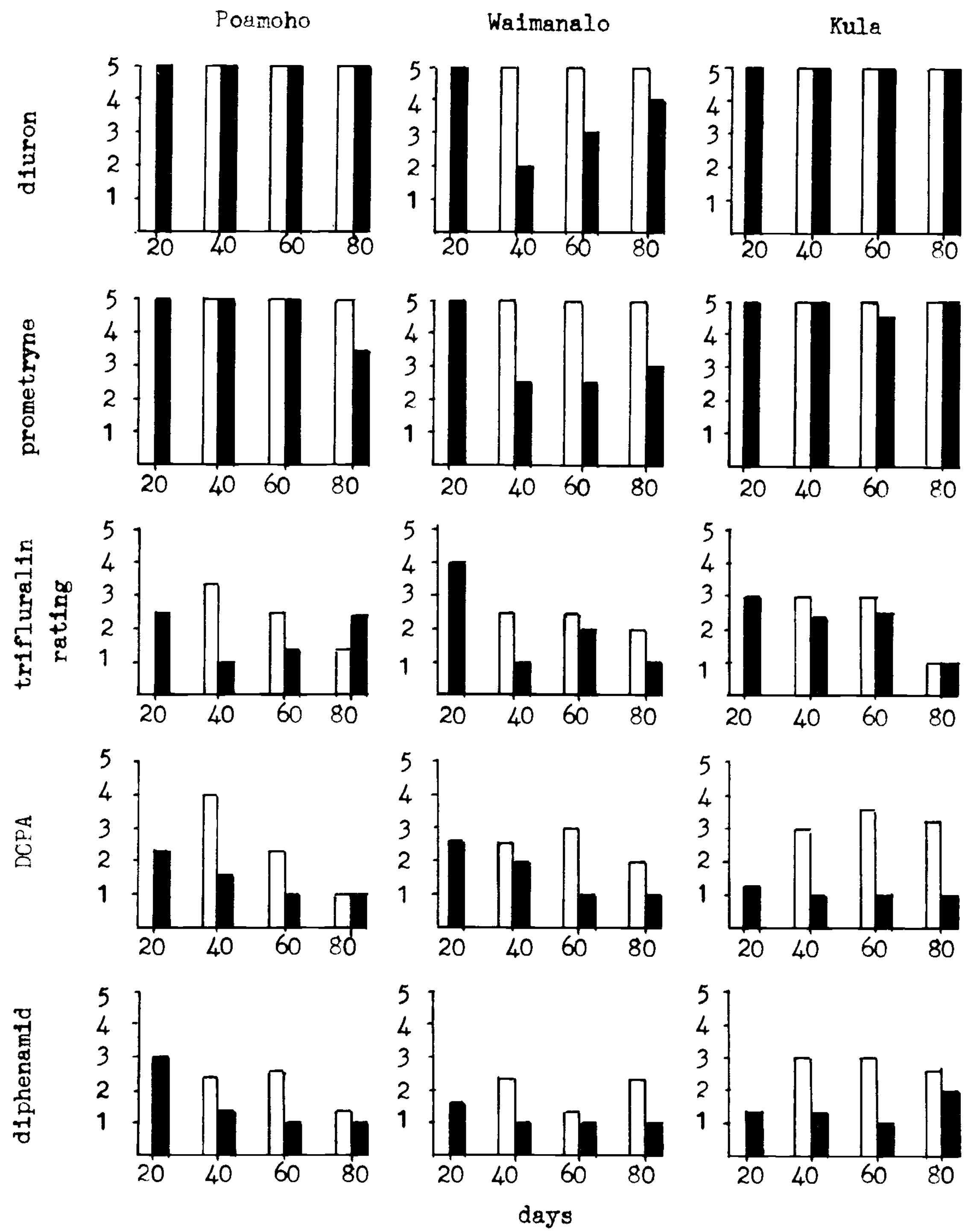


Figure 1. Toxicity of five herbicides to lettuce at 20, 40, 60, and 80 days after application, in decreasing order of phytotoxicity from top to bottom. (Light bar denotes first application and dark bar the second application.) No rating was taken on the 20th day of the first application.

Table 2. Persistence of five herbicides at three locations as determined by response to lettuce and cucumber seeded in the field 60 days after application.[1]

| Location | Treatment | | Tolerance rating at 20 days | |
|---|---|---|---|---|
| | Herbicide | lb actual per acre | Cucumber | Lettuce |
| Poamoho | Diphenamid | 6. 0 | 1. 3 | 1. 0 |
| | Prometryne | 4. 0 | 3. 3 | 2. 6 |
| | DCPA | 10. 5 | 1. 6 | 1. 0 |
| | Trifluralin | 4. 0 | 3. 0 | 3. 6 |
| | Diuron | 4. 0 | 5. 0 | 5. 0 |
| | Check | | 1. 0 | 1. 0 |
| | L. S. D. 5% (1%) | | 1. 1(1. 5) | 1. 2(1. 7) |
| Waimanalo | Diphenamid | 6. 0 | 1. 3 | 1. 6 |
| | Prometryne | 4. 0 | 1. 6 | 1. 3 |
| | DCPA | 10. 5 | 1. 3 | 1. 0 |
| | Trifluralin | 4. 0 | 3. 0 | 1. 3 |
| | Diuron | 4. 0 | 4. 3 | 3. 0 |
| | Check | | 1. 6 | 1. 0 |
| | L. S. D. 5% (1%) | | 1. 7(2. 4) | N. S. |
| Kula | Diphenamid | 6. 0 | 1. 3 | 1. 0 |
| | Prometryne | 4. 0 | 2. 0 | 1. 6 |
| | DCPA | 10. 5 | 1. 3 | 1. 3 |
| | Trifluralin | 4. 0 | 3. 3 | 2. 0 |
| | Diuron | 4. 0 | 5. 0 | 5. 0 |
| | Check | | 2. 0 | 1. 0 |
| | L. S. D. 5% (1%) | | 1. 1(1. 6) | . 7(1. 0) |

[1] Field disced prior to sowing seeds.

Diuron and prometryne continued expressing phytotoxicity long past the 80 days of Phase II in the soil persistence study. After 80 days, prometryne activity continued for three months at Waimanalo and Kula and four months at Poamoho. Diuron activity on the other hand, continued for at least six months at all three locations. One year later, diuron plots at Poamoho were free of weeds and a bio-assay test indicated phytotoxicity. Similar results were obtained by Austin, Andrews, and Skold (2).

## Effects of Tilling

Tilling the soil 60 days after application did not seem to affect herbicide inactivation with the exception of prometryne. There was little difference between the greenhouse bio-assay ratings and the field bio-assay ratings on the 80th day with the DCPA, trifluralin, diphenamid, and diuron treatments. The soil samples for the greenhouse bio-assay were taken from untilled areas. DCPA, trifluralin, and diphenamid activity was insignificant at 60 days. Therefore tilling the soil should have had little or no effect. Diuron on the other hand, like prometryne, was still active in the soil. It is possible that the prometryne was concentrated in the upper two inches of the soil and dilution took place by tilling the soil to a depth of 5-7 inches. Schweizer and Holstun (46) found prometryne concentrated in the upper two inches of the soil. When diuron was applied at one pound per acre they found it concentrated in the upper two inches. It might be that when applied at four pounds per acre, some of the diuron distributes itself to lower depths. This was observed by Harris (22).

Weiss and Hall (55) reported that lettuce and cucumber grew without injury four months after applying 1.5 pounds per acre of prometryne to an alluvial loam. The Kula soil is sometimes referred to as the Kula loam. It seems possible to grow lettuce and cucumber within three months after applying four pounds per acre of prometryne on the Kula soil, provided it is tilled before seeding. The same applies to the Waimanalo and Poamoho soils.

## Herbicide Solubility

The rainfall distribution during Phase II was relevant to the results.

Precipitation (1966)

| | Poamoho | Waimanalo | Kula |
|---|---|---|---|
| September | 1.02 inches | 0.92 inches | 1.67 inches |
| October | 9.56 inches | 1.15 inches | 3.40 inches |
| November | 18.21 inches | 12.68 inches | 3.63 inches |
| December | 5.61 inches | 3.10 inches | 1.83 inches |

The amount of rainfall during October and November could have caused some lateral movement of the herbicides. Diphenamid is known to move laterally (23). Plants in some check plots at locations showed herbicide damage following the heavy rains which could have been caused by diphenamid since it was in the adjacent plots.

The results do not seem to indicate that herbicide solubility was important in persistence of the herbicides. Prometryne, for example, was not affected by the heavy rain. Schweizer and Holstun (46) found a relationship of water solubility to persistence, with DCPA, trifluralin, diuron, prometryne, and norea (in order of increasing solubility).

The solubility of diphenamid is 260 ppm which is higher than norea (53). On this basis, diuron and prometryne should have been less active than DCPA and trifluralin. Harris (22) found that adsorption gave a much better indication of the resistance to movement than did solubility. This work agrees with the results obtained in the experiment. Talbert and Fletchall (52) as well as Obien, Suehisa, and Young (40) found that soil colloidal fixation and herbicidal inactivation were closely associated. The effects for photo-decomposition and volatilization were probably minimized because of heavy rains soon after application. It seemed that adsorption was an important force which affected soil persistence of the herbicides studied. It was possible that leaching affected DCPA, trifluralin, and diphenamid in Phase II. However, in one study, Jones, Duby, and Freeman (30) found diphenamid in the upper three inches of soil for at least four months.

## Soil Adsorption

At times inactivation seemed to be closely related to clay type rather than organic matter content or exchange capacity. Inactivation was more evident in the Waimanalo soil than in the Poamoho or Kula soils. Even diphenamid, which was found in previous studies to have little relationship between inactivation and clay content (17), was similarly affected. Yuen and Hilton (55) reported that in Hawaii, even soils of low organic matter content had high adsorption capacity. The

Kula soil is higher in organic matter content and exchange capacity than the Waimanalo or Poamoho soils. Yet, with the exception of DCPA, herbicide inactivation was slow in the Kula soil. Microbial activity is probably higher in Poamoho and Waimanalo than in the cooler climate of Kula. This may have accounted for the differences.

## Microbial Degradation

If microbial degradation was slow in the Kula soil, the rapid degradation of DCPA must be due to some other factors. There is the possibility that the microbes present in the Kula soils readily degraded DCPA. On the other hand, DCPA inactivation may be highly dependent on soil adsorption. A study by workers at the Boyce Thompson Institute(6) showed that DCPA activity was reduced in soil having a volcanic ash origin. It was suggested that adsorption of DCPA is not correlated with clay content of the soil but with exchange capacity, organic matter, and colloidal contents. It seems that clay type is an important factor, even with DCPA inactivation, but exchange capacity or organic matter content is the predominant factor. Le Baron (35) found that high temperature is important with DCPA toxicity. Miller _et al_. (39) found DCPA to be phytotoxic to sensitive weeds three months or more after application. An experiment by Jones and Andrews (29) showed DCPA as one of the more persistent herbicides. The Poamoho and Waimanalo soils are representative of the soil used for farming on Oahu. DCPA is more commonly used on Oahu than in the Kula area probably because of the longer residual effects as shown in the results.

## Rate of Application

The initial degree of phytotoxicity of DCPA and diphenamid was about the same as often observed on farms. But the effect from trifluralin was more severe than those observed on the farms. This is understandable since the farmers use trifluralin at a lower rate. Some farmers on Oahu have observed trifluralin to become inactive faster than diphenamid and DCPA, but from the results obtained, there should be very little difference. This agrees with work done by Romanowski, Tanaka, and Ito (45).

## Activity of Trifluralin

One chemical of particular interest was trifluralin. Field observations have shown that trifluralin consistently controlled weeds better in cooler areas like Kula, than in the warmer areas like Poamoho or Waimanalo. A similar result was noted in the experiment. A higher degree of plant injury was noticed in the trifluralin plots in Kula than in Poamoho and Waimanalo. Bardsley, Savage, and Childers (4) found that trifluralin phytotoxicity is related to organic matter content of the soil. Soil-adsorbed trifluralin can persist up to 93 days in toxic form and increasing the organic matter content resulted in more retention of trifluralin. Cucumber plant growth was significantly reduced with each increase in organic matter content 81 days after treatment. Schweizer and Holstun (46) reported inactivity of trifluralin after 154-231 days using oats as the bio-assay crop. Trifluralin activity on lettuce in Kula was significantly reduced between 60-80 days but damage to cucumber was evident in the field bio-assay 80 days after treatment. Bardsley, Savage, and Childers (4) found differences in crop response to trifluralin. Differences in species may be the reason for the differential response between lettuce and cucumber observed in the experiment. They suggest that trifluralin is lost primarily through volatilization. This is probably why trifluralin activity was observed for a longer period in Kula where low temperatures reduce volatilization. Low temperature plus high soil organic matter content of the Kula soil were probably the main factors connected with trifluralin activity.

Rapid volatilization may have been a factor in trifluralin inactivity in Poamoho and Waimanalo. This could also explain why some farmers on Oahu have observed trifluralin inactivity.

## Seeding After Application

Based on the information from Figure 1 and Table 2, it is possible to predict when lettuce may be seeded without sustaining injury from the herbicides in the soil. In the field bio-assay (Table 2), tilling reduced the toxicity of prometryne. This indicates that certain crops may be seeded on or soon after 80 days from prometryne application.

Table 3. Estimated number of days after herbicide treatment when lettuce can be safely seeded.

| Treatments | | Days after application | | |
|---|---|---|---|---|
| Herbicide | lb active per acre | Poamoho | Waimanalo | Kula |
| Diphenamid | 6.0 | 40 | 40 | 20 |
| DCPA | 10.5 | 60 | 60 | 20 |
| Trifluralin | 4.0 | 80 | 40 | 80 |
| Prometryne | 4.0 | >80 | >80 | >80 |
| Diuron | 4.0 | >80 | >80 | >80 |

## Phytotoxicity Study

Standard curves for the Poamoho and Waimanalo soils were constructed to show the association between the ratings and amount of chemicals in the soil (Figure 2). These curves can be used to predict phytotoxicity when given amounts of the herbicides are applied. A study of the weeds controlled at these different rates should be valuable, especially when such data can be related to the curves.

The field data (Figure 3, 4) from these logarithmic plots of Waimanalo and Poamoho showed similarities in toxicity responses to the various concentrations. The toxicity responses from cucumber (Figure 4) were similar for all the herbicides except diuron. This

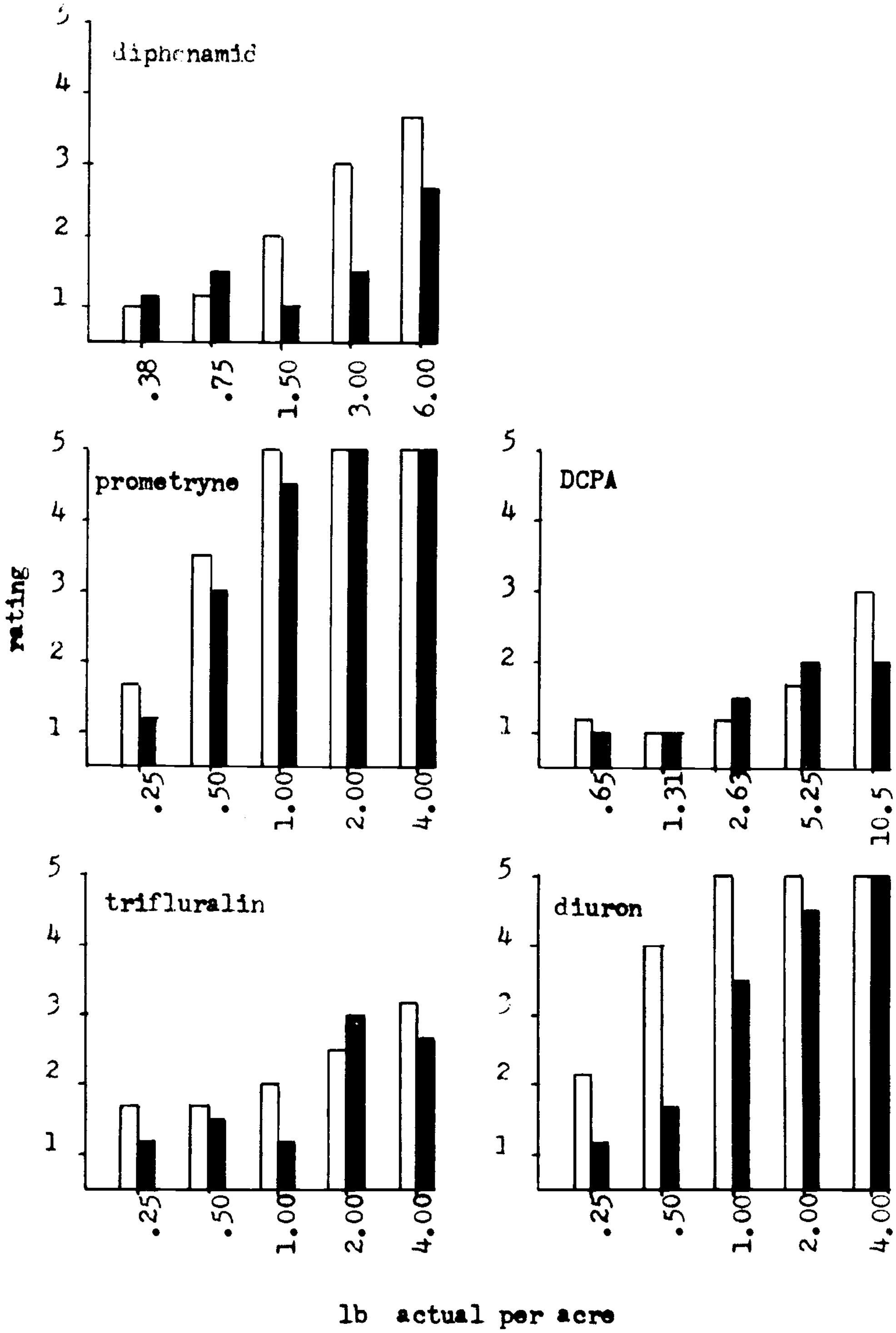


Figure 2. Toxicity of five herbicides to lettuce at five levels of concentrations in a greenhouse bio-assay. (Light and dark bars represent Poamoho and Waimanalo, respectively.)

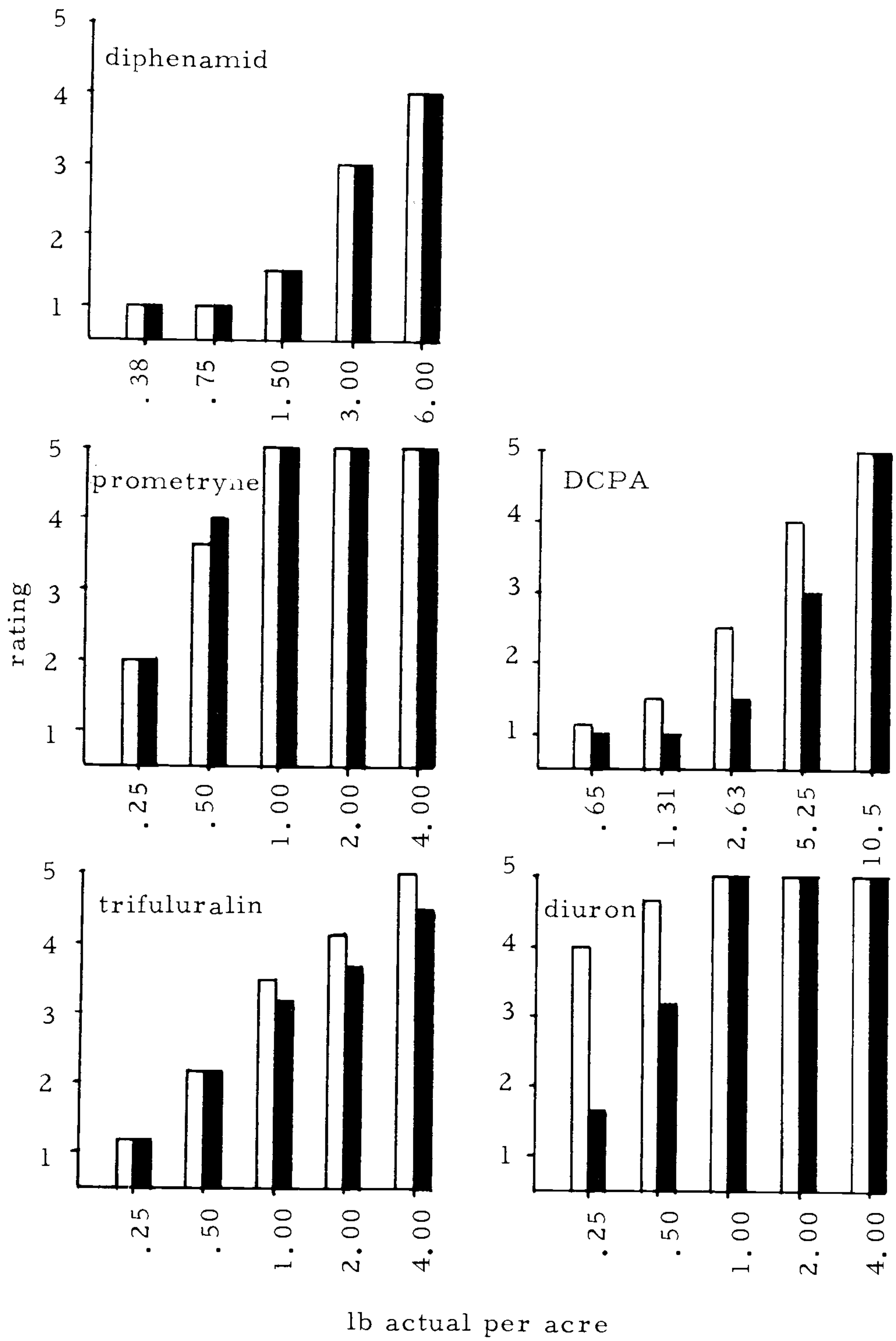


Figure 3. Toxicity of five herbicides to lettuce at five levels of concentrations in a field bio-assay. (Light and dard bars represent Poamoho and Waimanalo, respectively.)

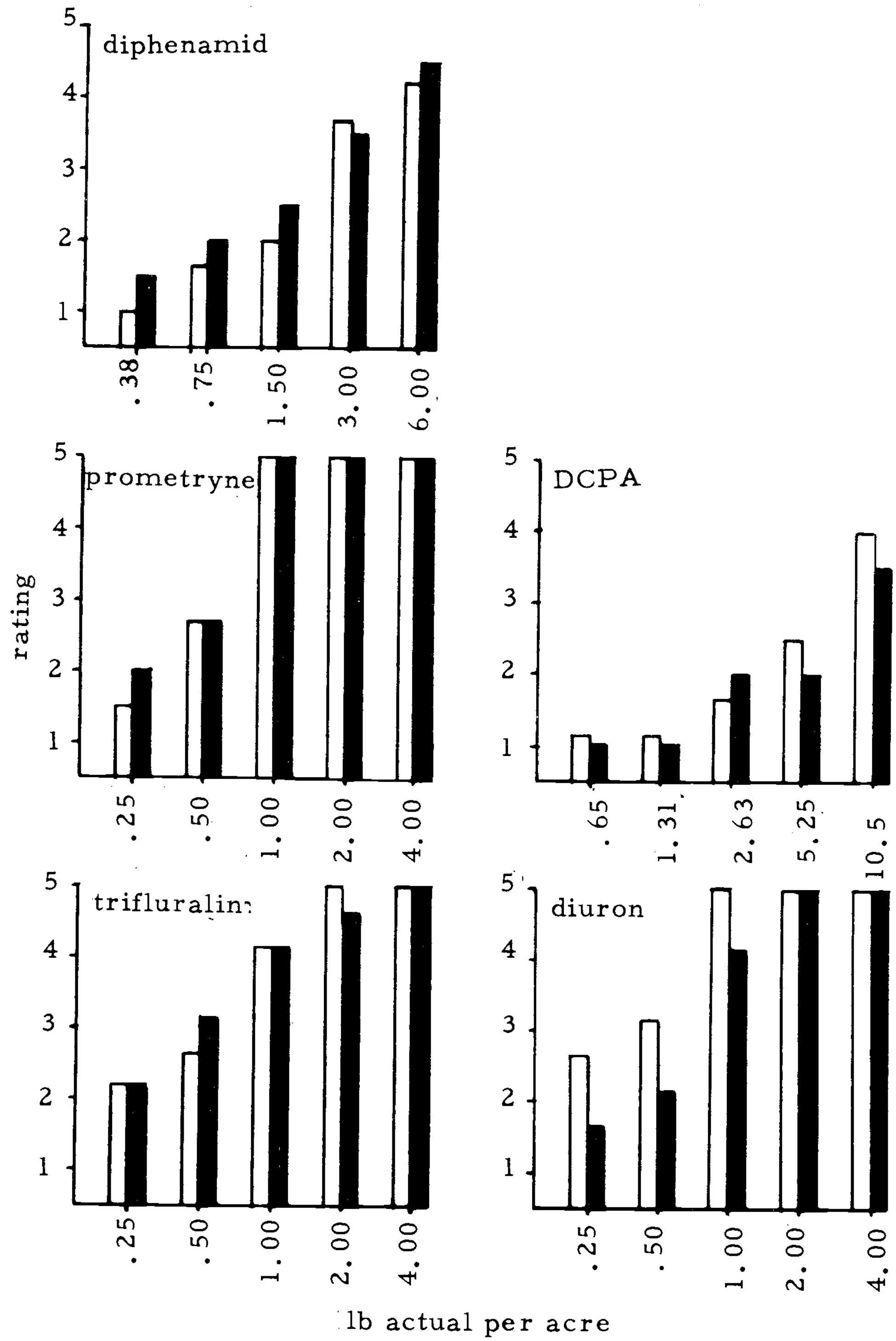


Figure 4. Toxicity of five herbicides to cucumber at five levels of concentrations in a field bio-assay. (Light and dark bars represent Poamoho and Waimanalo, respectovely.)

marked difference was also noted with lettuce and may have been due to the differences in soil type between the two locations (Figure 3). The toxicity response from the lettuce in the greenhouse (Figure 2) showed similarities although not as close as the field bio-assay. Similarities were also noted in the soil persistence study, especially with diphenamid and DCPA.

From these results, it may be feasible to construct one curve for both locations for each crop in contrast to one curve for both crops for each location. It seemed that more symptom variations existed between crops rather than soil types. Such curves would be beneficial for the farmers to reasonably predict crop responses to herbicide concentrations.

After analyzing the fresh and dry weights and phytotoxicity ratings data from the soil persistence study it appeared that the ratings could be used for evaluating phytotoxicity.

## Bio-Assay

The greenhouse bio-assay lettuce plants showed less evidence of phytotoxicity than the field bio-assay plants. This difference could be attributed to better growing conditions in the greenhouse. Bio-assay results of the experiment were somewhat variable because of the difficulties encountered in growing uniform lettuce plants. It was especially difficult to work with the Kula soil because it has poor moisture retention capacity. One soil scientist had suggested that the difficulties encountered with the Kula soil may have been due to unfavorable chemical reactions in moving soil from a cool area to a hot greenhouse condition. A different bio-assay plant, like cucumber, would probably have eliminated some of the problems. Ogle (41) obtained good results from using cucumber as a bio-assay plant.

# SUMMARY

It is well documented that persistency is affected by factors such as adsorption, micro-degradation, photo-decomposition, leaching and volatilization. The extent of influence any of these factors may play is dependent on the chemical, soil, environment, and rate of application.

The order of decreasing persistency was diuron, prometryne, trifluralin, DCPA, and diphenamid at the Kula, Poamoho, and Waimanalo Experiment Stations. Diuron and prometryne activities were recorded for at least six months and diuron phytotoxicity was noted in the Poamoho plot one year after application.

Degradation was faster when the herbicides were applied the second time in the same plots. For example, DCPA was inactivated between 60-80 days after application. Inactivation took place in 40-60 days in the second application. Tilling the soil did not seem to affect inactivation with the exception of prometryne.

Inactivation was most evident in the Wasmanalo soil. Adsorption and micro-degradation appeared to be the dominant factors in degradation. Inactivation was not related to herbicide solubility, even with high rainfall conditions.

The data indicated that lettuce could be safely resown in soil treated with diphenamid, DCPA, and trifluralin at 20 to 40, 20-60, and 40-80 days, respectively.

A phytotoxicity study at Poamoho and Waimanalo indicated that more variations existed in toxicity symptoms between lettuce and cucumber than between soil types of the two locations.

Subjective rating of the bio-assay crops (lettuce and cucumber) appeared to be a satisfactory method of evaluating phytotoxicity.

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