THESIS

This is to certify that the

dissertation entitled

THE INTERACTION OF ACIFLUORFEN AND BENTAZON
IN HERBICIDAL COMBINATIONS

presented by

Veldon Mont Sorensen

has been accepted towards fulfillment
of the requirements for

PhD degree in Crop and Soil Science

William Meggitt
Major professor
Dr. William F. Meggitt

Date June 19, 1984

THE INTERACTION OF ACIFLUORFEN AND BENTAZON IN HERBICIDAL COMBINATIONS

By

Veldon Mont Sorensen

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Crop and Soil Science

1984

e

t

2

c

o

(A

re

(S

an

cr

gr

in

ou

ad

res

syn

at

to

ABSTRACT

THE INTERACTION OF ACIFLUORFEN AND BENTAZON
IN HERBICIDAL COMBINATIONS

By

Veldon Mont Sorensen

Weed control and soybean (*Glycine max* (L). Merr.) injury were evaluated using several rates of acifluorfen (sodium 5-[2-chloro-4-trifluoromethyl)-phenoxy]-2-nitrobenzoate) and bentazon (3-isopropyl-1H-2,1,3-benzothiadiazin-4(3H)-one 2,2,dioxide) applied singly and in combination, and with and without a crop oil concentrate. Greenhouse and outside grown plants were used to evaluate control of velvetleaf (*Abutilion theophrasti* Medic.), jimsonweed (*Datura stramonium* L.), redroot pigweed (*Amaranthus retroflexus* L.) and common lambsquarters (*Chenopodium album* L.) and crop injury to soybeans. Common lambsquarters and velvetleaf showed a synergistic response to all combinations if no crop oil concentrate was added but was additive if present. Jimsonweed grown in the greenhouse had an antagonistic response to the combinations in the absence of a crop oil concentrate. If jimsonweed was grown outside or when a crop oil concentrate was present, the response was additive. Redroot pigweed grown in the greenhouse had an antagonistic response. Grown outside without crop oil concentrate, the response was synergistic and antagonistic if added. These interactions occurred only at the lowest rate of acifluorfen over all rates of bentazon. The injury to soybeans was additive.

The spread of a 2 μl droplet was not influenced by either herbicide or combination of herbicides only by crop oil concentrate.

Interactions of acifluorfen and bentazon may have occurred due to different sites of actions with the plant. The effect of each herbicide on the uptake of the other in radiolabled studies indicated that both acifluorfen and bentazon uptake was reduced in common lambsquarters when the other herbicide was present by a significant 15 and 17% respectively. In jimsonweed, which is more sensitive to bentazon, acifluorfen reduced the uptake of ^{14}C bentazon 4%. In redroot pigweed, bentazon reduced the uptake of ^{14}C acifluorfen 23% while acifluorfen increased the uptake of ^{14}C bentazon 10%. Neither herbicide was significantly influenced by the presence of the other in velvetleaf.

DEDICATION

To: Diane A. Sorensen, whose sacrifice and love mean more than any award or achievement.

Amy, Audrey, and Monte Sorensen, for offering hugs and kisses of encouragement.

Mont and Immogene Sorensen, for life and the courage to accomplish.

Ivan and Agatha Allen, for support and consideration.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to his major professor, Dr. William F. Meggitt, for his support and guidance in completing both the field and laboratory aspects of this study. Sincere thanks is also extended to Dr. Donald Penner for his laboratory assistance and patient review of the results. The assistance of Drs. Alan Putnam and Bernard Knezek as Guidance Committee members is gratefully acknowledged. A special thanks is extended to Mark and Dave Horny whose laboratory assistance was appreciated. A sincere thanks is extended to graduate students Jerry Wilhm, Ingert Kuzych, John Pawlak, Karen Renner, and Geoff List, technician Gary Powell, and secretary Jackie Schartzer for making the experience enjoyable. Finally, a sincere thanks to my wife, Diane, for typing, correcting, editing, and patient completion of this manuscript.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

LIST OF TABLES

LIST OF TABLES (cont.)

LIST OF TABLES (cont.)

LIST OF TABLES (cont.)

LIST OF TABLES (cont.)

LIST OF TABLES (cont.)

LIST OF FIGURES

LIST OF FIGURES (cont.)

CHAPTER 1

LITERATURE REVIEW

INTRODUCTION

Modern agriculture is a complex mix of systems. Each system is intertwined with the other to form an intricate network, that despite its complexity, is the most envied and admired by the world. Each facet of the system is important and comes with a labyrinthine series of unique problems. Since the advent of selective herbicides and increased use of organic pesticides in agriculture, the problem of pesticide mixtures has been evident. Crafts and Cleary (1936) first documented herbicide interaction. Since that time, researchers have documented numerous such measured interactions between pesticides.

The modern agriculturist has a literal arsenal of pesticides available for use. Some applicators are willing to combine almost any mixture of chemicals. Putnam and Penner (1974) indicated that many growers and commercial applicators choose to apply combinations of chemicals for economic reasons. Fewer trips across the field means lower expenditure of labor and less wear on equipment.

Herbicide mixtures are extremely popular due to the increased selectivity of the newer herbicides. Streibig (1981) pointed out that herbicide mixtures are used to broaden weed control over each herbicide used alone and to prevent the appearance of herbicide resistant weed species. In addition to favoring the survival of a particular species, the application of these highly selective chemicals aids in the establishment of populations of plant species and biotypes which are physiologically the most tolerant to the herbicide used. It would be logical then to assume that the use of mixtures of toxicants would provide more effective control of a population of mixed weed species, and may reduce the numbers of these individual biotypes that may be exceptionally tolerant to that particular herbicide program (Gowing, 1960). The advantage of herbicide mixing may be enhanced if the herbicides used kill the plant by acting on different physiological plant systems. Mixtures of herbicides also may be more effective on difficult to control weeds, especially perennials and woody species. Some mixes make it possible to decrease the total dose of the more environmental toxic or highly residual herbicide, and perhaps even protect the crop (Putnam and Penner, 1974). Knowledge of how the pesticides may interact can be helpful in preventing problems which may occur in crop production such as crop damage and herbicide carryover and decrease the herbicide dose to nontarget species.

Not all aspects of pesticide mixing, however, are positive. Some negative effects include increased toxicity to target plants and to nontarget species. This may result in increased residues in the soil and crop. One herbicide of a mix may inactivate one or more of the other components of the mix, which will result in reduced or lower weed control (Penner and Putnam, 1974). These pesticides, when applied in various combinations may interact with each other, resulting in responses not readily predictable from the performance of each chemical applied individually (Hatzios, 1981). One herbicide of a mix may act on some physiological system that causes the second herbicide to increase or decrease its normal activity in the plant. Eshel et al. (1976) noted that physical and chemical changes may cause herbicides in mixtures to interact, and thus the herbicide mixture may perform differently from any single component of the mixture applied separately.

Interactions that occur may be either positive or negative and serve two purposes. The first is the practical aspect, what does the combination do for the end user? The other reason is somewhat obscure in that the interaction may result in studies that might add to our limited understanding of the mechanism of plant growth and development (Lockhart, 1965).

A major problem encountered immediately when searching the literature for interaction information is the total lack of agreement among scientists concerning the very nature of the descriptive terms let alone their application. Terms such as additive and multiplicative models, interaction, synergism, antagonism, enhancement, and inhibition are discussed at length. It would seem appropriate that a discussion of these terms be included in this review.

Models are referred to by scientists as mathematical approximations of some biological sequence or event (Websters, 1981) and are used to reduce the amount of actual testing that has to be done. Models are also used to predict plant response under controlled circumstances. This reduces the need to perform tedious, replicated studies, when the results can be mathematically generated with a certain level of confidence. These models are based on solid evidence and sound scientific research. Two common models currently described by weed scientists in looking at herbicide interactions are the multiplicative and additive models. Each of these models will be described in detail later.

Interaction as a word and a concept has been somewhat misused and abused by weed scientists. Statisticians define interaction as a differential response to one factor, in combination with varying levels of a second factor applied simultaneously. That is, interaction is an additional effect due to the combined influence of two (or more) factors (Ostle and Mensing, 1975). An interaction may also be thought of as the failure of a response to one agent to be the same at different amounts of a second agent. Graphically, this means an interaction occurs if plotting the response of two levels of B against some agent A, the response will yield two curves that are not the same distances from each other at every value of A. Also graphically, if no interaction existed, the curves would be equal distance from each other at every value of A. If the response is a single function of A then the lines would be parallel to each other (Drury, 1980). An interaction occurs when two or more agents produce a response different than the individual sum of their responses (Nash, 1976). Thus, the term additive means that two or more agents produce a response that is equal to the individual sum of their responses within an acceptable variance. Generally, interaction is thought of as purely a statistical term. Lockhart (1965) proposed that it should be restricted to responses which have been shown to be interactions by the application of a Fisher's analysis of variance. It seems that this would be appropriate as Fishers analysis is a method that arithmetically partions the sum of square into the components of recognized sources of variation, i.e. treatments, rates, etc. In using the Fishers analysis, one assumes that the treatment effects are additive and that error is normally distributed around a zero mean with a common variance. In most situations dealing with herbicides, Fishers analysis is a valid test especially if these herbicides show a common site of action. If the interaction term is significant, the factors in the analysis are not independent of each other but one factor influences the r

t

b

ot

tr

ho

in

mea

var

tot

res

cons

to w

Gree

toge

subs

able

Scie

coop

grea

dem

to m

them

indep

State

Gren

results of another factor. Also if the interaction term is significant, the responses to combined treatments can no longer be considered additive but multiplicative. This is generally the response when herbicides act on different biochemical pathways. When this occurs, a logarithmic transformation can be used and the Fishers analysis is still appropriate, however, a different model is now used.

Thus, a statistical interaction indicates that the response of two independent variables is not independent. The interaction then is a measure of the effect of one variable on the response to the other variable. Nash (1981) suggested that an interaction occurs when the total response to a combination differs from the simple sum of its responses to the individual toxicants.

The term "synergism" is often misused. Although there is a general consensus in respect to the meaning, there is a general disagreement as to when it can be correctly applied. The word synergism comes from the Greek word "sunergos" (sun = together and ergon = work) meaning working together. A dictionary definition is, "...the action of two or more substances...to achieve an effect of which each is individually incapable" (Morris, 1980). In 1961 a terminology committee for the Weed Science Society of America accepted the definition of synergism as "the cooperative action of different chemicals such that the total effect is greater than the sum of independent effects" (Allen et al., 1961). The terminology committee modified the statement somewhat in a later report to read, "synergism is defined as cooperative action of different chemicals such that the total effect is greater than the sum of the independent effects" (Anonymous, 1964). Part of the confusion is the statements authors make concerning how they interpreted the word synergism. Hewlett (1960) for example, described synergism as a situa

of th

not r

doses

in ex

effec

rgist

for t

respo

the s

one p

site

not p

defin

in co

plant

stitu

singl

appli

Over

the te

positi

This c

Operat

Operat

Specif

using

situation in which the effect of a mixture exceeds the sum of the effects of the separate constituents. This may be somewhat misleading as he is not referring to an arithmetic sum of responses but rather the sum of two doses, hence confusion. Gowing (1959) described synergism as a response in excess of that which would be obtained from simple summation of the effects of the materials acting alone. Nash (1981) indicated a synergistic response where the incremental level of one chemical substituted for the other is less than expected or less than that for the additive response. Thus, smaller total amounts of chemical are needed to produce the same response. Finey (1952) described synergism as the presence of one preparation which makes the amount of the second preparation at the site of action behave as though it were greater than when the first was not present. Akobundu et al. (1975) used herbicides and rates in his definition of synergism. The combined effect of two herbicides applied in combination is synergistic, if over a range of rates and ratios the plant response is greater than that obtained when one chemical is substituted for the other at rates based on activity of each herbicide used singly. It is an important concept to note that the term synergism is applied over a range of rates and ratios, as disagreement usually arises over the term applied to single rates and ranges. Lockhart (1965) felt the term synergism should be restricted to those responses which show positive interactions. This is in agreement with most statisticians. This concept means that the proportional effects will be greater when the operation model is multiplicative or greater than additive when the operation is additive. This points to the fact that a model used must be specified. Using statistical terms Morse (1978) defines synergism by using a null hypothesis with which to compare the observed results. If

sy
th
Ho
th
su
suc
act
tio
are
meth

is s
abou
foli
by c
way f
trans
as th
photo
dimet
to oc
range
is su
chemi
if th
inter
actua

synergism occurs, the reference model or the null hypothesis represents the joint action that is assumed to occur if synergism is not present. However, the null hypothesis is difficult to define, especially if more than one component of the interaction is active. Some scientists have suggested abandoning the word synergism altogether and use word phrases such as "greater than predicted" to avoid implying anything about joint action (Loewe, 1953). In summary, it appears that all the above mentioned definitions all begin at the same point, namely, that when A and B are combined the results are greater than either applied singly. The method of measuring this response is the major source of disagreement.

The antonym of synergism would be antagonism. Generally, antagonism is somewhat easier to predict than synergism simply by knowing something about the toxicants involved. Contact herbicides generally antagonize foliar applied translocated herbicides. Rapid destruction of leaf tissue by contact herbicides reduces the necessary time and physiological pathway for the necessary uptake and movement of those herbicides that are translocated. Also the herbicidal action of the contact herbicides such as the bipyridylium family may be slowed or reduced by addition of the photosynthetic inhibitors such as monuron [3-(p-chlorophenyl)-1,1-dimethylurea] (Putnam and Penner, 1974). Usually antagonism is believed to occur if the effect of two herbicides applied in combination, over a range of rates and ratios, is less than that obtained when one chemical is substituted for the other at rates based on the activity of each chemical used singly (Akobundu, 1975). Describing antagonism by action, if the actions are negative, they will be less negative due to the interaction, or, if the action is positive, less positive. This is mutual antagonism (Drury, 1980). Thus, antagonism can be summarized as occurring when the observed response is less than that expected from either toxicant applied singly.

Morse (1978) pointed out that by definition synergism means one component increases in the presence of the other. In this strict sense, synergism and antagonism may be occurring at the same time. This condition would be most difficult to prove or to detect by experimentation. This anomaly is pointed out to emphasize the problems that exist in trying to adhere to strict definitions.

When discussing interactions, synergism and antagonism appear to be the most popular, but the additive effect is also important and often overlooked. Its value often lies in practical application, where the substitution of a more economical product for a more expensive one to accomplish the same job (Putnam and Penner, 1974). Statistically speaking, if the total response is the sum of two independent components, no interaction was measured and the response is termed additive (Nash, 1981). In a practical sense an additive model assumes that if one herbicide in a mixture is replaced wholly or in part by any biological equivalent dose of another, the biological response should remain unchanged (Streibig, 1981; Gowing, 1960; Akobundu, 1975). The sum is a simple sum and not the addition of logarithms, although additive in the strict sense, it is referring to a multiplicative model and is different, a point often overlooked.

Enhancement has for the most part referred to the effect of a herbicide and a non-toxic adjuvant applied in combination (Akobundu, 1975). Here the response is greater than either component applied separately but one of the components is not phytotoxic or biologically active by itself. This term seems to be well understood and easily applied.

va

tr

se

re

co

(19

va

the

pre

pres

who

inde

inde

an ea

propo

follo

that

intera

herbic

tended

activi

actions

Once th

made co

distinc

In some cases variables may behave independently. When two variables exert independent effects, the response to the simultaneous treatments with both variables is equal to the sum of the responses separately (Lockhart, 1965). Nash (1981) considered an independent response as part of the additive response when two chemicals are combined. This is contrary to what Tammes (1964) described. Drury (1980) argued that herbicides are examples of continuous, independent variables. Herbicides should properly be considered independent because they can be applied arbitrarily or can be thought of as arbitrarily present. They are continuous because they can be applied, or may be present in any amount over a wide range of values. Weed scientists, as a whole, tend to consider herbicide response as additive, even though independent. It appears that this is the current consensus concerning independent variables.

The criteria for determining if an interaction has occurred is not an easy matter nor are the methods well established. The results of proposed phytotoxic interactions is often confusing and unclear. The following discussion reviews the literature concerning the requirements that ought to be filled before looking for interactions.

It is difficult to know or be able to predict whether or not an interaction will occur from a herbicide mix by the responses of each herbicide applied singly (Putnum and Penner, 1974). Veldstra (1956) contended that since the herbicides have different sites of action and activity, then no plausible prediction about the possibility of interactions could be made unless their mode of action was fully understood. Once the mode of action is understood, then some predictions might be made concerning joint action or effect. Morse (1978) indicated that a distinction needed to be made between components which shared the same sites of action and affected the same systems and those which did not. She also agreed that something must be known or assumed about the mode of action of each of the components and the way these components affect the parameter to be measured (e.g. weight, height, survival, percent moisture, etc). If this information is lacking, there is no way of knowing if a departure from the reference model is due to interaction or inadequacy of the chosen model. In many cases the mechanism of interaction is complicated or unknown. Even if the sites and modes of action are fairly well known, interactions may occur places other than at the predicted site of action. The compounds may affect each other by interfering with the pattern of penetration, translocation, metabolism (Eshel, 1976), differential absorption, concentration at biochemical site(s) of action compared with each herbicide used separately (Steibig, 1981), reduced uptake, retention, penetration into leaves, environment conditions, temperature, incorporation, time interval between applications and sequence of applications of the herbicide mixtures (Olson et al., 1981). All these complex problems dealing with a wide array of physical and chemical changes make prediction of an interaction difficult, even when sites and modes of action are fairly well known and understood (Prendeville, 1969).

Before an interaction is determined the model must be known or predicted in advance of the analysis (Lockhart, 1965). Whether the model is additive or multiplicative has not always been noted or recognized and different methods of analysis have been confused with different models (Morse, 1978). Selecting a wrong model can lead to erroneous results or use of a wrong analysis to define the type of interaction measured.

Difficulty may also arise in the method used to measure an interaction due to the myriad of factors involved. Various herbicides may

Hag'

age

ing

of p

of m

spons

vatic

not e

resea

respoi

change

evolu

tion o

Akobun

respon

or dry

3) int

dosage

specie

weeds

O

Putnam

herbic

antagon

obtaine

that or

emulsif

may affect more than one process within the plant (Lockhart, 1965). Hagimoto et al. (1972) noted plant response to herbicides decreased with age due to 1) increasing difficulty of herbicide penetration, 2) increasing ability of the plant to detoxify herbicide 3) increasing plant volume of plant tissue (dilution effect). Most authors justified their method of measuring an interaction by relating it to some measured plant response affected by the particular herbicides in the mix. Visual observations were almost unanimously felt to be subjective and open to bias, not easily assessed as to magnitude and not communicated well. Most researchers rely on a weight or dimension method (Nash, 1981). Other responses include percent moisture, dry or fresh weight, stand reduction, change in length, and width, pigmentation, N content, O consumption, CO_2 evolution (Akobundu, 1975) and ID_{50} or the point at which a 50% inhibition occurs in a measured parameter (Akobundu, 1975 and Gowing, 1959). Akobundu (1975) listed methods for evaluating and classifying plant responses: 1) choose non-finite criteria for plant responses i.e. fresh or dry weight, 2) select data from the ID_{50} range not at the end points, 3) interpret data on basis of trends from many single and combination dosages, 4) restrict conclusions as to plant responses to those plant species for which data are available, rather than applying results to weeds or crops in general.

Other limitations or effects may influence herbicide interaction. Putnam and Penner (1974) noted the time of observation is critical. Some herbicides may appear synergistic at first but in the long term are antagonistic. This is especially true of perennial weeds. Responses obtained for one plant species may not occur on others. They also noted that one cannot neglect the effect of solvents, carriers, surfactants, emulsifiers, etc. on herbicide interactions. Gentner (1966) reported certain herbicides may predispose some plants to be more or less susceptible to subsequent herbicides. Differences in herbicide formulation may also influence herbicide response as well as period of time between treatment and harvest, method of application (soil vs foliar), and good field procedure (Gowing, 1960). These reported effects on interaction measurements and others make an interaction harder to assess, but reinforce the need to have adequate documentation in any interaction report.

The last requirement of noted importance before looking for an interaction is the type of plot system used in measuring the response. The field plot will probably always have its place as the final testing area for what has been observed in lab or greenhouse experiments. Although the data is generally less precise due to lack of control over the parameters it is still an important part of any interaction study (Gowing, 1960). As a practical field plot design the minimum set for the detection of an interaction should not be less than a two-by-two factorial (Drury, 1980).

INTERACTION CRITERIA

The criteria for determining an interaction is also somewhat vague and some disagreement exists in the literature about a proper procedure. It is fairly well agreed, however, that the common practice of pronouncing synergism or antagonism at each individual toxicant level is not correct (Morse, 1978; Akobundu, 1975). Due to the complex and diverse nature of chemical interactions and the systems involved, an identification of ranges over which interactions may occur appears more realistic than the single combination of rates (Campbell et al., 1981). Each individual scientist tends to use a method with which he feels most comfortable and confident. There is a plethora of such methods. Steibig (1981) used regression and isoboles to determine relative potency of herbicides. Colby's (1967) analysis has been used by many weed scientists to help evaluate interactions. Morse (1978) pointed out that many authors use logit regression lines to assess interactions. It does not necessarily follow, however, that herbicides that show similar graphing patterns will act in a similar manner. However, these regression lines may help to select the correct model. Isoboles have also been used to help determine what type of interaction may be occurring. Probit lines are useful at the screening level to determine interactions that later may be checked in actual well designed field tests (Gowing, 1959).

It is also generally agreed (Putnam and Penner, 1974) that interactions should be restricted to responses that have been shown to be interactions by use of an appropriate Fishers ANOV. If a researcher finds, however, that his data indicates synergism or antagonism and the statistical analysis shows no interaction, one may make confident statements about the type of response obtained by calculating an expected value and applying an appropriate statistical test. This should not be done at one single rate, but rather over a set of rates that are consistant. One also should check closely the model used if data appears to show interaction response and none is indicated. Most reports rely on the ability of the scientist to make intelligent decisions on what his observations actually mean and rely on models only to confirm these observations.

MODEL EVALUATIONS

Nearly all methods that may be used for identifying interactions have shortcomings. These methods are mathematical expressions for what is assumed to be happening in the plant system. The two basic approaches are the additive and multiplicative models (Nash, 1981; Morse, 1978). Although these models are approximations, they represent an improvement over no prediction estimates at all. These two models will each be discussed and then some of the current methods used to predict within these models will be evaluated.

Additive:

If the reference model assumes additive action of a mix, then one of the herbicides in that mixture can be replaced wholly or in part by an equivalent dose of the others and the biological response should remain unchanged (Streibig, 1981; Morse, 1978). It should be noted that the dose is a measure of biological response not in units of herbicide ingredient. Gowing (1960) referred to additive as the simple summation of the responses to the chemicals used separately. Morse (1978) pointed out that for the additive model, if the response surface for a mixture is plotted against an arithmetic scale of the doses, the contours of equal response will be straight lines. The additive model in most cases is a reasonable reference for herbicides with similar joint action.

Multiplicative:

This model does not give straight-line response isoboles. It requires the observations to be expressed in terms of a proportion or some value of a potential maximum. If a response from a mixture can be expressed as a proportion of some measured or hypothetical maximum, then the multiplicative model equates this proportion to the product of the corresponding proportions which would survive the components of the mixture, each tested singly (Morse, 1978). This model usually is applied to herbicides which act in different ways or effect different plant systems, neither influencing the effect of the other.

The ultimate use of these models would be fit curves to data for each herbicide applied singly and the results applied to the reference models to estimate joint or combined action. This would allow for selection of the correct model. These could then be compared to observations for the actual mix and an interaction determined.

ESTIMATES OF MODELS

The following is a review of the current models used by scientists to predict in either an additive or multiplicative model. These will be discussed as to advantages, disadvantages and model prediction.

Regression:

Regression has the capability of 1) extracting the main response features of a species and presenting it as an equation, 2) evaluate the model in terms of statistical validity (Campbell et al. (1981) 3) predict existence of an interaction, 4) the nature of the interaction (synergism or antagonism), 5) the magnitude of observed deviations from expected values and 6) statistical significance when determined from the LSD (Nash, 1981). If the relative potency of two herbicides is similar, their regression slopes are similar (Steibig, 1981). However, this does not mean they act in similar fashion. In general, the regression method predicts the occurrence of antagonism and synergism with similar results to the Colby method (Nash et al., 1973; Nash, 1981) even though they predict with different models. However, the regression method is not for the novice but takes skill and experience to interpret, especially when determining interactions (Cress, personal communication). This method also has a disadvantage of requiring a computer program to run and to draw the complicated line graphs. Regression fits the addititive model (Nash 1981, Morse 1978).

Calculus method:

The calculus method was proposed by Drury (1980) to find interactions in data. Multiple regression works just as well. Calculus method requires the use of complicated computer programs and the results are difficult to interpret. The calculus method assumes the additive model (Nash, 1981).

Isobole:

An isobole is a line of equal effects (Tammes, 1964). Isoboles are a method of comparing the bioactivity of herbicide mixtures. Several advantages are listed by Akobundu (1975): 1) simple to use and not time consuming, 2) does not require special graph tables or papers, and 3) can use many combination treatments. It has value as a graphical tool since it conveniently summarizes the results and demonstrates any departure from the reference model. It has to be interpreted with care, however. Generally, herbicidal interest is at the extreme ends of the isoboles where precision is low. Other disadvantages include many values on the isoboles curve are interpolated values, there is no test for significance (Morse, 1974; Nash, 1981), requires intricate computations (Tammes, 1964), time consuming, and the results often do not reveal phytotoxic interaction (Nash, 1981). The isobologram approach to interaction only assumes three possibilities; i.e. independent action, mutual promotion (synergism), mutual antagonism. If the action of the two agents do not always agree in sign or if one is a synergist and the other an antagonist, the isobologram fails because it cannot accommodate the situation where interacting agents have opposing actions (Drury, 1980). Isoboles assume an additive model.

Relief Graphing:

Nash (1981) indicated relief graphing was a simplier procedure than regression. In this procedure inhibition values are placed on a grid corresponding to the resultant pesticide concentrate which produced that inhibition. Its faults lie in the difficulty in the interpretation of the results, lack of statistical significance, and it is difficult to do without computer replicated data. The model is additive.

Colbys:

Colby's (1967) analysis has been used extensively by weed scientists in evaluating herbicide interactions (Waldrop and Banks, 1983). It is popular because it expresses the magnitude of each interaction and characterizes the results immediately as synergistic or antagonistic (Hatzios, 1981). Other advantages include the ease with which it can be calculated (Nash and Jensen, 1973) and the results were similar to those of difficult regression estimate and the two-parameter method (Nash, 1981).

Disadvantages of the Colby method is the wastefulness of the experimental design. In order to use the formulas, each treatment has to be replicated many times over a wide range of rates. This is to provide adequate coverage of the response range for each component, as well as the mix. This requires a large number of treatments (Morse, 1978). Colby's is not well adapted to statistical interpolation (Nash and Jensen, 1973; Hamill and Penner, 1973). Hamill and Penner (1973), however, overcame the statistical problem by using a ratio of two means and calculating an upper and lower confidence level. Akobundu (1975) found that the expected results were variable. At one set of rates the results were antagonistic, at another they were synergistic. He also expressed concern that at extreme herbicide dosages, plant responses could be exaggerated by use of the Colby's method. If evaluation is performed over a wide range of rates and applied with prudence, the Colby method is similar to the results obtained by other more complicated procedures. Colby's predicts in the multiplicative model.

ANOV:

The analysis of variance is used to help distinguish between models i.e. additive or multiplicative. In the simple additive system the variance will be independent of the mean (no interaction). In a multiplicative system (using logarithms) the variance will be directly proportional the mean squared or the standard deviation will be directly proportional to the mean (Nash, 1981). Duncan's multiple range test can be used to assess differences between means of interaction data but gives little information as to the character (synergistic or antagonistic) of the interaction. Another advantage of the ANOV is that most universities and recently with the popularity and availability of the personal computers, statistical packages are available that can help in analyzing for interactions. The ANOV is an additive model but the data can be transformed to logarithms and evaluated as a multiplicative model (Waldrop and Banks, 1983). A popular method is to use the ANOV to locate interactions and then use the Colby's analysis to determine the character of that interaction.

Algerbraic method:

The algebraic method is one described by Rummens (1974). This method uses algebra to assign parameters to the response curve of individual agents and defines the expected response function for combinations of agents by the weighted algebraic means of the individual parameters. This method is difficult to use and uses a computer program to make the calculations. It is an additive model.

Log-Probit:

A probit analysis consists of plotting the log concentration of a toxicant against the percentage response on a probability scale, and fitting a weighted regression line to the data (Gowing, 1959). This method was used in work with insecticides and was used to locate or establish the LD_{50} (amount of toxicant required to kill 50% of a given population) level. The data were plotted on log-probability paper and the reciprocal of this dose was used as the final plot. If a line drawn through the points is straight, this indicates joint action. If the curve goes above this line, synergism is indicated and a curve below the line is antagonism (Burchfield and Wilcoxon, 1954).

Probit analysis is recommended at the screening level and is useful in construction of field trials. The results of the probit are quite easy to interpret if the slope of a probit line is steep the herbicide is considered very effective. Expected results are plotted using a 1:1 ratio of two herbicides both at the 50% mortality range. When compared to the actual responses, synergism or antagonism can be evaluated by where the line falls compared to the 1:1 line. The pictorial representation provided by the log probit is helpful in determining which combinations of herbicide may have the greatest potential. This method is used only to back up good field procedure. Results from probits should be used as directive and not final. The reliability is near the LD_{50} level. Usually the information needed about herbicides are at the extremities of the probit and not at the center where the reliable data exists because equal increments of dose generally do not produce equal increments of response. Statistical values cannot be attached. Computations are complex and special graphic techniques are need (Gowing, 1959; Akobundu, 1975). The log-probits predicts in the additive model.

Conclusion:

Because of the complex and diverse nature of chemical interactions and biological systems, the identification of ranges of levels where interactions may occur is a realistic approach to the study of herbicide interactions. Although the above mentioned methods of assessing interactions are diverse and different they had the same starting point, that is, an interaction was observed to occurred. Which procedures, methods or terms are chosen to be the most correct by an individual author, will probably be scrutinized and challenged by mathematicians and statisticians who will not soon easily decide this issue.

DESIGN OF EXPERIMENTS

There is generally a lack of agreement as to what types of experimentation and statistical analysis are necessary to prove whether one really has an interaction (Putnam and Penner, 1974). The design of these experiments has not received much attention. Nash (1981) indicated that several rates of each herbicide should be used so that if an interaction is measured it could be over a rate range. Drury (1980) felt a minimum data set for detection of an interaction was a two by two factorial. A factorial design is usually considered to be the best design to measure the effect herbicide interactions on plants. This way combinations of rates of herbicides can be tested (Nash and Jensen, 1973). Even though lab research has its place, the ultimate test of an interaction is in the field (Gowing, 1960). There is no real replacement for a well designed, well executed field plot experiment. The experiment should be designed so that the question raised by the research is answered, the number of factors kept to a minimum to reduce confounding and the method of measuring the response clearly understood (i.e. height, dry weight, percent moisture, etc.). A method of determining if interactions occur should be considered previously to design implementation (e.g. Colby, regression) because some methods require more data points to determine interactions than others. It is important to limit results to the weed or crop species involved and the rates tested. Responses that are synergistic on one species may not be synergistic on other weed or crop species at the same rates. The number of replications also depends on the statistical design and the method of interaction evaluation. Most researchers use three or four replications and experiments are generally repeated twice. Although not usually a common procedure, most weed scientists should consult with a statistician before laying out extensive field research plots to measure herbicide interactions to prevent voids that may develop during analysis.

TYPES OF INTERACTIONS

References exist in the literature of herbicide interactions with fungicides, nematicides, growth regulators, fertilizers, spray adjuvants, environmental factors, and other herbicides. Since this a review of specific herbicide interactions the others will not be discussed here as reviews exist elsewhere (Putnam and Penner, 1974; Hatzios and Penner, 1982; Hatzios and Penner, 1984 in press). The herbicide interactions termed antidote, predisposition and environmental factors are also delt with in other reviews (Putnam and Penner, 1974; Hatzios and Penner, 1982;

Hatzios and Penner, 1984 in press) but are mentioned here only because they must be considered as a part of any herbicide interaction. The main concern of this review is with the herbicides acifluorfen [sodium 5-[2-chloro-4-trifluoromethyl)-phenoxy]-2-nitrobenzoate] and bentazon [3-isopropyl-1H-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide]. Both are commonly used together and with other herbicides. A brief review of documented interactions of acifluorfen and bentazon with other herbicides will be discussed as no literature exists at present documenting an interaction between acifluorfen and bentazon.

Acifluorfen interactions:

Acifluorfen is a contact herbicide (Ashton and Crafts, 1981) that is currently labeled as a broadleaf and grass herbicide in soybeans [Glycine max (L.) Merr.] and peanuts (Arachis hypogaea L.) and rice (Oryza sativa L.). Tank mixes are common to reduce the phytotoxicity of acifluorfen to soybeans and to increase its weed spectrum. Waldrop and Banks (1983) reported antagonistic and additive responses when acifluorfen was combined with 2,4-DB [4-(2,4,diclorophenoxy)butanoic acid] on sickle pod (Cassia obtusifolia L.). Acifluorfen and toxaphene (mixture of chloronated bornanes) produced only additive responses in the greenhouse, but synergistic responses in the field. Mefluidide M-[2,4-dimethyl-5-[[(trifluoromethyl)-sulfonyl]amino]phenyl)acetamide plus acifluorfen increased injury to ivyleaf morning glory ((Ipompea hederacea (L).) Jaeq), velvetleaf (Abutilon theophrasti Medic.), and common cocklebur (Xanthium pensylvanicum Wallr.) compared to the injury from either applied alone (Hook and Glenn, 1984) Benazolin (4-chloro-2-oxobenzothiazolin-3-ylacetic acid) in combination with acifluorfen gave more than additive control of cocklebur, velvetleaf and jimsonweed

(*Datura stramonium* L.). Benazolin had no effect, however, on the uptake or movement of ^{14}C-labeled acifluorfen in these weeds (Bugg et al., 1980). Reports from many scientists (Hartzler and Foy, 1983; Nalewaja et al., 1981; Kells et al., 1981; Renner and Harvey, 1983) reported antagonistic or reduced grass weed control when acifluorfen was mixed with the current translocated grass herbicides, i.e. sethoxydim [2-(1-(ethoxyimino)butyl)-5-(2-ethylthio)propyl)-3-hydroxy-2-cyclohexen-1-one], fluazifop-butyl [2-(4-((5-(trifluoromethyl)-2-pyridinyl)oxy)phenoxy) propanoate] and diclofop-methyl [methyl-2-(4-((3-chloro-5-(trifluoromethyl)-2-pyridinyl)oxy)phenoxy)propanoate]. There does not seem to be a reduction in broadleaf weed control from the combinations.

Bentazon interactions:

Bentazon is classed as a contact herbicide (Ashton and Crafts, 1981) and is labeled as a selective post-emergence herbicide on broadleaf weeds and sedges. It is currently labeled for use in soybeans, rice, corn (*Zea Mays* L.), beans (*Phaseolus vulgaris* L.), peas (*Pisum sativum* L.), turf, mint (Labiatea sp.) and peanuts. Because of its limited spectrum, it is rarely applied alone except for a specific weed problem such as nutsedge (*Cyprus esculentus* L.). Mixtures of bentazon and bromoxynil (3,5-dibromo-4-hydroxybenzonitrile(4-cyano-2,6-dibromophenol) reduced the cost of controlling annual sunflowers (*Helianthus annus* L.) compared to either applied singly and also reduced the soybean injury (Irons and Burnside, 1982). Pretreatment of Canada thistle (*Cirsium arvense* (L.) Scop.) with $GA_{4/7}$ increased the herbicidal activity of bentazon more than four-fold (Sterrett, 1983). When mixed with toxaphene, 2,4-D (2,4-dichlorophenoxy acetic acid) and acifluorfen, bentazon showed negligible interactions when applied to sickle pod (Waldrop and Banks, 1983). Benazolin in combination with bentazon gave more than additive control of cocklebur, velvetleaf, and jimsonweed (Copping and Garrod, 1980). Benazolin had no effect on ^{14}C-labeled bentazon uptake by cocklebur but it doubled the movement of bentazon out of the treated leaf (Bugg et al., 1980). Mefluidide plus bentazon controlled a broader spectrum of grasses and broadleaved weeds in soybeans than did either herbicide alone (Gates, 1983). Paulo et al. (1982) reported synergism with mefluidide and bentazon on pigweed (*Amaranthus retroflexus* L.) and common lambsquarters (*Chenopodium album* L.). Red rice (*Oryza refipogan* Griff.) control was reported by Rao (1981) to be synergistic using the same combination. Antagonism or significantly reduced control was reported by numerous scientists when bentazon was tank mixed with any of the translocated grass herbicides i.e. sethoxydim, fluazifop-butyl, and diclofop-methyl (Renner and Harvey, 1983; Kells et al., 1981; Nalewaja et al., 1981; Hartzler, 1983). Bentazon also reduced the activity of diclofop-methyl on annual grasses (Campbell and Penner, 1982). No reduction in broadleaf weed control, however, was reported.

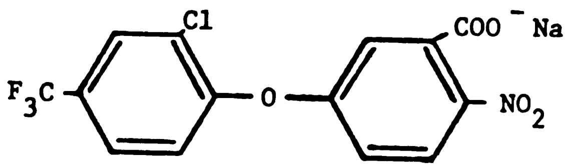
HERBICIDE ACTIVITY

The two herbicides acifluorfen and bentazon will be discussed separately. Each discussion will include herbicidal effects, movement in the plant, selectivity, effects of light and comments on the proposed mode of action.

Acifluorfen:

Acifluorfen is a member of the substituted diphenyl ether herbicide family. This family has a common nucleus of two phenyl rings joined by an ether linkage. A nitro group is bonded to the para-position (4-

position) of one of the phenyl rings. Herbicides in this family differ from one another by substituting various R-groups to one or both of the phenyl rings. The chemical name of acifluorfen is sodium 5-[2-chloro-4-(trifluoromethyl)-phenoxy]-2-nitrobenzoate and has the following structure:



In soils, acifluorfen is strongly absorbed to soil colloids and is not subject to leaching. The toxicity to mammals is low (Anderson, 1983; Beste et al., 1983).

Researchers have noted several biological areas in plants that acifluorfen may influence. Acifluorfen is considered a contact herbicide, thus, visual results on a susceptible plant species are rapid foliar necrosis (Waldrop, 1983; Vanstone and Strobbe, 1979). The effects of acifluorfen resemble those of stress factors i.e. increase in lipid peroxidation, membrane permeability, ethylene production and phenylalanine ammonia-lyase activity (Komives and Casida, 1983). Vanstone and Strobbe (1967) compared the diphenyl ethers to paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) as both herbicides are considered contact herbicides, require light for activation, and cause loss of membrane integrity. A comparison of acifluorfen to paraquat will be discussed later in this review. The diphenyl ether herbicides have also been shown to cause stomatal closure due to increased membrane permeability. This closure also increases leaf temperature (Gorske and Hopen, 1978). Leong and Briggs, 1982) noted the plants treated with acifluorfen were sensitized to phototropism at rates below that needed to sensitize the untreated control. The responses to phototropism varied with concentration of herbicide applied. Acifluorfen had no effect on elongation or geotropism, however.

The phytotoxicity of acifluorfen is increased by the addition of a surfactant (Less and Oliver, 1982). The increase in phytoxicity was noted regardless of temperature or humidity (Ritter and Coble, 1981). Ritter (1980) had noted in an earlier paper that increased penetration and translocation occurred when applications of herbicide were made under high humidity. This resulted in increased phytotoxicity. Wills and McWhorter (1981) also noted increases in phytotoxicity at 100 percent relative humidity compared to 40 percent relative humidity. Acifluorfen was also more toxic at higher temperatures (27 and 35^{o}C) than at lower temperatures (18^{o}C).

Review of previous carbon labeled work indicated that labeled acifluorfen applied to leaf tissue of velvetleaf or jimsonweed was not absorbed readily. More than 98 percent was washed from the leaf surface by a 1 minute aqueous buffer solution (Lambert and Basler, 1983). Little movement of labeled acifluorfen was detected in ragweed (_Ambrosia artemisiifolia_ L.) or cocklebur over a 24 hour period. Audioradiographs showed limited acropetal movement in 48 hours. Soybeans in the same study showed no movement in 48 hours of the labeled acifluorfen (Ritter and Coble, 1983). As soil moisture decreased the percentage of ^{14}C-acifluorfen herbicide translocated out of the treated leaf decreased. The decrease in soil moisture decreased the amount of ^{14}C-label that was moved to the opposite true leaf, upper leaves and growing point. The soil moisture decrease also increased the percentage of herbicide translocated to the root, stem and cotyledonary leaves (Mann and Rieck, 1979). Temperature and humidity increased ^{14}C-acifluorfen uptake. There was a four-fold increase in label taken up at 27 and 35°C over that at 18°C and a three- to four-fold increase in uptake rate at 100 versus 40 percent relative humidity (Wills and McWhorter, 1981). When labeled acifluorfen was injected directly into the stem tissue of jimsonweed and velvetleaf, it was translocated into the leaf tissue within a 4 h period. Only six percent was translocated to leaf tissue in soybean. Basipetal translocation was negligible in all species and very little translocation occurred either acropetally or basipetally after the four hour period (Lambert and Basler, 1983).

The selectivity of acifluorfen appears to be related to the ability of tolerant plants to metabolize the parent compound. Ritter and Coble (1981) showed susceptible weed species had slower metabolism, faster penetration and faster translocation of acifluorfen than did soybeans. More than 50% of the labeled acifluorfen was metabolized to nontoxic compounds in 4 hours by the soybeans, where little acifluorfen was metabolized by susceptible weed species (Lambert and Basler, 1983). Frear (1983) studied the metabolites of acifluorfen in soybean and showed the diphenyl ether bond was rapidly cleaved. From 85-95 percent of the absorbed label was metabolized in less than 24 h by soybean. It appears that acifluorfen metabolism was related to plant susceptibility.

Like other diphenyl ether herbicides, acifluorfen requires light for activation (Devlin et al., 1983). The most effective wave length is 565 to 615 nm, which suggests a pigment absorbing in this region is the photoreceptor (Vanstone and Strobbe, 1979). Radiolabeled foliar applications of acifluorfen resulted in no significant difference in translocation in light or dark. However, light after treatment is required for herbicidal activity and various lengths of dark periods prior to application does not influence herbicidal response as long as light followed dark (Fodayomi, 1976). In a similar experiment Vanstone and Strobbe (1979) noted plants were not injured when placed in the dark for as long as 4 days after herbicide treatment. Injury did occur, however, when plants were brought into the light. Injury increased as light intensity increased. In membrane preparations from oat (Avena sativa L.) coleoptiles, blue light photoreception was greatly enhanced by acifluorfen. Acifluorfen appeared to act as a blue light sensitive cytochrome-flavin complex (Leong and Briggs, 1982). Knowing that diphenyl ether herbicides are inactive in nonpigmented tissue, it is assumed that some other light-harvesting pigment(s) may be involved in the activation of these herbicides. Orr and Hess (1982) using various chlorophyllous mutants of rice, corn, and soybean, suggested carotenoids, and perhaps a xanthophyll, plays a role in the light activating mechanism of this herbicide group. In a similar study, Fadayomi (1976), reported white mutants of corn are much more resistant to the herbicide than a greenish-yellow mutant or a normal plant. A yellow mutant of soybean was equally as susceptible as the normal type. The results suggest that acifluorfen is activated by the yellow plant pigments.

The exact mode of acifluorfen is still not known but many plausible and reliable pathways have been proposed. It appears that acifluorfen may act in several areas of the plant and affect more than one system. As potent inhibitors of photosynthesis, the diphenyl ethers were proposed to block electron transport (Moreland et al., 1970; Bugg et al., 1980) inhibit energy transfer (Sanderman et al., 1981) and affect plasma membrane systems (Leong and Briggs, 1982). Bugg et al. (1980) reported evidence which indicated the site of inhibition of the diphenyl ether herbicides was in the plastoquinone-cytochrome f region between photosystem I and photosystem II. Others reported, however, that the inhibition of electron transport in the chloroplasts is secondary to some other mechanism (Matsunaka, 1969; Fadayomi and Warren, 1976; Prendeville and Warren, 1977; Vanstone, 1978; Vanstone and Strobbe, 1979, and Pritchard et al., 1980). Vanstone (1978) reported chlorophyll content was not reduced by diphenyl ethers and that photosynthesis was affected only after membrane integrity was disrupted. Further evidence by Orr and Hess (1982) showed that acifluorfen continued to exhibit activity in grain tissue even when the photosynthetic inhibitors (DCMU and DBMIB) were present, indicating that chlorophyll and the photoelectron transport system may not be necessary for acifluorfen activity.

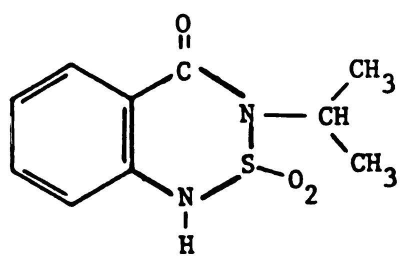
To help determine if the diphenyl ethers caused plant death in the same method as paraquat, the use of eletrolytic conductivity as a measure of cell membrane disruption was used. The highest conductivity resulted from the paraquat treatments and the highest concentration of each herbicide resulted in higher conductivity readings. Paraquat affects cell membranes early, diphenyl compounds require 8 h to produce severe injury. No conductivity changes occurred during the first 6 h of the treatment with the diphenyl ether herbicide (Vanstone and Strobbe, 1967). Further tests indicated that by increasing diphenyl ether concentrations 1000 fold, the final conductivity end points hardly doubled. Paraquat end points, however, were tripled with a 10-fold concentration increase. This difference in conductivity response implies a different mode of action for the diphenyl ethers than that of paraquat. Orr and Hess (1982) found no evidence to support that diphenyl ethers exert their herbicidal influence through toxic products formed following light activation of the compound. Orr et al. (1983) concluded that the mechanisms involving direct oxidation and reoxidation of the diphenyl ether molecule are probably not the basis for the action of this herbicide family.

One method of protection against the diphenyl ether herbicides was shown to be a pretreatment of seedlings with fluridone, a carotenoid biosynthesis inhibitor (Orr and Hess, 1982). Thus, it appears that the carotenoid pigments do have a role in diphenyl ether response.

It appears a consensus that diphenyl ether herbicides after being activated by light, express their primary effect as general membrane perturbation (Orr and Hess, 1982; Orr and Hess, 1981; Gorske and Hopen, 1978; Vanstone and Strobbe, 1967). This perturbation occurs rapidly (10-15 minutes) following herbicide application (Orr and Hess, 1982) and the result is a loss of the membranes selective permeability characteristics and eventual cell death. This membrane disruption was verified lately by electron microscopy and the detection of lipophilic free radicals (Orr and Hess, 1982). Devlin et al. (1983) proposed the activation of the substituted diphenyl ether herbicides may occur as a result of absorption of light energy from the carotenoids.

The following scheme is a summary from the reported data concerning diphenyl ether activity. Light absorbed by yellow plant pigments activates the diphenyl ether molecule. The carotenoids appear to be the major plant pigment involved and are destroyed following herbicide activation. The light activated herbicide molecule may then be involved in the initiation of a radical chain reaction through the removal of molecules from the polyunsaturated fatty acid chains in the lipid membrane. This fairly stable, free radical could then react with molecular oxygen to form a lipid peroxide which could readily spread throughout the hydrophobic matrix of the membrane (Orr and Hess, 1982) and destroy membrane integrity. This hypothesis is supported by the facts 1) These compounds are active in green and etiolated tissue 2) damage does not occur if carotenoid biosynthesis is prevented by fluridone 3) injury is expressed as an increase in membrane permeability about 10-15 minutes after light activation 4) early injury of the chloroplast envelope 5) detection of stress materials after treatment i.e. ethane and ethylene 6) visual verification of membrane destruction by electron microscope and detection of lipophilic radicals.

Bentazon: Bentazon is not considered part of any distinct herbicide family but is a unique structure. It contains a benzene ring connected to a thiadiazin ring in the following manner:



The chemical name is 3-isopropyl-1H-2,1,3-benzothiadiazin-4(3H)-one 2,2,-dioxide. Bentazon is not absorbed to soil particles but is rapidly metabolized by soil microorganisms so does not leach appreciably (Abernathy and Wax, 1973). Being somewhat selective, bentazon is generally applied as a tank mix with some other herbicide. The addition of spray adjuvants may be helpful by preventing bentazon from washing from plants (Nalewaja et al., 1975). Vegetable and petroleum oil adjuvants generally increased the toxicity of bentazon. Except for overcoming the detrimental effects of rainfall following bentazon application, surfactants have not always significantly increase toxicity (Doran and Anderson, 1975).

The uptake and translocation of bentazon has been studied in both susceptible and resistant species. Audioradiographs indicate that bentazon is accumulated in the tips and margins of treated plants. Translocation appears to be slightly increased with increased plant susceptibility (Martin et al., 1978). Temperature and light influence bentazon activity and translocation both before and after application. Increases in light and temperature increases susceptibility to bentazon in susceptible species.

Differences in susceptibility were not correlated to epicuticular wax but the stomata were suggested to play a significant role in bentazon entry by Davis et al. (1975). The herbicidal effects of bentazon tend to develop slowly after translocation has occurred if bentazon is taken up by the roots in a flooded condition. When weed foliage is contacted directly with lethal amounts of bentazon the effects appear rapidly (Mine et al., 1975). The absorption and translocation of bentazon did not differ greatly between highly resistant and susceptible plants (Mine and Miyakada, 1975). Decrease in soil moisture decreased the amount of bentazon movement out of the treated leaf to the opposite true leaf, upper leaves and growing point and increased the percentage of herbicide translocated to the root, stem and cotyledonary leaves (Mann and Rieck, 1979). Surfactants increased acropetal movement of bentazon in sunflowers but no increase in basipetal movement was noted (Irons and Burnside, 1982). Others (Mahoney and Penner, 1975 and Penner, 1974) have noted that movement of bentazon was primarily acropetal. The uptake of bentazon was found to be relatively slow and influenced by time of day (Dunleavy et al., 1982).

Bentazon is not active unless plants are placed in the light following an application. Plants kept in the dark after bentazon appl

sympt

treat

When

the h

was r

rapid

tory

after

requi

about

plasts

chlor

and ne

both w

spheri

plasts

illum

membr

application showed no visual symptoms or ultrastructure toxicity symptoms. Furthermore, respiration and leaf expansion of control and treated plants continued to be the same when kept in total darkness. When exposed to various levels of bentazon and light, it was noted that the higher the illuminance the faster necrosis developed and that light was required for necrosis to develop. Photosynthesis was arrested more rapidly as the dose rate of bentazon increased. Bentazon was more inhibitory to photosynthesis 3 h after application and to respiration 1 day after in susceptible plants (Penner, 1975). Regardless of the time required to stop the photosynthesis, the necrosis symptoms were visible about 7 h after photosynthesis was arrested. The rupture of the chloroplasts was followed shortly by necrosis. At low illuminance the treated chloroplasts became more spherical and aggregated before they ruptured and necrosis was noted. In comparing the control and treated plants when both were placed in darkness, the chloroplasts in both situations became spherical and aggregated. Therefore, shape and distribution of chloroplasts are not considered a toxic response to bentazon. At high illuminance chloroplast shape and distribution did not change before membrane rupture (Potter and Wergin, 1975).

The activity of bentazon on plants tends to be centered around the photosynthetic pathways. Although this may be the major area of impact, Dunleavy et al. (1982) suggested that a reduction in transpiration due to stomatal closure following bentazon application was important in the mode of action sequence. The major impact, however, is in the chloroplast. The effect of bentazon on the grana stack is well documented. The chloroplasts of bentazon treated plants appear to be shorter and thicker than those of the control plants. They appear as chloroplasts of control plants grown under low light levels. The amount of chloroplast lamella is enhanced, as is the stacking degree of the thylakoids and the grana area. This chloroplast change occurs even when bentazon treated plants are exposed to high light intensities (Meijer et al., 1980), Meijer et al., 1981). Penner (1974) noted that plant injury due to bentazon increased as soil moisture increased. Even tolerant plants were injured by bentazon when grown under excessive soil moisture. These results confirmed those reported by Anderson et al. (1974). Another plant activity affected by bentazon, is that of carbon fixation. Photosynthetic carbon fixation was totally inhibited within 2 h following a bentazon application. Lethal dosages of bentazon inhibited all photosynthetic activity and caused net carbon dioxide evolution in the light (Potter and Wergin, 1975).

The difference between a susceptible and tolerant plant species appears to be in the ability of the tolerant species to rapidly metabolize the bentazon molecule (Hayes and Wax, 1975; Mine et al., 1975; Penner, 1974; Mahoney and Penner, 1975). The metabolites are reported to be water soluble and four have been identified. The pretreatment of a tolerant species with other herbicides did not influence or decrease the metabolism of bentazon (Mahoney and Penner, 1974). Penner (1975) also noted an increased spray retention by a susceptible weed species as compared to tolerant soybean. The increased retention would logically allow for greater absorption of bentazon and increase the level of herbicide inside the plant. Metabolism of the bentazon molecule appears to be a main factor in resistance as both susceptible and tolerant species absorb and translocate similar amount of bentazon (Mine et al., 1975). Hayes and Wax (1975) compared different cultivars of soybeans and found a correlation between bentazon injury and bentazon metabolism. As metabolism of the parent bentazon molecule increased, toxicity symptoms decreased.

The herbicidal activity of bentazon is mainly as a photosynthetic inhibitor. It can be taken up through the roots or foliage. Penner (1975) reported that under high soil moisture soybean tolerance to bentazon was reduced. Covering the soil with vermiculite prior to spraying avoided the loss in soybean tolerance which suggests bentazon absorption by roots may occur under flooding conditions. Translocation is mainly acropetal through the xylem. Intercellular penetration is usually in the lipophilic (fat loving) rather than the hydrophilic (water loving) form. The herbicide is mainly a photosynthetic inhibitor, blocking the electron system between photosystem I and II (Retzdaff and Hamm, 1977). Suwanketnikom et al. (1982) concluded that the site of bentazon inhibition of the photosynthetic electron transport is at the reducing side of photosystem II between the primary electron acceptor Q and plastoquinone. Pfister et al. (1974) indicated in an earlier paper that bentazon inhibits the photoreaction of photosystem II but does not affect the reactions of system I. They also noted that bentazon prevents the formation of the light induced pH-gradient and suppresses the variable fluorescence. Bentazon although needing light to be active is not photoactivated in a similar manner as the diphenyl ether herbicides. Potter and Wergin (1975) indicated that bentazon caused degeneration of the plasma membrane which is lethal. When this membrane is ruptured, turgor pressure drops to zero and the cell collapses. This is the final step to necrosis.

Concl

A

only

separa

same t

aciflu

bioche

Conclusion:

Acifluorfen and bentazon are both contact herbicides and are active only in the light. Their herbicidal activity, however, appears to be in separate biochemical pathways. Since both are commonly applied at the same time, it is important to know what impact a combination of acifluorfen and bentazon may have on each other both physically and biochemically once inside the plant system.

CHAPTER 2

DETERMINING THE INTERACTION

INTRODUCTION

It is a common practice to combine herbicides. The combinations are used to increase the activity on an individual weed species or to broaden the spectrum of weeds controlled by a single spray application. Combinations of herbicides may result in interactions which are not obvious from either herbicide applied singly. The interactions may vary depending on the rate of herbicide used and weed species present (Akobundu et al., 1975; Nash, 1981). Adjuvants may also influence interactions or the activity of herbicides (Nalewaja et al., 1975; Doran and Anderson, 1975). The types of interactions that may occur are listed as synergistic, antagonistic or additive. Several methods have been proposed and reviewed (Colby, 1967; Putnam and Penner, 1974; Nash, 1981; Akobundu, 1975; Gowing, 1960; Morse, 1978) for calculating expected responses and how to relate these responses to actual observed responses and determine if an interaction occurred. Although there is general disagreement concerning which method is most appropriate, the method proposed by Colby (1967) is most often used. The Colby method is considered correct by weed scientists as long as the proper model is applied (Morse, 1978). The Colby method is easier to use than other models and the results have been generally similar (Morse, 1978; Nash, 1981).

wee

the

comm

retr

(Abu

effe

exis

then

antag

the a

inves

acifl

two s

exper

three

0.43,

Each e

three

soil c

as fin

5.5 an

treate

Acifluorfen and bentazon have been used as a common tank mix for weed control in Michigan soybeans [Glycine max (L.) Merr.]. Generally the weed spectrum will include one or more of the following species: common lambsquarters (Chenopodium album L.), redroot pigweed (Amaranthus retroflexus L.), jimsonweed (Datura stramonium L.) and velvetleaf (Abutilon theophrasti Medic.). None of these four weed species is effectively controlled by either herbicide alone.

The objective of this study was to determine if an interaction exists between acifluorfen and bentazon. If an interaction is measured, then the nature of the interaction will be determined (i.e. synergistic, antagonistic, or additive). The effect of species, herbicide rate, and the addition of a crop oil concentrate on the interaction will also be investigated.

MATERIALS AND METHODS

The experiments to determine whether an interaction exists between acifluorfen and bentazon when applied in combination were conducted in two study areas, greenhouse and outdoor, container grown plants. These experiments were completely randomized factorials with the following three factors: crop oil concentrate (0, 2.3 L/ha), acifluorfen (0, 0.28, 0.43, and 0.56 kg ai/ha) and bentazon (0, 0.56, 0.84 and 1.12 kg ai/ha). Each experiment had three replications and each experiment was repeated three times. The soil was an artificial mix of 1/3 peat, sand and field soil calculated on a volume/volume basis. The field soil was classified as fine-loamy, mixed, mesic Aeric Ochraqualf. The soil mix had a pH of 6.5 and soluble salt reading of 3.0 mmhos/cm^2. The soil mix was steamed treated prior to use.

The containers used had a volume of 946 cm^2. The seeds of the four weed species studied were sown and covered with 0.75 cm of soil. Following weed seed germination and subsequent emergence, the plants were thinned to four plants per pot. Watering was from the surface. Weed seed was from indigenous Michigan plants and collected the fall prior to experiment implementation.

Each plant species was at the recommended label size and growth stage at herbicide application. The herbicide was applied with an 8001E flat fan nozzle at 229 kPa pressure and in a volume of 355 L/ha. The 2L formulation of acifluorfen was used. The crop oil concentrate was a paraffinic based petroleum oil.*

The greenhouse plants were maintained at an average temperature of 22 $\pm$ 4^{o}C with relative humidity normally near 80%. Light was from natural sunlight and was assisted by sodium halide lights emitting 250 μE m^{-2} sec^{-1}. The sodium lights were set for a 16 h photoperiod. Plants were not grown in the greenhouse during the summer period.

The plants were grown outside during the months of May through September. They were exposed to all external environmental stresses of a field grown plant except root volume was restricted by the container. The average maximum and minimum temperature was 17 to 28^{o}C. Light was only from natural sunlight. The experiment was repeated at various times through the summer to reduce the effect of day length as a factor in the interaction.

Ten days following the herbicide application treatments, the greenhouse and outside grown plants were visually rated for herbicide injury. The plant tissue above the soil surface was harvested, weighed,

*80% petroleum hydrocarbon, 16% surfactant blend, 4 formulation aids sold under the trade name Herbi-max.

and placed in a forced air drying oven for 5 days at 75°C. The plant material was allowed to equilibrate for 2 to 3 days following which a dry weight was taken and a percent moisture calculated.

The fresh weight, dry weight and percent moisture data were subjected to ANOV. This allowed for mean separation and to assess significant interactions. If the two herbicides showed a significant interaction, it was assumed that the additive model did not apply and a Colbys analysis (Colby, 1967) could be appropriately performed to determine what type of interaction existed. As directed by Colby, the expected response was expressed as the product of the observed responses from each herbicide applied singly divided by the value of the control treatment, where the control treatment value was set at 100 percent. The expected response value was then expressed as a percentage of the nontreated control. Since acifluorfen and bentazon are contact herbicides, it was determined that percent moisture reflected more clearly the amount of herbicide damage than did the other measured parameters (dry weight, fresh weight, or visual ratings). These other measurements, however, were used to help assess the interaction. If the plant was not completely killed by the herbicide application, the amount of regrowth (in 10 days) was not sufficient to significantly distinguish it from those plants which were controlled if only fresh weights or dry weights were compared. Visual ratings were too subjective and variable from time to time. Percent moisture was a consistent indicator of herbicide damage and did not cover a wide spectrum of percentages but was in the range of 20 to 75 percent of the plant weight. Thus, more damage indicated a lower moisture. The type of interaction measured depended on where the expected response fell in relation to the observed response. Synergistic interactions were those where the observed response to the herbicide combinations were less than the expected (less plant moisture); antagonism occurred when the observed response was greater than the expected (more plant moisture) and additive occurred when the ANOV showed no interaction. To determine if the difference between the expected and observed was significant the following formula as described by Hamill and Penner (1973) was used:

HAMILL AND PENNER

$\bar{X}_1$ = Observed combination mean

$\bar{X}_2$ = Control mean

$$C = \frac{(\bar{X}_2)^2}{(\bar{X}_2)^2 - \frac{(S^2)}{N}(T^{*})^2}$$

$$R = \frac{\bar{X}_1}{\bar{X}_2}$$

$$LSD \cong \sqrt{(C - 1)(CR^2 + 1)}\ \sqrt{2}\ (100)$$

This method utilizes the observed combination mean, the value for the control mean, the mean square error from the analysis of variance (S^2) and a "t" value to approximate an LSD (least significant difference) value. The LSD value was set at .05 level of probability.

A field test was also established on velvetleaf to evaluate the same herbicide combinations. The treatments were replicated three times and established on a natural infestation that varied from 1 to 144 velvetleaf plants per m^2. The plots were 3 by 12 meters in a completely randomized design. The velvetleaf was 7 to 15 cm tall with four to seven leaves at herbicide application. Herbicide was applied in 262 L/ha water at 343 kPa pressure. The plots were visually rated on a 1 to 10 scale where 0 was no injury and 10 was total plant death, at 2, 5, 10 and 21 days following herbicide application. The soil type was classified as a fine-loamy, mixed, mesic Aeric Ochraqualf. The organic matter was 3.9 percent with a calculated CEC (cation exchange capacity) of 12 and a pH of 7.0. A preplant incorporated treatment of trifluralin (α,α,α-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine) at 0.56 kg/ha was used to control grass weed species.

The parameters measured for each weed species were percent moisture, fresh weight and dry weight values. Each weed species was treated under four conditions: 1) greenhouse grown, 2) outside grown, 3) greenhouse grown with a herbicide plus a crop oil concentrate, 4) outside grown with a herbicide plus a crop oil concentrate. The percent moisture, fresh and dry weight of each weed species in each condition was subjected to the ANOV and means were separated using the Duncan's multiple range test.

RESULTS AND DISCUSSION

Common lambsquarter:

Greenhouse: Both acifluorfen and bentazon significantly reduced all the measured parameters of common lambsquarters grown in the greenhouse (Table 1). Averaged over main effects of rates indicated that increasing rates of acifluorfen or bentazon generally increased the effect of the herbicide by significantly decreasing percent moisture (Table 2). The dry and fresh weights were significantly decreased by the herbicides, although the decrease was not always significant with increasing rates. The main effects also indicated that acifluorfen was more effective at the lower rates (0.28 and 0.43 kg/ha) in reducing common lambsquarters fresh weight than was bentazon. This difference was not apparent in a comparison of dry weights.

When the averages of the measured parameters were observed over herbicide rates (Table 3), there was a significant decrease in the

Table 1. The analysis of variance of common lambsquarters grown in the greenhouse on the measured parameters of percent moisture, fresh weight and dry weight.

		Significance (* = .05, ** = .01)		
Source	Degrees of freedom	% Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	**	**	**

Table 2. The effects of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of common lambsquarters grown in the greenhouse averaged over the main effects of herbicide.[a]

Rate	Moisture	Fresh weight	Dry weight
(kg/ha)	(%)	(mg)	(mg)
Acifluorfen			
0.00	85 a	488 a	71 a
0.28	49 b	96 b	25 b
0.43	44 c	90 b	24 b
0.56	40 d	60 b	22 b
Bentazon			
0.00	81 a	388 a	60 a
0.56	50 b	162 b	33 b
0.84	45 c	115 bc	27 bc
1.12	42 d	68 c	23 c

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 3. The effect of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of common lambsquarters grown in the greenhouse averaged over herbicide rates.[a]

Herbicide rate				
Acifluorfen	Bentazon	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	84.8 a	807 a	120 a
0.00	0.56	87.2 a	560 b	77 b
0.00	0.84	86.4 a	384 c	52 c
0.00	1.12	82.2 ab	200 d	35 c-f
0.28	0.00	86.4 a	291 cd	40 cd
0.43	0.00	77.5 bc	283 cd	44 c
0.56	0.00	76.7 bc	173 d	37 cde
0.28	0.56	43.7 d	35 e	20 def
0.28	0.84	35.3 e	30 e	29 def
0.28	1.12	30.4 ef	27 e	20 def
0.43	0.56	41.1 d	31 e	18 ef
0.43	0.84	29.2 f	23 e	17 ef
0.43	1.12	27.2 f	24 e	18 ef
0.56	0.56	27.4 f	20 e	15 f
0.56	0.84	27.6 f	25 e	19 ef
0.56	1.12	28.9 f	22 e	17 ef

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

perce

acifl

Chang

confi

effec

for b

weigh

T

theref

4). E

moistu

signif

combin

herbic

consid

tions

combin

fresh

synerg

enough

Althou

tion,

appear

cantly

singly

respon

S

affecte

percent moisture indicating greater phytotoxicity for combinations of acifluorfen and bentazon compared to either herbicide used singly. Changes in fresh weight and to a lesser extent dry weight values confirmed these observations. Acifluorfen and bentazon, although effective singly, were more effective when combined. This was evident for both percent moisture and fresh weight measurements but not dry weights although the same trends were apparent.

The ANOV interaction of acifluorfen x bentazon was significant, therefore, Colby's analysis was used to estimate expected values (Table 4). Every combination of acifluorfen and bentazon resulted in percent moisture values that were significantly less than predicted. This significant decrease in percent moisture indicated more injury from the combined herbicides than was predicted from values measured from either herbicide applied singly (Figure 1). The decrease in percent moisture is considered a significant synergistic response to the herbicide combinations or a significant increase in plant injury when the herbicide combinations were used compared to each herbicide applied singly. When fresh weights were subjected to the Colby's analysis the response was synergistic but the difference between observed and predicted was not enough to be considered significant in all cases (Table 5, Figure 2). Although the ANOV of dry weight values indicated a significant interaction, a Colby's analysis was not performed because the dry weight values appeared to be confounded. The combination rates were not all significantly greater than the single values for acifluorfen or bentazon applied singly. The multiplicative model is considered appropriate with the response being synergistic.

<u>Outside</u>: Common lambsquarters grown outside was significantly affected by acifluorfen and bentazon (Table 6) by a reduction of percent

Table 4. Colby's analysis using percent moisture of common lambsquarters grown in the greenhouse.

Acifluorfen	Bentazon	Actual Moisture	Observed (% of control)	Predicted Colby's value	Difference (observed - predicted)	Synergism/ antagonism	LSD
(kg/ha)	(kg/ha)	(%)	(%)				
0.00	0.00	84.78	100.0				
0.00	0.56	87.22	102.9				
0.00	0.84	86.44	102.0				
0.00	1.12	82.22	97.0				
0.28	0.00	86.44	102.0				
0.28	0.56	43.78	51.6	104.9	-53.3*	syn	6.6
0.28	0.84	35.33	41.7	104.0	-62.3*	syn	6.4
0.28	1.12	30.44	35.9	98.9	-63.0*	syn	6.2
0.43	0.00	77.56	91.5				
0.43	0.56	41.11	48.5	94.1	-45.6*	syn	6.5
0.43	0.84	29.22	34.5	93.3	-58.8*	syn	6.2
0.43	1.12	27.22	32.1	88.7	-56.6*	syn	6.2
0.56	0.00	76.78	90.6				
0.56	0.56	27.44	32.4	93.2	-60.8*	syn	6.2
0.56	0.84	27.56	32.5	92.3	-59.8*	syn	6.2
0.56	1.12	27.89	32.9	87.8	-54.9*	syn	6.2

*Significance at the .05 level.

The value of 't' = 1.9901
The value of 'n' = 9
The mean square error = 28.131

Figure 1. Percent moisture of common lambsquarters grown in the greenhouse 10 days following treatment with acifluorfen and bentazon (solid lines) and in all possible combinations (dashed lines) versus the observed percent of control.

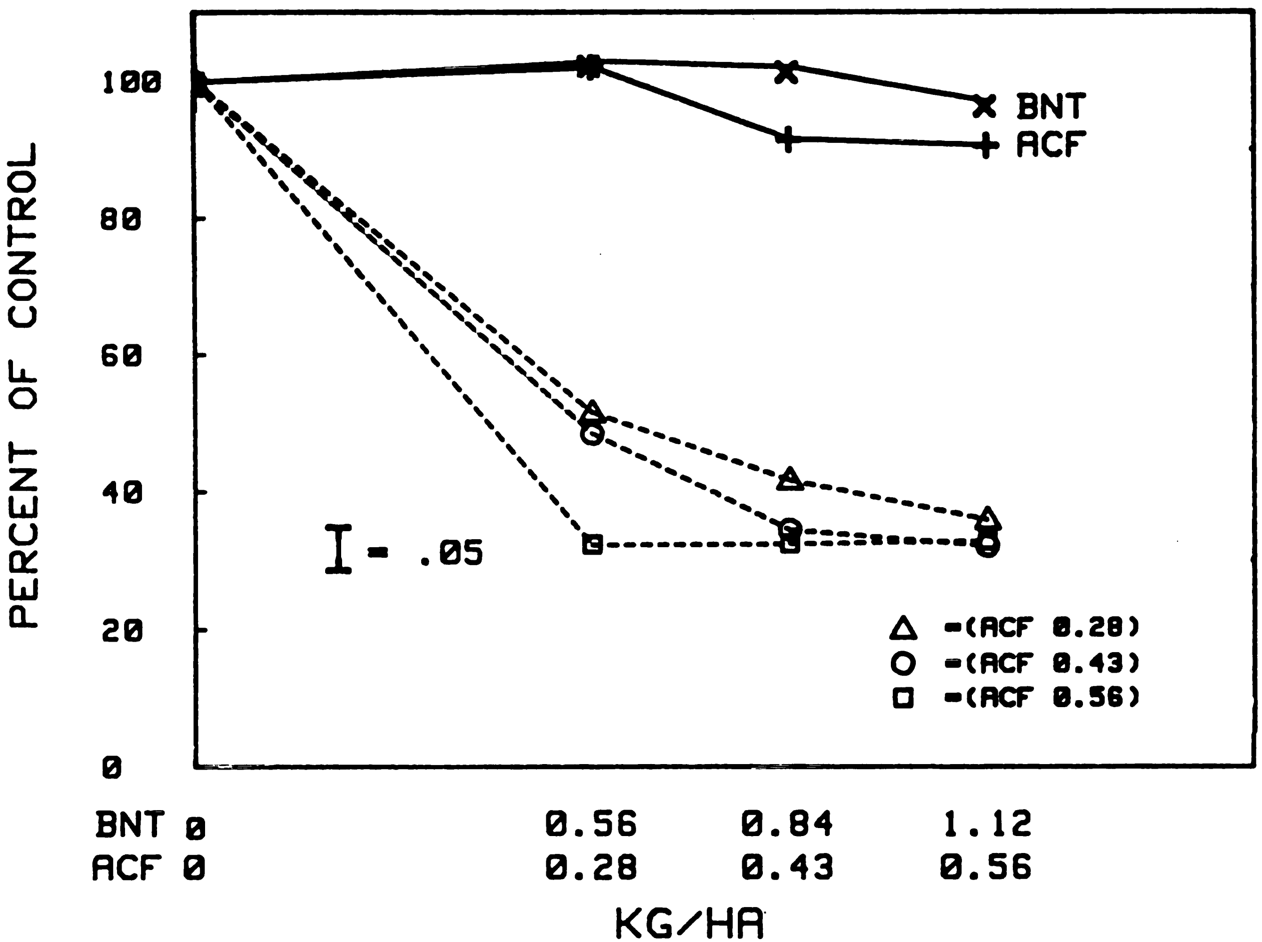

100
80
60
40
20
0
PERCENT OF CONTROL
BNT
ACF
I = .05
△ =(ACF 0.28)
○ =(ACF 0.43)
□ =(ACF 0.56)
BNT 0 0.56 0.84 1.12
ACF 0 0.28 0.43 0.56
KG/HA

Figure 1

Table 5. Colby's analysis using fresh weight of common lambsquarters grown in the greenhouse.

Acifluorfen	Bentazon	Actual fr. wt.	Observed (% of control)	Predicted Colby's value	Difference (observed - predicted)	Synergism/ antagonism	LSD
(kg/ha)	(kg/ha)	(mg)	(%)				
0.00	0.00	807	100.0				
0.00	0.56	560	69.4				
0.00	0.84	384	47.5				
0.00	1.12	200	24.8				
0.28	0.00	291	36.0				
0.28	0.56	35	4.3	25.0	-20.7*	syn	16.0
0.28	0.84	30	3.7	17.1	-13.5	syn	16.0
0.28	1.12	27	3.3	8.9	- 5.6	syn	16.0
0.43	0.00	283	35.1				
0.43	0.56	31	3.8	24.3	-20.5*	syn	16.0
0.43	0.84	23	2.8	16.7	-13.9	syn	16.0
0.43	1.12	24	3.0	8.7	- 5.7	syn	16.0
0.56	0.00	173	21.5				
0.56	0.56	20	2.5	14.9	-12.4	syn	16.0
0.56	0.84	25	3.1	10.2	- 7.1	syn	16.0
0.56	1.12	22	2.7	5.3	- 2.7	syn	16.0

*Significance at the .05 level.

The value of 't' = 1.9901
The value of 'n' = 9
The mean square error = 0.01865

Figure 2. Fresh weight of common lambsquarters grown in the greenhouse 10 days following treatment with acifluorfen and bentazon (solid lines) and in all possible combinations (dashed lines) versus the observed percent of control.

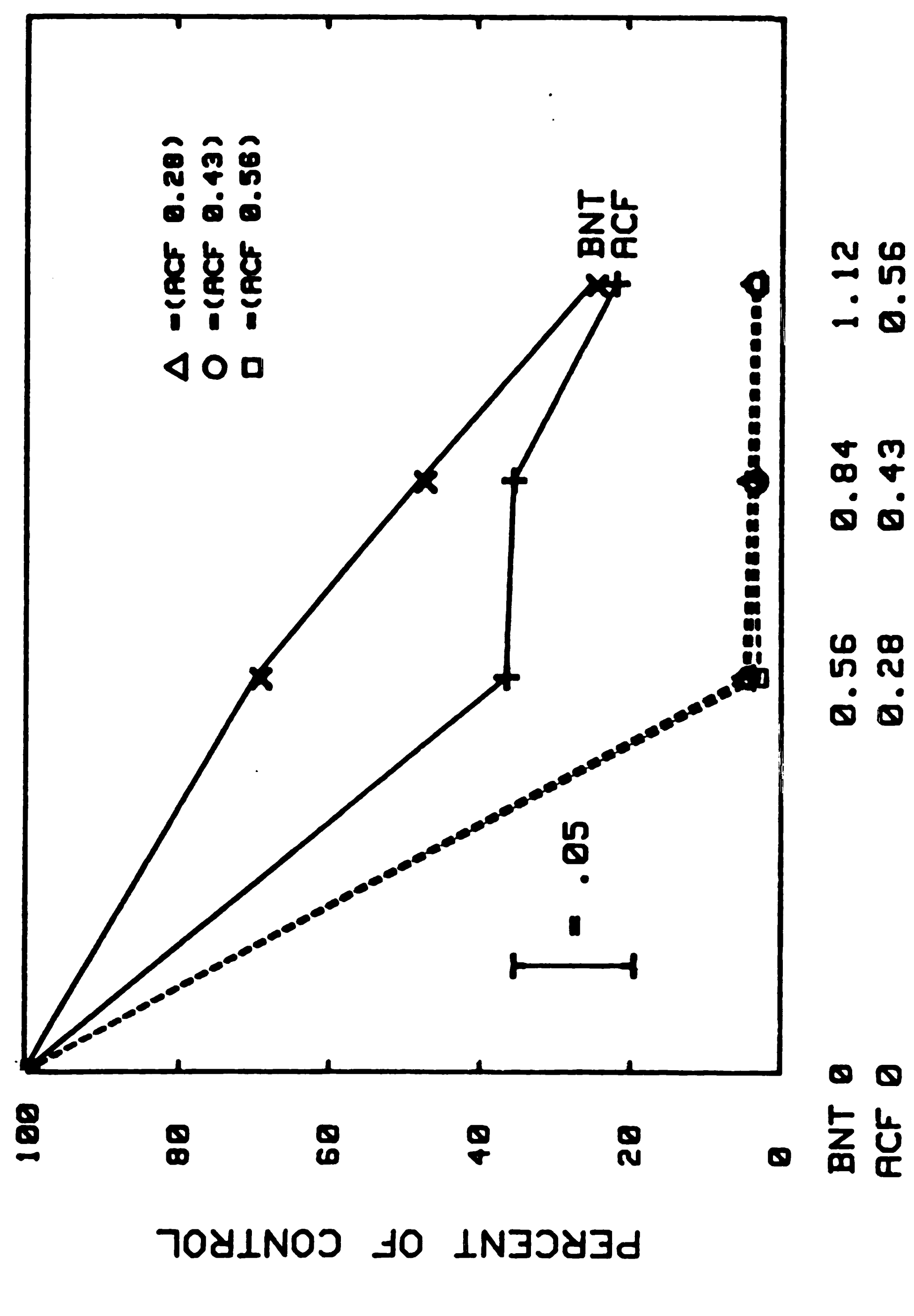

PERCENT OF CONTROL
100
80
60
40
20
0
BNT 0
ACF 0
0.56
0.28
0.84
0.43
1.12
0.56
KG/HA
Δ =(ACF 0.28)
O =(ACF 0.43)
□ =(ACF 0.56)
BNT
ACF
= .05

Figure 2

Table 6. The analysis of variance of common lambsquarters grown outside on the measured parameters of percent moisture, fresh weight and dry weight.

Source	Degrees of freedom	Significance (* = .05, ** = .01) % Moisture	Fresh weight	Dry weight
Replication	2	-	*	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	**	**	**

Table 7. The effects of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of common lambsquarters grown outside averaged over the main effects of herbicide.[a]

Rate	Moisture	Fresh weight	Dry weight
(kg/ha)	(%)	(mg)	(mg)
Acifluorfen			
0.00	75.3 a	715 a	154 a
0.28	64.1 b	509 b	136 b
0.43	60.0 c	409 c	113 c
0.56	56.5 c	371 c	113 c
Bentazon			
0.00	79.1 a	984 a	207 a
0.56	69.1 b	460 b	115 b
0.84	58.9 c	319 c	97 c
1.12	48.8 d	240 d	96 c

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

moisture, fresh and dry weight values. When averaged over the main effect of herbicide rates (Table 7), all measured parameters generally decreased as herbicide rate increased. Bentazon rates significantly decreased each measured parameter with each rate increase except dry weight. This was probably due to the limited 10 day interval following herbicide application not being long enough to allow for significant regrowth. Acifluorfen averaged over rates did not significantly increase injury to common lambsquarters as measured by any parameter over the 0.43 kg/ha rate.

The effect of acifluorfen and bentazon averaged over herbicide rates (Table 8) indicated little difference in percent moisture between acifluorfen and bentazon applied singly. There was a significant difference, however, when fresh weights and dry weights were compared as both were significantly lower with the bentazon than with acifluorfen treatments. This reflects the observation that percent moisture is a more critical indicator of herbicide damage than are fresh and dry weights although these parameters may reflect herbicide stunting or foliar injury. These data also indicate why visual ratings are often misleading as visual ratings are based on herbicide stunting and foliar injury.

When the averages of the measured parameters were observed over individual herbicide rates (Table 8), there was a significant decrease in the percent moisture and fresh weight values indicating greater phototoxicity for combinations of acifluorfen and bentazon compared to either herbicide used singly. Dry weights were also significantly reduced by all combinations of acifluorfen and bentazon compared to each applied singly except when the highest rate of bentazon was present singly or in the combination.

Table 8

Herl
Acifluo
(kg/ha
0.00
0.00
0.00
0.00
0.28
0.43
0.56
0.28
0.28
0.28
0.43
0.43
0.43
0.56
0.56
0.56

[a]Means
differ

Table 8. The effect of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of common lambsquarters grown outside averaged over herbicide rates.[a]

Herbicide rate				
Acifluorfen	Bentazon	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	81.3 a	1063 ab	201 b
0.00	0.56	78.3 a	738 c	160 cd
0.00	0.84	73.8 ab	611 d	135 de
0.00	1.12	67.7 bc	448 e	118 ef
0.28	0.00	77.9 a	1134 a	255 a
0.43	0.00	79.0 a	955 b	202 b
0.56	0.00	78.3 a	784 c	172 bc
0.28	0.56	68.7 bc	420 ef	109 ef
0.28	0.84	61.3 c	285 fgh	91 fg
0.28	1.12	48.5 d	194 h	90 fg
0.43	0.56	67.0 bc	336 efg	92 fg
0.43	0.84	50.8 d	176 h	74 g
0.43	1.12	43.3 d	168 h	84 fg
0.56	0.56	62.3 c	344 ef	98 fg
0.56	0.84	49.8 d	205 gh	89 fg
0.56	1.12	35.8 d	151 h	93 fg

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

fo

an

in

si

co

The

he

rat

10,

the

com

aci

11)

con

val

inte

for

acif

Rain

rate

acros

where

mist

were

n sig

The ANOV interaction of acifluorfen and bentazon was significant for percent moisture, fresh and dry weight values, therefore a Colby's analysis for common lambsquarters was calculated. The Colby's analysis indicated that all the combinations of acifluorfen and bentazon were significantly synergistic except the lowest rate of bentazon when combined with the 0.28 and 0.43 kg/ha acifluorfen (Table 9, Figure 3). The Colby's analysis of fresh weights indicated the response to the herbicide combinations was significantly synergistic over all combined rates of acifluorfen and bentazon compared to each applied singly (Table 10, Figure 4). A Colby's analysis of dry weight values indicated that all the combinations of acifluorfen and bentazon were synergistic when compared to each herbicide applied singly and across all rates of acifluorfen and bentazon except at the highest rate of bentazon (Table 11). The correct model is multiplicative.

Greenhouse (oil): Both acifluorfen and bentazon plus a crop oil concentrate significantly reduced percent moisture, fresh and dry weight values of common lambsquarters grown in the greenhouse (Table 12). The interaction term was significant for fresh and dry weight values but not for percent moisture. Bentazon appears to be more effective than acifluorfen at reducing all the measured parameters when averaged over main effects (Table 13). This is confirmed when individual herbicide rates are compared (Table 14). The lowest rate of bentazon (0.56 kg/ha) across all rates of acifluorfen was the only consistent rate of bentazon where the combination of herbicides significantly reduced percent moisture values below the single rate of bentazon. When fresh weights were considered, once the rate of 0.84 kg/ha of bentazon was in the mix, no significant effect was measured due to the addition of any rate of acifluorfen. Since the acifluorfen and bentazon interaction concerning

Table 9. Colby's analysis using percent moisture of common lambsquarters grown outside.

Acifluorfen	Bentazon	Actual Moisture	Observed (% of control)	Predicted Colby's value	Difference (observed - predicted)	Synergism/ antagonism	LSD
(kg/ha)	(kg/ha)	(%)	(%)				
0.00	0.00	81.25	100.0				
0.00	0.56	78.33	96.4				
0.00	0.84	73.75	90.8				
0.00	1.12	67.67	83.3				
0.28	0.00	77.92	95.9				
0.28	0.56	68.67	84.5	92.5	-7.9	syn	11.9
0.28	0.84	61.25	75.4	87.0	-11.7*	syn	11.4
0.28	1.12	48.50	59.7	79.9	-20.2*	syn	10.6
0.43	0.00	79.00	97.2				
0.43	0.56	67.00	82.5	93.7	-11.3	syn	11.8
0.43	0.84	50.75	62.5	88.3	-25.8*	syn	10.7
0.43	1.12	43.25	53.2	81.0	-27.7*	syn	10.3
0.56	0.00	78.25	96.3				
0.56	0.56	62.33	76.7	92.8	-16.1*	syn	11.5
0.56	0.84	49.83	61.3	87.4	-26.1*	syn	10.7
0.56	1.12	35.75	44.0	80.2	-36.2*	syn	9.9

*Significance at the .05 level.

The value of 't' = 1.984
The value of 'n' = 12
The mean square error = 83.01

Figure 3. Percent moisture of common lambsquarters grown outside 10 days following treatment with acifluorfen and bentazon (solid lines) and in all possible combinations (dashed lines) versus the observed percent of control.

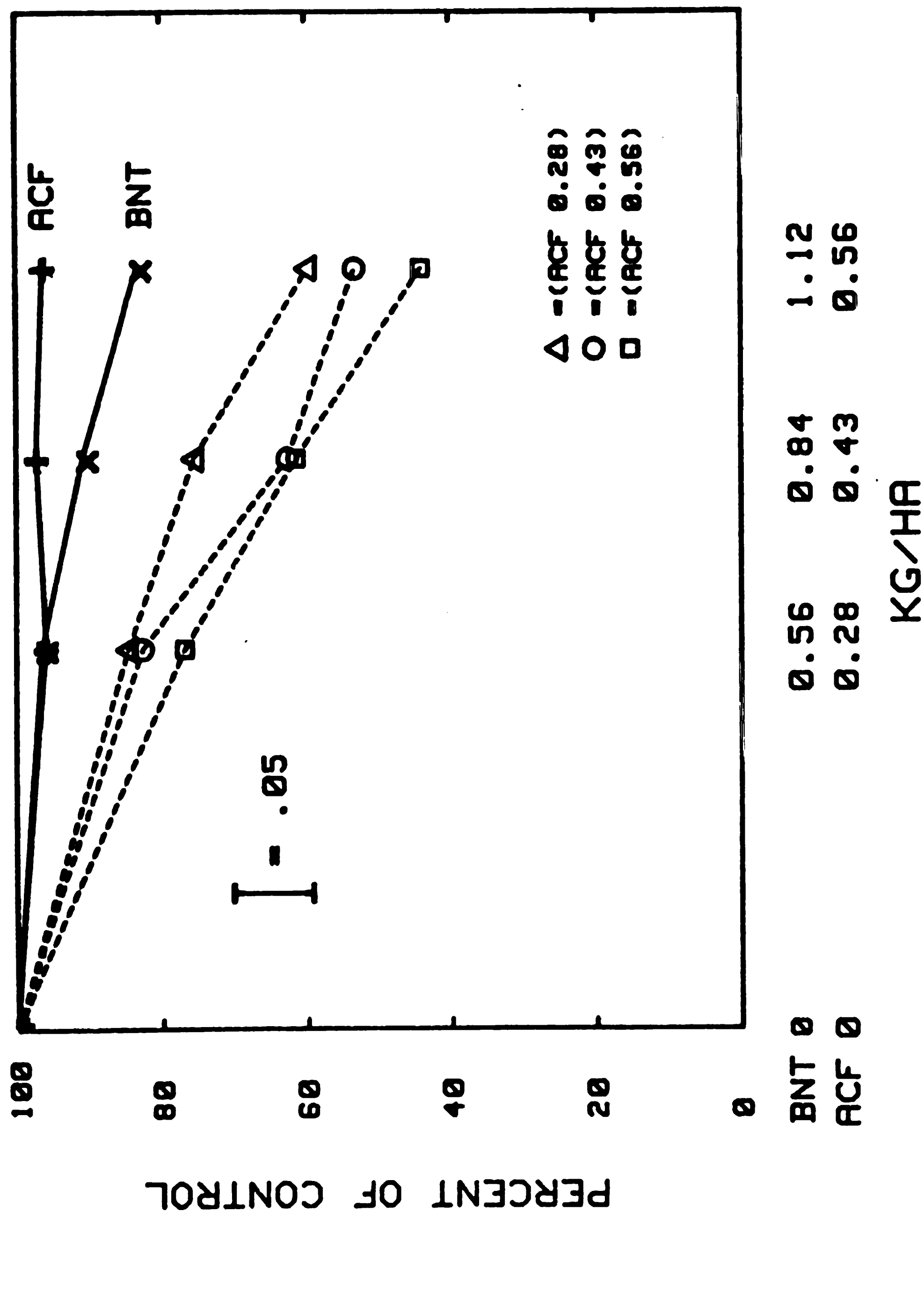

ACF
BNT
= .05
Δ =(ACF 0.28)
O =(ACF 0.43)
□ =(ACF 0.56)
100
80
60
40
20
0
PERCENT OF CONTROL
BNT 0
ACF 0
0.56
0.28
0.84
0.43
1.12
0.56
KG/HA

Figure 3

Table 10. Colby's anal

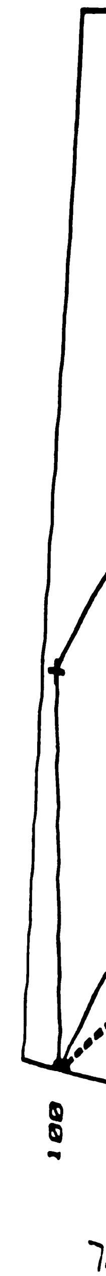
Table 10. Colby's analysis using fresh weight of common lambsquarters grown outside.

Acifluorfen	Bentazon	Actual fr. wt.	Observed (% of control)	Predicted Colby's value	Difference (observed - predicted)	Synergism/ antagonism	LSD
(kg/ha)	(kg/ha)	(mg)	(%)				
0.00	0.00	1063	100.0				
0.00	0.56	738	69.4				
0.00	0.84	611	57.5				
0.00	1.12	448	42.2				
0.28	0.00	1134	106.7				
0.28	0.56	420	39.5	74.1	-34.6*	syn	12.7
0.28	0.84	285	26.8	61.3	-34.5*	syn	12.3
0.28	1.12	194	18.3	45.0	-26.7*	syn	12.0
0.43	0.00	955	89.8				
0.43	0.56	336	31.6	62.4	-30.8*	syn	12.4
0.43	0.84	176	16.5	51.6	-35.1*	syn	12.0
0.43	1.12	168	15.8	37.9	-22.0*	syn	12.0
0.56	0.00	784	73.8				
0.56	0.56	344	32.4	51.2	-18.9*	syn	12.5
0.56	0.84	205	19.2	42.4	-23.2*	syn	12.1
0.56	1.12	151	14.2	31.1	-16.9*	syn	12.0

*Significance at the .05 level.

The value of 't' = 1.984
The value of 'n' = 12
The mean square error = 0.024

Figure 4. Fresh weight of common lambsquarters grown outside 10 days following treatment with acifluorfen and bentazon (solid lines) and in all possible combinations (dashed lines) versus the observed percent of control.



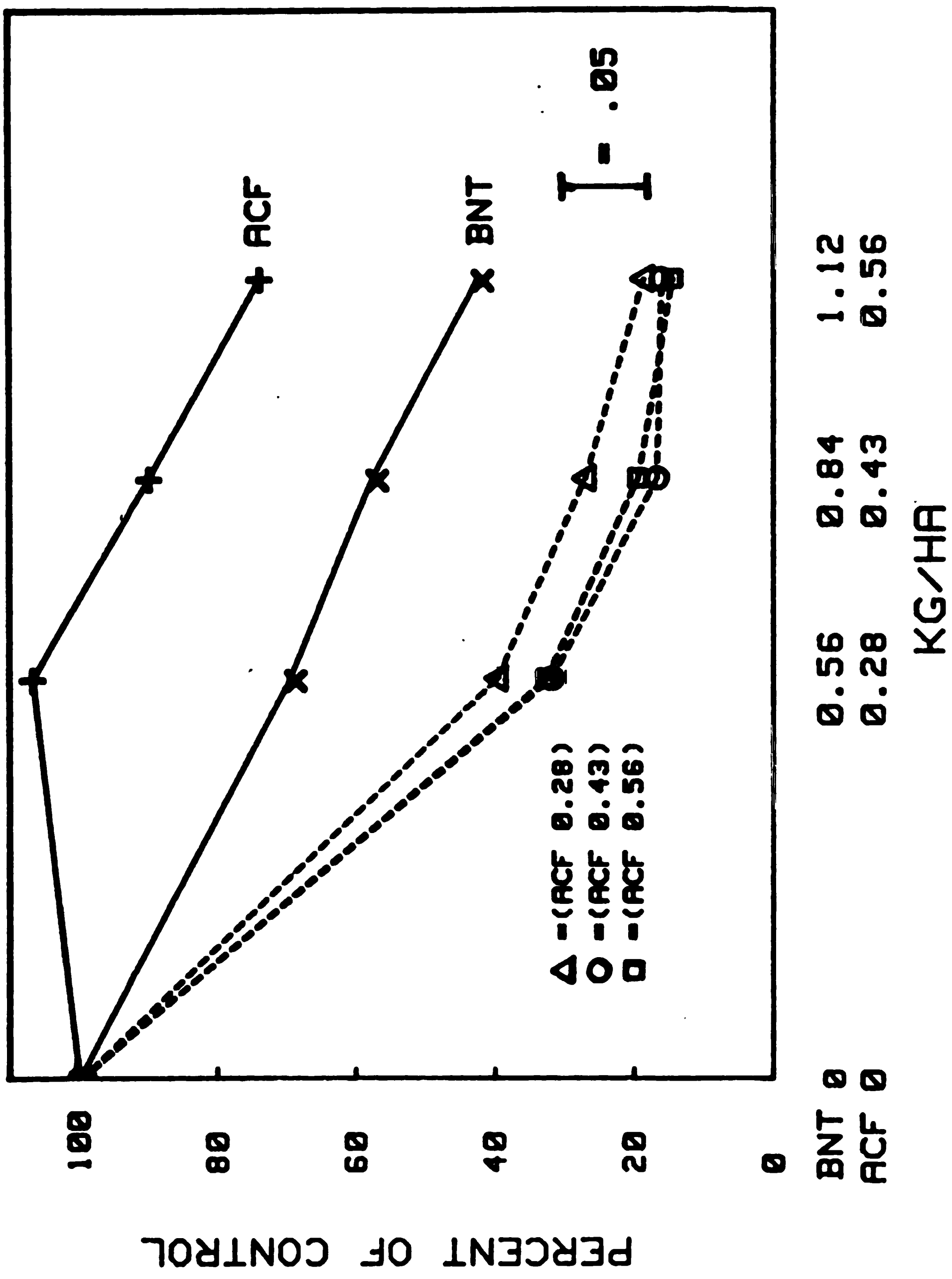

PERCENT OF CONTROL
100
80
60
40
20
0
BNT 0
ACF 0
0.56
0.28
0.84
0.43
1.12
0.56
KG/HA
ACF
BNT
= .05
Δ =(ACF 0.28)
O =(ACF 0.43)
□ =(ACF 0.56)

Figure 4

Table 11. Calib

Table 11. Colby's analysis using dry weight of common lambsquarters grown outside.

Acifluorfen	Bentazon	Actual dr. wt.	Observed (% of control)	Predicted Colby's value	Difference (observed - predicted)	Synergism/ antagonism	LSD
(kg/ha)	(kg/ha)	(mg)	(%)				
0.00	0.00	201	100.0				
0.00	0.56	160	79.7				
0.00	0.84	135	66.9				
0.00	1.12	118	58.9				
0.28	0.00	255	126.6				
0.28	0.56	109	54.3	100.9	-46.6*	syn	16.6
0.28	0.84	91	45.3	84.7	-39.4*	syn	16.0
0.28	1.12	90	44.8	74.5	-29.7*	syn	16.0
0.43	0.00	202	100.4				
0.43	0.56	92	45.4	80.0	-34.4*	syn	16.1
0.43	0.84	74	36.5	67.1	-30.6*	syn	15.6
0.43	1.12	84	41.7	59.1	-17.4*	syn	15.8
0.56	0.00	172	85.6				
0.56	0.56	98	48.7	68.2	-19.5*	syn	16.3
0.56	0.84	89	44.1	57.2	-13.1	syn	16.0
0.56	1.12	93	46.2	50.4	- 4.1	syn	16.1

*Significance at the .05 level.

The value of 't' = 1.984
The value of 'n' = 12
The mean square error = .001

Table 12. The analysis of variance of common lambsquarters grown in the greenhouse on the measured parameters of percent moisture, fresh weight and dry weight as affected by a crop oil concentrated added to acifluorfen and bentazon.

		Significance (* = .05, ** = .01)		
Source	Degrees of freedom	% Moisture	Fresh weight	Dry weight
Replication	2	*	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	-	**	**

Table 13. The effects of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of common lambsquarters grown in the greenhouse averaged over the main effects of herbicide.[a]

Rate	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(L/ha)	(%)	(mg)	(mg)
Acifluorfen				
0.00	2.3	58.7 a	927 a	231 a
0.28	2.3	50.5 b	382 b	124 b
0.43	2.3	47.2 bc	387 b	136 b
0.56	2.3	45.9 c	321 b	124 b
Bentazon				
0.00	2.3	71.5 a	1385 a	308 a
0.56	2.3	53.6 b	253 b	102 b
0.84	2.3	40.9 c	193 b	99 b
1.12	2.3	36.3 d	188 b	106 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 14. The effect of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of common lambsquarters grown in the greenhouse averaged over herbicide rates.[a]

Herbicide rate					
Acifluorfen	Bentazon	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(L/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	0.0	79.4 a	2794 a	576 a
0.00	0.00	2.3	79.6 a	2879 a	581 a
0.00	0.56	2.3	65.9 b	368 d	118 d
0.00	0.84	2.3	43.6 cde	206 de	99 d
0.00	1.12	2.3	45.7 cde	253 de	127 d
0.28	0.00	2.3	71.8 ab	963 b	218 bc
0.43	0.00	2.3	69.0 b	982 b	244 b
0.56	0.00	2.3	65.6 b	714 c	189 c
0.28	0.56	2.3	49.8 cd	205 de	88 d
0.28	0.84	2.3	41.3 de	172 e	88 d
0.28	1.12	2.3	39.1 ef	188 de	100 d
0.43	0.56	2.3	50.8 c	225 de	102 d
0.43	0.84	2.3	39.4 ef	188 de	98 d
0.43	1.12	2.3	29.6 g	152 e	100 d
0.56	0.56	2.3	47.7 cde	213 de	97 d
0.56	0.84	2.3	39.4 ef	205 de	113 d
0.56	1.12	2.3	39.9 fg	154 e	98 d

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

percer
perfor
weight
measur
the co
fresh
C
signif
common
signif
B
all th
herbic
herbic
than w
bentaz
rate c
signif
when p
indica
to the
A
aciflu
signif
confou
differ
consis

percent moisture was not significant, the Colby's analysis was not performed. The significant interaction observed in the fresh and dry weight measurements, however, appeared to be confounded. Acifluorfen measurements were consistently high; bentazon measurements were close to the combination rates, therefore, a Colby's analysis was not performed on fresh or dry weights. The response model appears to be additive.

Outside (oil): Both acifluorfen and bentazon plus a crop oil significantly reduced percent moisture, fresh and dry weight values of common lambsquarters grown outside (Table 15). The interaction term was significant for fresh and dry weight values but not for percent moisture.

Bentazon appears to be more effective than acifluorfen at reducing all the measured parameters when averaged over the main effects of herbicide (Table 16). This is confirmed when averaged over individual herbicide rates (Table 17). Percent moistures were lower with bentazon than with acifluorfen but not always significantly. The lowest rate of bentazon (0.56 kg/ha) across all rates of acifluorfen and the highest rate of acifluorfen (0.56 kg/ha) combined with any rate of bentazon was significantly better in combination than either herbicide applied singly when percent moistures were compared. A comparison of fresh weights indicates that the response of the combinations is generally proportional to the amount of bentazon in the mix.

A Colby's analysis was not calculated, since the interaction of acifluorfen and bentazon on percent moisture was not significant. The significant interaction measured with fresh and dry weights appears to be confounded as the values of bentazon applied singly are not significantly different from the combination values and acifluorfen measurements were consistently high. The response model appears to be additive.

A
E

T

(k

Ac

0.
0.
0.
0.

Ben

0.
0.
0.
1.1

aMea
dif

Table 15. The analysis of variance of common lambsquarters grown outside with a crop oil concentrate added on the measured parameters of percent moisture, fresh weight and dry weight.[a]

Source	Degrees of freedom	Significance (* = .05, ** = .01) % Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	-	**	**

Table 16. The effects of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of common lambsquarters grown outside averaged over the main effects of herbicide.[a]

Rate	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(L/ha)	(%)	(mg)	(mg)
Acifluorfen				
0.00	2.3	61.2 a	646 a	158 a
0.28	2.3	52.3 b	399 b	113 b
0.43	2.3	50.3 b	355 bc	110 b
0.56	2.3	49.3 b	328 c	108 b
Bentazon				
0.00	2.3	71.9 a	939 a	207 a
0.56	2.3	53.7 b	339 b	99 b
0.84	2.3	44.9 c	242 c	93 b
1.12	2.3	42.6 c	208 c	89 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 17. The effect of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of common lambsquarters grown outside averaged over herbicide rates.[a]

Herbicide rate		Crop oil	Moisture	Fresh weight	Dry weight
Acifluorfen	Bentazon				
(kg/ha)	(kg/ha)	(L/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	0.0	80.0 a	1620 a	324 a
0.00	0.00	2.3	79.8 a	1610 a	346
0.00	0.56	2.3	63.2 c	412 de	102 cd
0.00	0.84	2.3	49.4 d	275 efg	88 d
0.00	1.12	2.3	52.5 d	287 efg	94 d
0.28	0.00	2.3	72.5 b	899 b	190 b
0.43	0.00	2.3	67.1 bc	734 c	165 b
0.56	0.00	2.3	68.1 bc	512 d	128 c
0.28	0.56	2.3	50.3 d	261 efg	84 d
0.28	0.84	2.3	47.8 de	258 efg	95 d
0.28	1.12	2.3	38.6 f	180 g	83 d
0.43	0.56	2.3	51.1 d	310 efg	1000 cd
0.43	0.84	2.3	44.5 def	212 g	93 d
0.43	1.12	2.3	38.3 f	163 g	83 d
0.56	0.56	2.3	50.3 d	372 def	109 cd
0.56	0.84	2.3	37.8 f	222 fg	97 d
0.56	1.12	2.3	41.1 ef	205 g	98 d

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Jimsonweed:

Greenhouse: Jimsonweed grown in the greenhouse had a significant response to the main effects of acifluorfen and bentazon and the interaction term across all the measured parameters (Table 18).

Increasing rates of acifluorfen and bentazon averaged, over the main effects of herbicide, rate significantly decreased percent moisture but did not significantly influence fresh or dry weight values. Jimsonweed appears to be more sensitive to bentazon (Table 19).

The effect of acifluorfen and bentazon applied singly and averaged over individual rates indicated that both herbicides significantly reduced percent moisture and fresh weight when compared to the control (Table 20). Bentazon, however, was significantly more effective in reducing percent moisture and fresh weight values. Any rate of acifluorfen added to any rate of bentazon, significantly increased percent moisture. Fresh weight values were never significantly different from the single rate of bentazon present in the combination. Percent moisture and fresh weight values were always significantly less than the rate of acifluorfen in the mix used singly. Thus, it appears that acifluorfen antagonizes bentazon.

Since the interaction of acifluorfen and bentazon on percent moisture was significant, a Colby's analysis was performed. Colby's values indicated that acifluorfen antagonized bentazon at every combination level (Table 21). This antagonism was considered significant at every level (Figure 5). A Colby's analysis was not performed on fresh and dry weight values as they were considered confounded as no combination values were significantly different from the single rate of bentazon present in the mix. The correct model is assumed to be multiplicative.

Table 18. The analysis of variance of jimsonweed grown in the greenhouse on the measured parameters of percent moisture, fresh weight and dry weight.

		Significance (* = .05, ** = .01)		
Source	Degrees of freedom	% Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	*
Bentazon	3	**	**	*
Acifluorfen x Bentazon	9	**	**	**

Table 19. The effects of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of jimsonweed grown in the greenhouse averaged over the main effects of herbicide.[a]

Rate	Moisture	Fresh weight	Dry weight
(kg/ha)	(%)	(mg)	(mg)
Acifluorfen			
0.00	39.4 c	329 a	89 a
0.28	54.6 a	151 b	42 b
0.43	50.0 b	128 bc	42 b
0.56	42.5 c	108 c	43 b
Bentazon			
0.00	78.8 a	504 a	91 a
0.56	42.9 b	80 b	42 b
0.84	30.1 d	63 b	41 b
1.12	34.7 c	68 b	42 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 20. The effect of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of jimsonweed grown in the greenhouse averaged over herbicide rates.[a]

Herbicide rate				
Acifluorfen	Bentazon	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	89.8 a	1148 a	221 a
0.00	0.56	29.2 h	70 e	50 b
0.00	0.84	16.7 i	46 e	40 b
0.00	1.12	22.0 i	52 e	44 b
0.28	0.00	81.9 b	362 b	51 b
0.43	0.00	80.3 b	290 c	47 b
0.56	0.00	63.2 c	215 d	45 b
0.28	0.56	56.6 d	102 e	42 b
0.28	0.84	41.2 ef	74 e	39 b
0.28	1.12	38.9 fg	66 e	38 b
0.43	0.56	46.6 e	68 e	36 b
0.43	0.84	29.1 h	61 e	42 b
0.43	1.12	44.0 ef	85 e	45 b
0.56	0.56	39.3 fg	80 e	40 b
0.56	0.84	33.3 gh	73 e	45 b
0.56	1.12	34.0 gh	67 e	42 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 21. Colby's analysis using percent moisture of jimsonweed grown in the greenhouse.

Acifluorfen	Bentazon	Actual Moisture	Observed (% of control)	Predicted Colby's value	Difference (observed - predicted)	Synergism/ antagonism	LSD
(kg/ha)	(kg/ha)	(%)	(%)				
0.00	0.00	89.78	100.0				
0.00	0.56	29.22	32.5				
0.00	0.84	16.67	18.6				
0.00	1.12	22.00	24.5				
0.28	0.00	81.89	91.2				
0.28	0.56	56.56	63.0	29.7	33.3	ant	8.2
0.28	0.84	41.22	45.9	16.9	29.0*	ant	7.6
0.28	1.12	38.89	43.3	22.4	21.0*	ant	7.5
0.43	0.00	80.33	89.5				
0.43	0.56	46.56	51.9	29.1	22.7*	ant	7.8
0.43	0.84	29.11	32.4	16.6	15.8*	ant	7.3
0.43	1.12	44.00	49.0	21.9	27.1*	ant	7.7
0.56	0.00	63.22	70.4				
0.56	0.56	39.33	43.8	22.9	20.9*	ant	7.6
0.56	0.84	33.33	37.1	13.1	24.1*	ant	7.4
0.56	1.12	34.00	37.9	17.3	20.6*	ant	7.4

*Significance at the .05 level.

The value of 't' = 1.9901
The value of 'n' = 9
The mean square error = 43.782

Figure 5. Percent moisture of jimsonweed grown in the greenhouse 10 days following treatment with acifluorfen and bentazon (solid lines) and in all possible combinations (dashed lines) versus the observed percent of control.

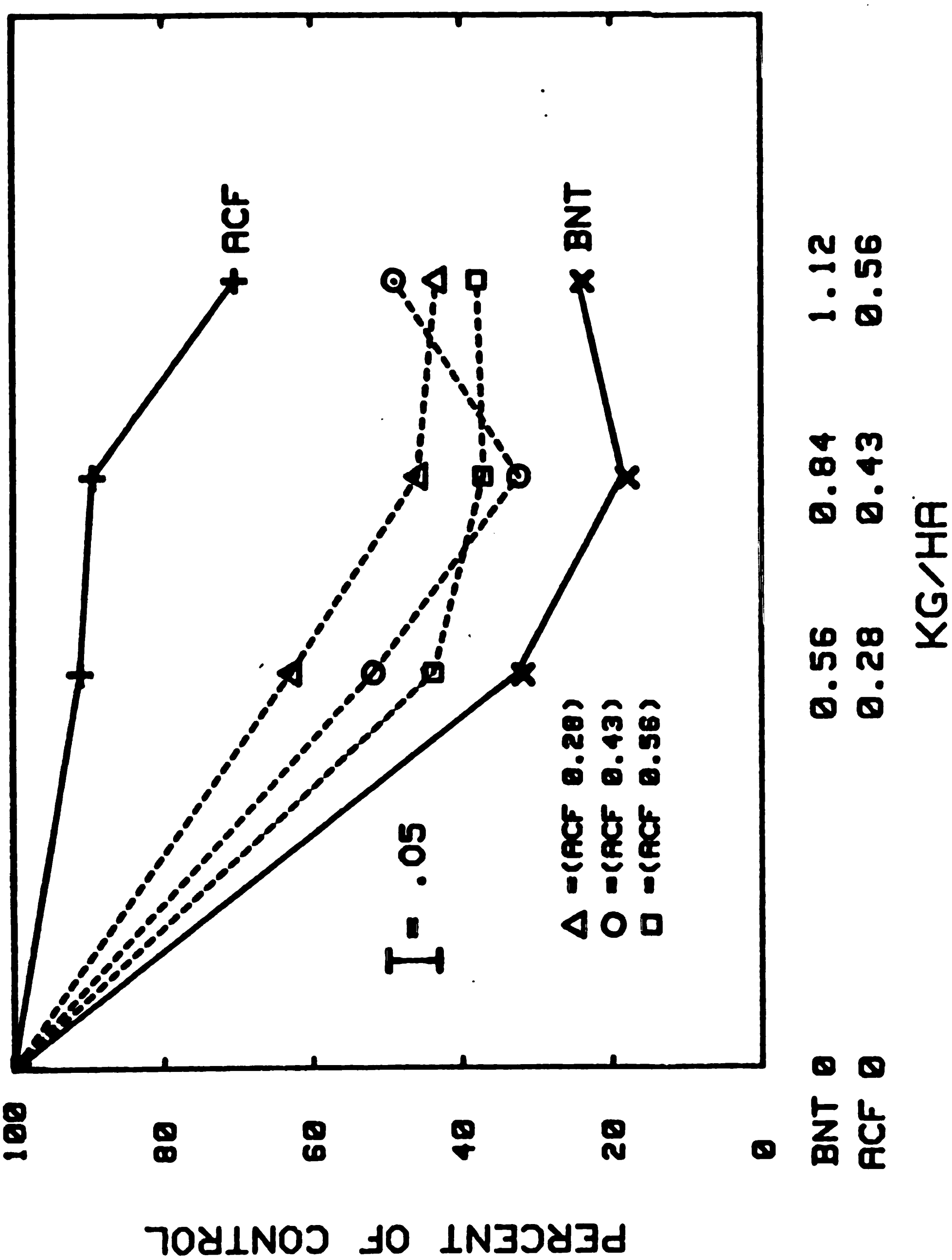

PERCENT OF CONTROL
100
80
60
40
20
0
BNT 0
ACF 0
0.56
0.28
0.84
0.43
1.12
0.56
KG/HA
ACF
BNT
= .05
△ =(ACF 0.28)
○ =(ACF 0.43)
□ =(ACF 0.56)

Figure 5

Jimsonweed grown outside was significantly reduced by both acifluorfen and bentazon over all measured parameters. No interaction was measured with percent moisture but fresh and dry weight interactions were significant (Table 22).

Outside: Jimsonweed grown outside was more sensitive to bentazon than to acifluorfen. Increasing rates of both herbicides had no significant effect on any measured parameter except acifluorfen significantly reduced fresh weight values at rates greater than 0.43 kg/ha (Table 23).

Percent moisture values for the combinations were lower than either herbicide applied singly except for the lowest combined rate of each. Fresh and dry weight values for the combinations were never significantly different from the single value of bentazon in the mix but always lower than the rate of acifluorfen present (Table 24).

Although the percent moisture values were significantly lower for the combination than each herbicide applied singly, the values were within the range of the additive ANOV model and no interaction was noted for percent moisture. The interaction measured by fresh and dry weight values was considered confounded because the combination rates were not different from any single rate of bentazon so Colby's analysis was not performed. The response for jimsonweed grown outside was considered additive.

Greenhouse (oil): Acifluorfen and bentazon plus a crop oil concentrate applied to jimsonweed grown in the greenhouse significantly reduced percent moisture, fresh and dry weight parameters. The interaction values were also significant (Table 25).

Table 22. The analysis of variance of jimsonweed grown outside on the measured parameters of percent moisture, fresh weight and dry weight.

		Significance (* = .05, ** = .01)		
Source	Degrees of freedom	% Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	-	**	**

Table 23. The effects of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of jimsonweed grown outside averaged over the main effects of herbicide.[a]

Rate	Moisture	Fresh weight	Dry weight
(kg/ha)	(%)	(mg)	(mg)
Acifluorfen			
0.00	52.1 a	535 a	129 a
0.28	31.9 b	267 b	110 b
0.43	26.5 b	213 c	107 b
0.56	25.6 b	201 c	108 b
Bentazon			
0.00	62.1 a	783 a	160 a
0.56	28.2 b	153 b	98 b
0.84	23.4 b	138 b	98 b
1.12	22.3 b	141 b	99 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 24. The effect of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of jimsonweed grown outside averaged over herbicide rates.[a]

Herbicide rate				
Acifluorfen	Bentazon	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	86.0 a	1585 a	219 a
0.00	0.56	44.3 cd	198 d	104 d
0.00	0.84	37.1 de	161 d	91 d
0.00	1.12	40.9 de	198 d	101 d
0.28	0.00	58.0 b	665 b	157 b
0.43	0.00	55.9 bc	472 c	132 c
0.56	0.00	48.7 bcd	413 c	132 c
0.28	0.56	29.0 ef	149 d	94 d
0.28	0.84	20.2 fg	122 d	93 d
0.28	1.12	20.2 fg	130 d	97 d
0.43	0.56	21.4 fg	140 d	97 d
0.43	0.84	18.3 fg	128 d	99 d
0.43	1.12	10.3 g	113 d	101 d
0.56	0.56	18.0 fg	126 d	97 d
0.56	0.84	18.1 fg	143 d	109 d
0.56	1.12	17.7 fg	124 d	95 d

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

(
a
r
r
i
re
mo
Pro
aci

and
the

When a crop oil concentrate was present, both acifluorfen and bentazon appeared equally effective in reducing percent moisture, fresh and dry weights over the main effects of herbicide rates (Table 26).

When averaged over individual treatment rates, however, acifluorfen decreased percent moisture and fresh and dry weight values significantly by increasing the rate from 0.28 to 0.43 kg/ha (Table 27). Increasing the rate of bentazon above 0.56 kg/ha did not significantly decrease any measured parameter. Dry weight values were never significantly lower than those obtained for the single values of bentazon regardless of the rate or combination used. When combinations were compared to the herbicides applied singly, there was not a consistent increase or decrease of percent moisture or fresh weight values over rates or combinations, but rather a random response. The highest combined rates of both herbicides, however, had consistently lower percent moisture and fresh weight values than either herbicide applied singly or in any combination. Since the interaction terms were significant, a Colby's analysis was performed on percent moisture values (Table 28). The results of the Colby's analysis also indicated a lack of consistent response across rate combinations. This lack of consistency cannot be interpreted as a synergistic response, but perhaps an independent response. It appears that the correct model is probably the additive model and the interactions of all the parameters in this case are probably confounded due to the significant effect that bentazon and acifluorfen both have on jimsonweed when a crop oil concentrate is added.

Outside (oil): Jimsonweed parameters of percent moisture, fresh and dry weight values when grown outside were significantly decreased by the main effects of acifluorfen and bentazon with a crop oil concentrate

Table 25. The analysis of variance of jimsonweed grown in the greenhouse on the measured parameters of percent moisture, fresh weight and dry weight as effected by a crop oil concentrate added to acifluorfen and bentazon.

		Significance (* = .05, ** = .01)		
Source	Degrees of freedom	% Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	**	**	**

Table 26. The effects of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of jimsonweed grown in the greenhouse averaged over the main effects of herbicide.[a]

Rate	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(L/ha)	(%)	(mg)	(mg)
Acifluorfen				
0.00	2.3	64.0 a	1101 a	222 a
0.28	2.3	50.1 b	597 b	188 b
0.43	2.3	48.5 b	487 c	173 b
0.56	2.3	41.7 c	423 c	176 b
Bentazon				
0.00	2.3	62.1 a	1364 a	281 a
0.56	2.3	53.4 b	454 b	165 b
0.84	2.3	45.4 c	422 b	160 b
1.12	2.3	43.8 c	367 b	153 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 27. The effect of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of jimsonweed grown in the greenhouse plus a crop oil concentrate averaged over herbicide rates.[a]

Herbicide rate					
Acifluorfen	Bentazon	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(L/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	0.0	84.9 a	2610 a	394 a
0.00	0.00	2.3	85.9 a	2702 a	384 a
0.00	0.56	2.3	56.3 bcd	492 def	158 d
0.00	0.84	2.3	58.2 bc	680 cd	182 d
0.00	1.12	2.3	56.9 bc	530 de	164 d
0.28	0.00	2.3	62.8 b	1105 b	276 b
0.43	0.00	2.3	50.6 cde	851 c	235 c
0.56	0.00	2.3	49.2 cde	798 c	228 c
0.28	0.56	2.3	57.1 bc	554 de	170 d
0.28	0.84	2.3	36.3 f	363 efg	157 d
0.28	1.12	2.3	44.2 def	367 efg	148 d
0.43	0.56	2.3	46.9 c-f	358 efg	156 d
0.43	0.84	2.3	46.4 c-f	360 efg	148 d
0.43	1.12	2.3	50.1 cde	380 efg	153 d
0.56	0.56	2.3	53.1 bcd	413 efg	176 d
0.56	0.84	2.3	40.8 ef	287 fg	153 d
0.56	1.12	2.3	23.8 g	194 g	148 d

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 28. Colby's analysis using percent moisture of jimsonweed grown in the greenhouse with a crop oil concentrate present.

Acifluorfen	Bentazon	Actual Moisture	Observed (% of control)	Predicted Colby's value	Difference (observed - predicted)	Synergism/ antagonism	LSD
(kg/ha)	(kg/ha)	(%)	(%)				
0.00	0.00	85.89	100.0				
0.00	0.56	56.33	65.6				
0.00	0.84	58.22	67.8				
0.00	1.12	56.89	66.2				
0.28	0.00	62.78	73.1				
0.28	0.56	57.11	66.5	47.9	18.6*	ant	14.8
0.28	0.84	36.33	42.3	49.5	-7.2	syn	13.4
0.28	1.12	44.22	51.5	48.4	3.1	ant	13.9
0.43	0.00	50.56	58.9				
0.43	0.56	46.89	54.6	38.6	16.0*	ant	14.1
0.43	0.84	46.44	54.1	39.9	14.2*	ant	14.0
0.43	1.12	50.11	58.3	39.0	19.4*	ant	14.3
0.56	0.00	49.22	57.3				
0.56	0.56	53.11	61.8	37.6	24.2*	ant	14.5
0.56	0.84	40.78	47.5	38.8	8.6	ant	13.7
0.56	1.12	23.78	27.7	35.0	10.3	syn	12.8

*Significance at the .05 level.

The value of 't' = 1.9901
The value of 'n' = 9
The mean square error = 126.58

present (Table 29). The interaction of the main effects of acifluorfen and bentazon was also significant.

When averaged over the main effects of herbicide rates, there appears to be little herbicidal difference between acifluorfen and bentazon on the measured parameters (Table 30). Increasing the acifluorfen rate from 0.28 to 0.56 kg/ha significantly decreased percent moisture and was the only increase in rate which produced a significant response to any measured parameter for either herbicide.

The effect of acifluorfen and bentazon plus a crop oil concentrate averaged over individual herbicide rates (Table 31), indicated that jimsonweed responded equally well to all single rates and rate combinations of acifluorfen and bentazon regardless of the parameter measured. Although a significant interaction of acifluorfen and bentazon was measured, it appeared to be confounded due to the fact that both herbicides when crop oil concentrate was added, caused the measured parameters to respond essentially equal. A Colby's analysis was not performed on any data as the herbicide rates were probably too high to measure interactions. Both herbicides appeared to be independent of each other, therefore, the model in this case is assumed to be additive.

Redroot pigweed:

Greenhouse: Redroot pigweed grown in the greenhouse was significantly reduced by the main effects of acifluorfen and bentazon over all the measured parameters (Table 32). An interaction was also measured between acifluorfen and bentazon over all the measured parameters.

The effects of acifluorfen and bentazon on the percent moisture of redroot pigweed grown in the greenhouse averaged over the main effects of

Table 29. The analysis of variance of jimsonweed grown outside on the measured parameters of percent moisture, fresh weight and dry weight as effected by a crop oil concentrate added to acifluorfen and bentazon.

		Significance (* = .05, ** = .01)		
Source	Degrees of freedom	% Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	**	**	**

Table 30. The effects of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of jimsonweed grown in the greenhouse averaged over the main effects of herbicide.[a]

Rate	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(L/ha)	(%)	(mg)	(mg)
Acifluorfen				
0.00	2.3	40.3 a	1759 a	247 a
0.28	2.3	32.0 b	269 b	174 b
0.43	2.3	28.4 bc	266 b	181 b
0.56	2.3	24.8 c	268 b	192 b
Bentazon				
0.00	2.3	41.3 a	761 a	244 a
0.56	2.3	29.2 b	259 b	179 b
0.84	2.3	29.0 b	277 b	189 b
1.12	2.3	26.0 b	265 b	182 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table

Her
Acifluo
(kg/ha
0.00
0.00
0.00
0.00
0.00
0.28
0.43
0.56
0.28
0.28
0.28
0.43
0.43
0.43
0.56
0.56
0.56

[a]Means f
differe

Table 31. The effect of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of jimsonweed grown outside averaged over herbicide rates.[a]

Herbicide rate					
Acifluorfen	Bentazon	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(L/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	0.0	83.0 a	2300 a	391 a
0.00	0.00	2.3	82.1 a	2210 a	392 a
0.00	0.56	2.3	25.7 cde	258 b	186 b
0.00	0.84	2.3	32.0 bcd	298 b	198 b
0.00	1.12	2.3	21.4 e	268 b	211 b
0.28	0.00	2.3	29.3 b-e	288 b	189 b
0.43	0.00	2.3	28.8 b-e	293 b	208 b
0.56	0.00	2.3	24.9 cde	251 b	185 b
0.28	0.56	2.3	35.8 b	257 b	161 b
0.28	0.84	2.3	33.4 bc	284 b	182 b
0.28	1.12	2.3	29.4 b-e	245 b	166 b
0.43	0.56	2.3	31.4 bcd	265 b	182 b
0.43	0.84	2.3	27.8 b-e	229 b	161 b
0.43	1.12	2.3	25.8 cde	278 b	173 b
0.56	0.56	2.3	23.9 de	256 b	189 b
0.56	0.84	2.3	22.9 de	298 b	215 b
0.56	1.12	2.3	27.4 b-e	267 b	177 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

T

S

Re

Ac

Be

Ac
Be

Ta

Ra

(kg

Aci

0
0
0.
0.

Ben

0.
0.
0.
1.

aMea
diff

Table 32. The analysis of variance of redroot pigweed grown in the greenhouse on the measured parameters of percent moisture, fresh weight and dry weight.

Source	Degrees of freedom	Significance (* = .05, ** = .01) % Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	**	**	**

Table 33. The effects of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of redroot pigweed grown in the greenhouse averaged over the main effects of herbicide.[a]

Rate	Moisture	Fresh weight	Dry weight
(kg/ha)	(%)	(mg)	(mg)
Acifluorfen			
0.00	84.9 a	370 a	58 a
0.28	39.7 b	64 b	28 b
0.43	37.2 b	51 b	27 b
0.56	30.9 c	46 b	29 b
Bentazon			
0.00	35.9 c	253 a	56 a
0.56	53.4 ab	114 b	35 b
0.84	54.9 a	92 c	26 b
1.12	48.6 b	71 d	25 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

herbi

(Tabl

perce

weigh

signi

T

rates

moistu

rates

any ra

aciflu

weight

any ra

weight

singly

dry wei

Si

all the

Colby's

values

means w

Colby's

signific

at the h

This ant

due to t

short 10

correct r

herbicide rates, indicated that bentazon is antagonistic to acifluorfen (Table 33). The main effect of acifluorfen rates showed a decrease of percent moisture with increased rates of acifluorfen. Fresh and dry weight averages, however, were not affected by rates, although they were significantly lower than the control values.

The effect of acifluorfen and bentazon when averaged over individual rates indicated that bentazon had no significant effect on percent moisture but did significantly decrease fresh weight with increasing rates (Table 34). The combined rates were all significantly less than any rate of bentazon and significantly higher than any rate of acifluorfen applied singly when percent moisture was measured. Fresh weights were significantly reduced by increasing rates of bentazon, but any rate of acifluorfen present in a mix significantly reduced fresh weight below any rate of bentazon applied singly. Acifluorfen applied singly or in a combination with bentazon at any rate reduced fresh and dry weight to values equal to the amount of acifluorfen in the mix.

Since the acifluorfen and bentazon interaction was significant over all the measured parameters, a Colby's analysis was performed. However, Colby's was not performed on the fresh or dry weight results as the values were probably confounded because the combination and acifluorfen means were not significantly different from each other (Table 34). The Colby's analysis of the percent moisture values indicated that bentazon significantly antagonized acifluorfen across all rate combinations except at the highest rate of acifluorfen and bentazon (Table 35, Figure 6). This antagonism was probably not measured in fresh and dry weight values due to the sensitivity of the redroot pigweed to acifluorfen and the short 10 day period between herbicide application and plant harvest. The correct model is assumed to be multiplicative.

Table 34. The effect of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of redroot pigweed grown in the greenhouse averaged over herbicide rates.[a]

Herbicide rate				
Acifluorfen	Bentazon	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	85.1 a	821 a	131 a
0.00	0.56	85.0 a	269 b	41 b
0.00	0.84	85.1 a	226 c	34 bcd
0.00	1.12	84.2 a	166 d	26 d
0.28	0.00	20.1 cd	83 e	30 bcd
0.43	0.00	22.3 cd	63 ef	32 bcd
0.56	0.00	15.9 d	45 ef	29 cd
0.28	0.56	49.1 b	69 ef	31 bcd
0.28	0.84	48.0 b	507 ef	27 d
0.28	1.12	41.7 b	46 ef	25 d
0.43	0.56	40.7 b	55 ef	28 cd
0.43	0.84	44.3 b	44 ef	23 d
0.43	1.12	41.6 b	41 ef	24 d
0.56	0.56	38.7 b	61 ef	38 bc
0.56	0.84	42.3 b	44 ef	22 d
0.56	1.12	26.9 b	32 ef	24 d

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 35. Colby's analysis using percent moisture of redroot pigweed grown in the greenhouse.

Acifluorfen	Bentazon	Actual Moisture	Observed (% of control)	Predicted Colby's value	Difference (observed - predicted)	Synergism/ antagonism	LSD
(kg/ha)	(kg/ha)	(%)	(%)				
0.00	0.00	85.11	100.0				
0.00	0.56	85.00	99.9				
0.00	0.84	85.11	100.0				
0.00	1.12	84.22	99.0				
0.28	0.00	25.67	30.0				
0.28	0.56	49.11	57.7	30.1	27.6*	ant	15.6
0.28	0.84	48.00	56.4	30.2	26.2*	ant	15.5
0.28	1.12	39.44	46.3	29.8	16.5*	ant	14.9
0.43	0.00	24.56	28.9				
0.43	0.56	38.44	45.2	28.8	16.4*	ant	14.8
0.43	0.84	44.33	52.1	28.9	23.2*	ant	15.2
0.43	1.12	38.56	45.3	28.5	16.8*	ant	14.8
0.56	0.00	17.00	20.0				
0.56	0.56	38.67	45.4	19.9	25.5*	ant	14.8
0.56	0.84	41.22	48.4	20.0	28.5*	ant	15.0
0.56	1.12	25.77	30.3	19.8	10.5	ant	14.1

*Significance at the .05 level.

The value of 't' = 1.9901
The value of 'n' = 9
The mean square error = 147.89

Figure 6. Percent moisture of redroot pigweed grown in the greenhouse 10 days following treatment with acifluorfen and bentazon (solid lines) and in all possible combinations (dashed lines) versus the observed percent of control.

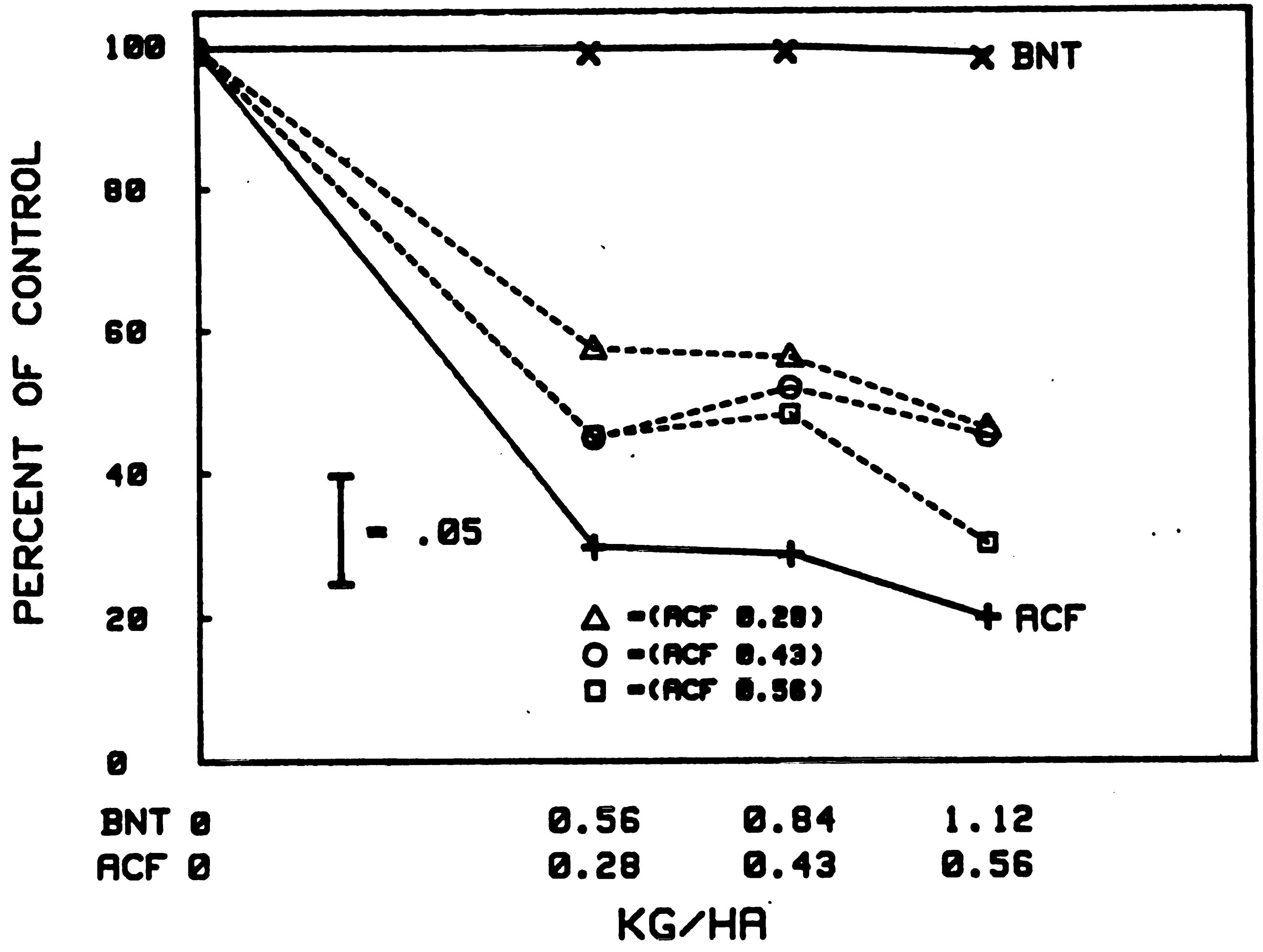

PERCENT OF CONTROL
100
80
60
40
20
0
BNT
ACF
= .05
△ =(ACF 0.28)
○ =(ACF 0.43)
□ =(ACF 0.56)
BNT 0
ACF 0
0.56
0.28
0.84
0.43
1.12
0.56
KG/HA

Figure 6

Outside: Redroot pigweed grown outside was significantly reduced across all the measured parameters by acifluorfen and bentazon (Table 36). Interactions between acifluorfen and bentazon were measured in fresh and dry weights but not in percent moisture.

Both herbicides significantly decreased all measured values below the control over all measured parameters. When averaged over the main effects of herbicide rates, generally there was not a significant decrease in any measured parameter due to increasing rate except on percent moisture with acifluorfen (Table 37).

The effect of bentazon when averaged over individual herbicide rates indicated that no rate of bentazon applied alone, was significantly different from the control when percent moisture was compared (Table 38), but there was a significant decrease in fresh and dry weight values. Acifluorfen rates significantly decreased percent moisture values with an increase from 0.28 to 0.56 kg/ha. The combination of acifluorfen and bentazon when percent moisture was compared was significantly lower than either herbicide applied singly only at the lowest rate of acifluorfen (0.28 kg/ha) across all the rates of bentazon. Once the rate of acifluorfen was at least 0.43 kg/ha in any combination, a significant decrease in percent moisture was no longer measured but was similar to the single rate of acifluorfen. This significant decrease was not measured with fresh or dry weights. Since a significant interaction was not measured across all rate combinations, a Colby's analysis was only performed on those rates (0.28 kg/ha acifluorfen and all rates of bentazon) which were significantly different (Table 38).

Colby's analysis (Table 39) indicated that at the lowest rate of acifluorfen (0.28 kg/ha) across all rates of bentazon the combination was significantly lower than either herbicide applied singly. This synergism

B

Ac
Be

Ta

Ra

(kg/

Acif

0.
0.
0.
0.5

Benta

0.0
0.56
0.84
1.12

aMeans
differ

Table 36. The analysis of variance of redroot pigweed grown outside on the measured parameters of percent moisture, fresh weight and dry weight.

Source	Degrees of freedom	Significance (* = .05, ** = .01) % Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	-	**	**

Table 37. The effects of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of redroot pigweed grown outside averaged over the main effects of herbicide.[a]

Rate	Moisture	Fresh weight	Dry weight
(kg/ha)	(%)	(mg)	(mg)
Acifluorfen			
0.00	80.3 a	1052 a	184 a
0.28	42.5 b	221 b	110 b
0.43	33.8 c	165 b	97 b
0.56	29.3 c	152 b	101 b
Bentazon			
0.00	53.9 a	578 a	164 a
0.56	45.8 b	377 b	113 b
0.84	45.6 b	348 b	109 b
1.12	40.7 b	307 b	106 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 38. The effect of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of redroot pigweed grown outside averaged over herbicide rates.[a]

Herbicide rate				
Acifluorfen	Bentazon	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	80.7 a	1474 a	288 a
0.00	0.56	83.2 a	1022 b	185 b
0.00	0.84	83.8 a	921 bc	147 bc
0.00	1.12	73.4 a	792 c	142 bcd
0.28	0.00	53.4 b	329 d	136 bcd
0.43	0.00	45.0 bc	222 de	111 cde
0.56	0.00	36.0 cde	206 de	120 bcde
0.28	0.56	39.6 cd	184 de	102 cde
0.28	0.84	41.1 cd	206 de	109 cde
0.28	1.12	35.9 cde	164 de	95 de
0.43	0.56	32.7 cdef	160 de	95 de
0.43	0.84	25.1 ef	136 e	97 de
0.43	1.12	32.2 cdef	140 e	86 e
0.56	0.56	27.9 def	143 de	97 de
0.56	0.84	31.4 def	128 e	84 e
0.56	1.12	21.3 f	131 e	101 cde

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 39. Colby's analysis using percent moisture of redroot pigweed grown outside.

Acifluorfen	Bentazon	Actual Moisture	Observed (% of control)	Predicted Colby's value	Difference (observed - predicted)	Synergism/ antagonism	LSD
(kg/ha)	(kg/ha)	(%)	(%)				
0.00	0.00	80.67	100.0				
0.00	0.56	83.22	103.2				
0.00	0.84	83.78	103.9				
0.00	1.12	73.44	91.0				
0.28	0.00	53.44	66.3				
0.28	0.56	39.56	49.0	68.4	-19.3*	syn	16.0
0.28	0.84	41.11	51.0	68.8	-17.8*	syn	16.2
0.28	1.12	35.89	44.5	60.3	-15.8*	syn	15.8
0.43	0.00	45.00	55.8				
0.43	0.56	32.67	40.5	57.6	-17.1*	syn	15.5
0.43	0.84	25.11	31.1	57.9	-26.8*	syn	15.1
0.43	1.12	32.22	39.9	50.8	-10.8	syn	15.5
0.56	0.00	36.33	45.0				
0.56	0.56	27.89	34.6	46.5	-11.9	syn	15.2
0.56	0.84	31.44	39.0	46.8	-7.8	syn	15.5
0.56	1.12	21.33	26.4	41.0	-14.6	syn	14.9

*Significance at the .05 level.

The value of 't' = 1.981
The value of 'n' = 15
The mean square error = 42.17

was

fres

diff

sing

acif

cons

treat

a sig

across

aciflu

parame

B

herbic

for be

percen

signif

increas

fresh c

influen

herbici

Wh

singly

(Table 4

values

alone.

decrease

signific

was considered significant (Figure 7). The interactions measured by the fresh and dry weight values were considered confounded as they did not differ significantly from the value of the acifluorfen in the mix applied singly. The correct model would be multiplicative at the lowest rate of acifluorfen and as the rate increased an additive model would be considered appropriate.

Greenhouse (oil): Redroot pigweed grown in the greenhouse and treated with acifluorfen and bentazon plus a crop oil concentrate, showed a significant reduction to the main effects of acifluorfen and bentazon across all measured parameters (Table 40). The interaction of acifluorfen and bentazon was also significant across all measured parameters.

Bentazon appeared to antagonize acifluorfen when the main effects of herbicide rates were compared as the average values of percent moisture for bentazon were significantly increased from the overall average of percent moisture where no bentazon was present (Table 41). Acifluorfen significantly reduced percent moisture values with increasing rates. The increasing rates of acifluorfen, however, had no decreasing effect on fresh or dry weight measurements. Bentazon did not significantly influence any measured parameter when averaged over the main effect of herbicides.

When averaged over individual herbicide rates, bentazon applied singly had significantly higher percent moisture values than the control (Table 42). Except for the controls, all fresh and most dry weight values were significantly lower than the values for bentazon applied alone. The percent moisture of the acifluorfen treated plants did not decrease significantly with increasing rates, however, they were significantly less than any single rate of bentazon or any combination of

Figure 7. Percent moisture of redroot pigweed grown outside 10 days following treatment with acifluorfen and bentazon (solid lines) and in all possible combinations (dashed lines) versus the observed percent of control.

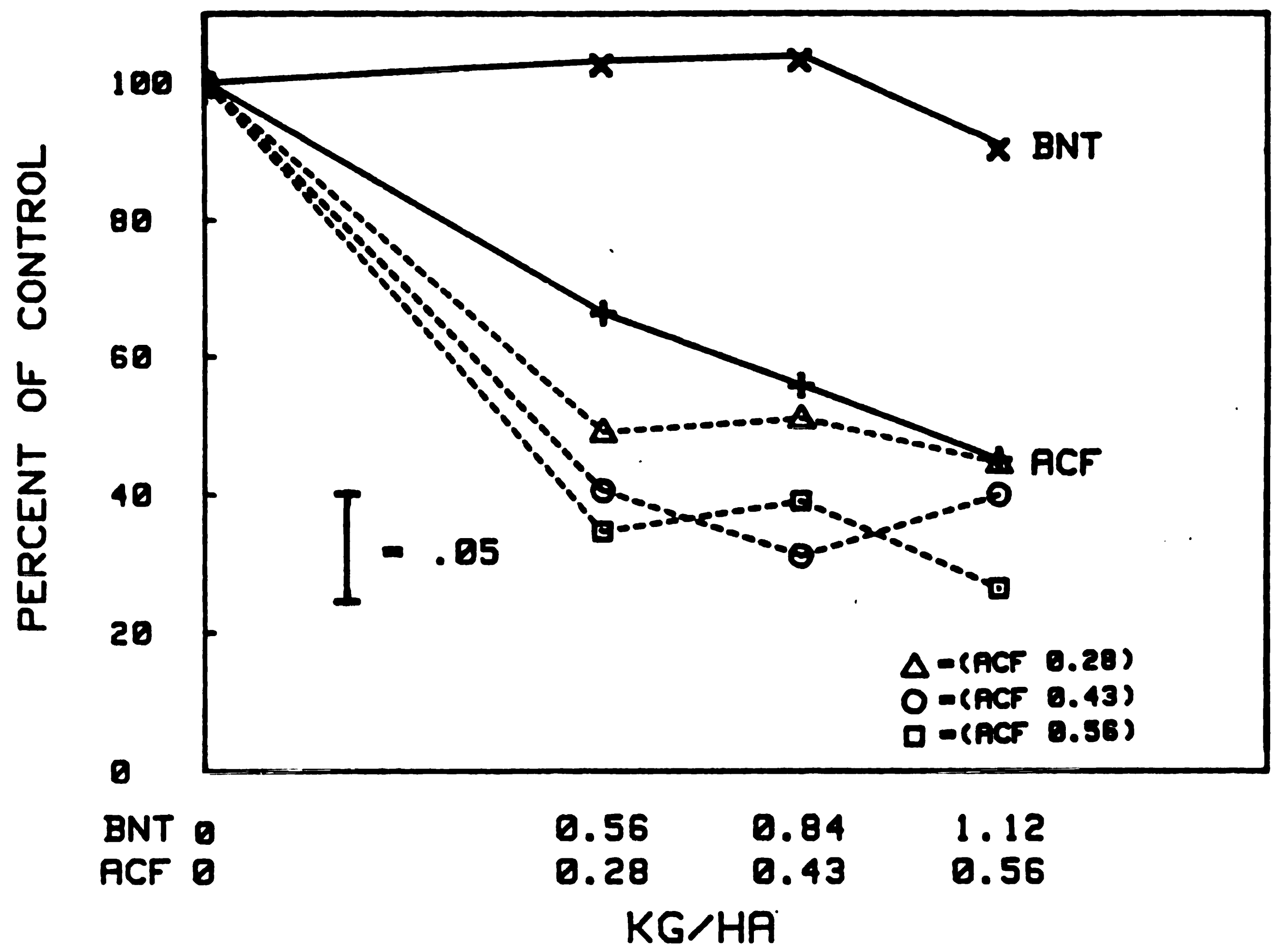

PERCENT OF CONTROL
100
80
60
40
20
0
BNT
ACF
= .05
△ =(ACF 0.28)
○ =(ACF 0.43)
□ =(ACF 0.56)
BNT 0
ACF 0
0.56
0.28
0.84
0.43
1.12
0.56
KG/HA

Figure 7

Table 40. The analysis of variance of redroot pigweed grown in the greenhouse on the measured parameters of percent moisture, fresh weight and dry weight as affected by a crop oil concentrate added to acifluorfen and bentazon.

Source	Degrees of freedom	Significance (* = .05, ** = .01) % Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	**	**	**

Table 41. The effects of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of redroot pigweed grown in the greenhouse averaged over the main effects of herbicide.[a]

Rate	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(L/ha)	(%)	(mg)	(mg)
Acifluorfen				
0.00	2.3	85.2 a	1530 a	239 a
0.28	2.3	33.6 b	206 b	111 b
0.43	2.3	27.5 c	178 b	116 b
0.56	2.3	25.1 d	163 b	115 b
Bentazon				
0.00	2.3	31.9 b	717 a	214 a
0.56	2.3	46.6 a	466 b	124 b
0.84	2.3	46.4 a	440 b	121 b
1.12	2.3	46.5 a	450 b	119 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 42. The effect of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of redroot pigweed grown in the greenhouse averaged over herbicide rates.[a]

Herbicide rate					
Acifluorfen	Bentazon	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(L/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	0.0	82.4 b	2381 a	490 a
0.00	0.00	2.3	80.6 b	2363 a	460 a
0.00	0.56	2.3	86.4 a	1283 b	168 b
0.00	0.84	2.3	87.4 a	1199 b	153 bc
0.00	1.12	2.3	86.4 a	1276 b	163 b
0.28	0.00	2.3	17.4 e	154 c	120 cdef
0.43	0.00	2.3	15.6 e	178 c	135 bcde
0.56	0.00	2.3	14.1 e	174 c	143 bcd
0.28	0.56	2.3	39.3 c	234 c	109 def
0.28	0.84	2.3	39.9 c	252 c	119 cdef
0.28	1.12	2.3	37.7 c	183 c	95 f
0.43	0.56	2.3	32.3 d	193 c	114 def
0.43	0.84	2.3	30.3 d	169 c	107 ef
0.43	1.12	2.3	31.9 d	172 c	110 def
0.56	0.56	2.3	28.4 d	154 c	105 ef
0.56	0.84	2.3	27.8 d	156 c	105 ef
0.56	1.12	2.3	30.1 d	168 c	107 ef

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

acifl

perce

weigh

signi

where

of ac

aciflu

combi

S

Colby'

all c

(Table

signif

of aci

Colby'

O

aciflu

reduct

of aci

parame

Wh

aciflu

rates (

the ave

higher

present

signifi

acifluorfen or bentazon. Combination rates also had significantly lower percent moisture values than any single rate of bentazon. All fresh weights, regardless of the rate of bentazon or acifluorfen present, were significantly less than any rate of bentazon applied alone. Dry weights where bentazon was applied alone were significantly higher than any rate of acifluorfen applied singly or in any tank mix combination of acifluorfen and bentazon if 0.43 kg/ha or more of acifluorfen was in that combination regardless of the rate of bentazon.

Since the acifluorfen and bentazon interaction was significant, a Colby's analysis was performed. Bentazon antagonized acifluorfen across all combination rates of acifluorfen and was considered significant (Table 43, Figure 8). Fresh and dry weight values, although showing a significant interaction, were not consistently different from the values of acifluorfen applied singly and were considered confounded so a Colby's analysis was not performed. The correct model is multiplicative.

Outside (oil): Redroot pigweed grown outside and treated with acifluorfen and bentazon plus a crop oil concentrate showed a significant reduction across all the measured parameters (Table 44). The interaction of acifluorfen and bentazon was also significant across all the measured parameters.

When averaged over the main effects of herbicide, the presence of acifluorfen significantly decreased percent moisture with increasing rates (Table 45). Bentazon appears to be antagonistic to acifluorfen as the average values of percent moisture for bentazon are significantly higher from the overall average of percent moisture where no bentazon was present. Overall fresh and dry weight values do not appear to be significantly influenced by increasing acifluorfen or bentazon rates.

Table 43. Colby's analysis using percent moisture of redroot pigweed grown in the greenhouse with a crop oil concentrate present.

Acifluorfen	Bentazon	Actual Moisture	Observed (% of control)	Predicted Colby's value	Difference (observed - predicted)	Synergism/ antagonism	LSD
(kg/ha)	(kg/ha)	(%)	(%)				
0.00	0.00	80.6	100.0				
0.00	0.56	86.4	107.2				
0.00	0.84	87.4	108.4				
0.00	1.12	86.4	107.2				
0.28	0.00	17.4	21.6				
0.28	0.56	39.3	48.8	23.1	25.6*	ant	6.1
0.28	0.84	39.9	49.5	23.4	26.1*	ant	6.1
0.28	1.12	37.7	46.8	23.1	23.6*	ant	6.1
0.43	0.00	15.6	19.4				
0.43	0.56	32.3	40.1	20.7	19.3*	ant	5.9
0.43	0.84	30.3	37.6	21.0	16.6*	ant	5.9
0.43	1.12	31.9	39.6	20.7	18.8*	ant	5.9
0.56	0.00	14.1	17.5				
0.56	0.56	28.4	35.2	18.8	16.5*	ant	5.8
0.56	0.84	27.8	34.5	19.0	15.5*	ant	5.8
0.56	1.12	30.1	37.3	18.8	18.6*	ant	5.9

*Significance at the .05 level.

The value of 't' = 1.9901
The value of 'n' = 9
The mean square error = 22.18

Figure 8. Percent moisture of redroot pigweed grown in the greenhouse 10 days following treatment with acifluorfen and bentazon (solid lines) and in all possible combinations (dashed lines) with all treatments containing a crop oil concentrate versus the observed percent of control.

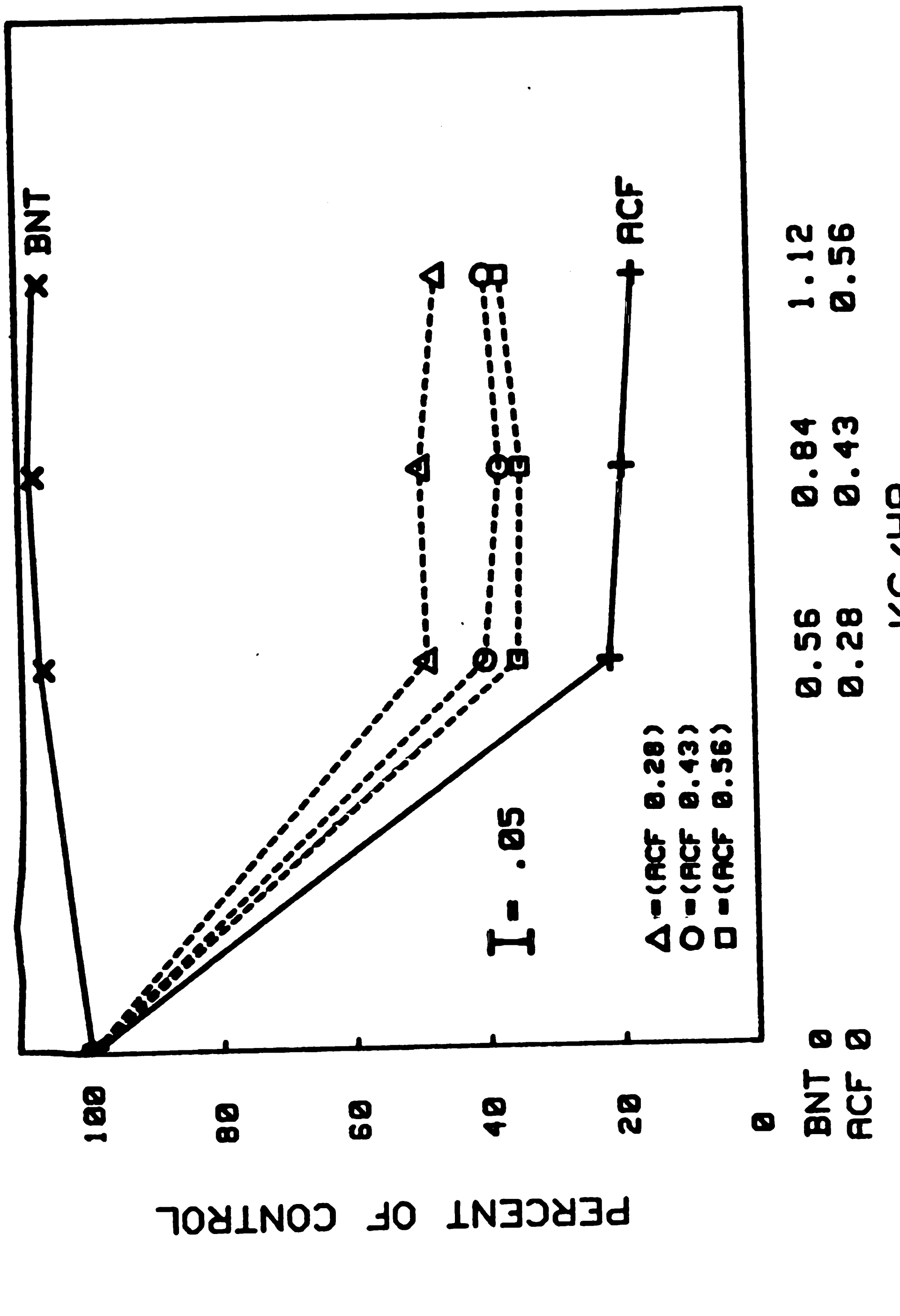

PERCENT OF CONTROL
100
80
60
40
20
0
BNT 0
ACF 0
0.56
0.28
0.84
0.43
1.12
0.56
KG/HA
BNT
ACF
I= .05
Δ =(ACF 0.28)
O =(ACF 0.43)
□ =(ACF 0.56)

Figure 8

Table 44. The analysis of variance of redroot pigweed grown outside on the measured parameters of percent moisture, fresh weight and dry weight as affected by a crop oil concentrate added to acifluorfen and bentazon.

Source	Degrees of freedom	Significance (* = .05, ** = .01) % Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	*	**	**

Table 45. The effects of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of redroot pigweed grown outside averaged over the main effects of herbicide.[a]

Rate	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(L/ha)	(%)	(mg)	(mg)
Acifluorfen				
0.00	2.3	79.0 a	1104 a	230 a
0.28	2.3	36.5 b	286 b	158 b
0.43	2.3	31.7 c	236 bc	144 b
0.56	2.3	27.6 d	217 c	145 b
Bentazon				
0.00	2.3	39.2 b	529 a	195 a
0.56	2.3	44.5 a	452 b	163 b
0.84	2.3	45.1 a	426 b	178 b
1.12	2.3	45.9 a	436 b	159 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

The effect of acifluorfen and bentazon plus a crop oil concentrate when averaged over individual herbicide rates indicated that percent moisture was not significantly influenced by any rate of bentazon when compared to the control (Table 46). Fresh and dry weight measurements of the bentazon treated plants were significantly less than the control at all single rates of bentazon and were significantly larger than the weights of any rate of acifluorfen applied singly or in any rate combination with bentazon. When percent moistures were compared, the lowest rate of acifluorfen (0.28 kg/ha) across all rates of bentazon plus a crop oil concentrate significantly increased percent moisture values above any single rate of acifluorfen and lower than any single rate of bentazon and actually increased percent moisture with increasing rates of bentazon (Figure 9). Other rate combinations had percent moisture values that were significantly lower than the value of bentazon, but were not generally different from the single rate of acifluorfen in the combination.

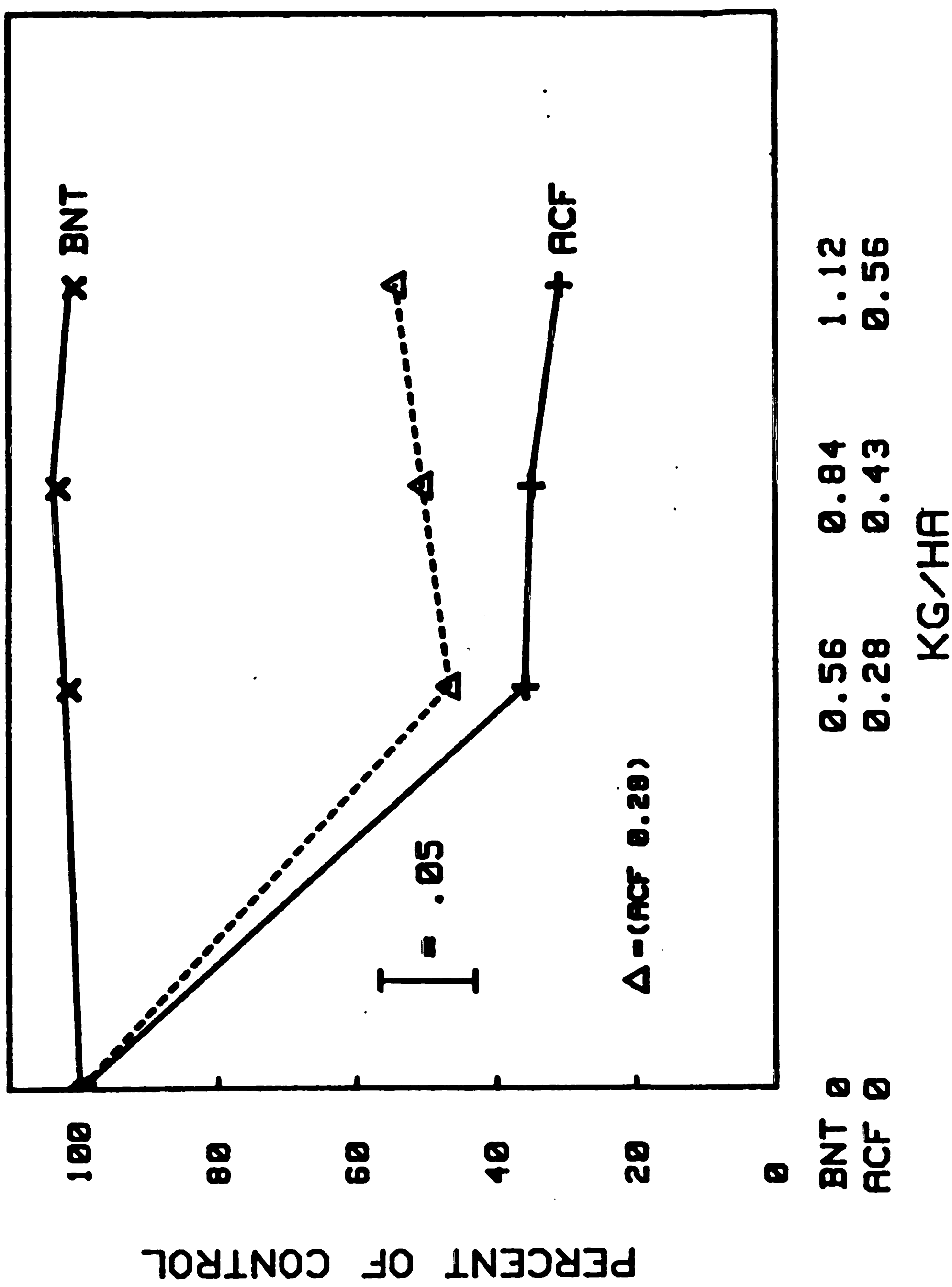
Since the interaction of acifluorfen and bentazon was significant, a Colby's analysis was calculated (Table 47) and indicated that the antagonism noted at the lowest rate of acifluorfen (0.28 kg/ha) was significant. Although antagonism is indicated with other rate combinations it was not consistent. The Colby's analysis was not performed on the fresh or dry weights as the means were generally not significantly different from each other and were considered confounded. The correct model is multiplicative and once the rate of acifluorfen is above 0.43 kg/ha the antagonism would be considered under an additive model.

Table 46. The effect of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of redroot pigweed grown in the greenhouse averaged over herbicide rates.[a]

Herbicide rate					
Acifluorfen	Bentazon	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(L/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	0.0	78.2 a	1321 a	288 a
0.00	0.00	2.3	77.6 a	1301 a	293 a
0.00	0.56	2.3	79.2 a	1112 b	225 b
0.00	0.84	2.3	80.5 a	1000 b	196 bc
0.00	1.12	2.3	78.6 a	1004 b	206 bc
0.28	0.00	2.3	27.9 efg	317 c	181 cd
0.43	0.00	2.3	27.2 fg	267 c	158 de
0.56	0.00	2.3	24.1 g	271 c	149 de
0.28	0.56	2.3	36.3 cd	228 c	153 de
0.28	0.84	2.3	39.3 bc	267 c	147 de
0.28	1.12	2.3	42.3 b	271 c	149 de
0.43	0.56	2.3	35.1 cd	290 c	146 de
0.43	0.84	2.3	31.23 def	245 c	141 de
0.43	1.12	2.3	33.1 de	217 c	129 e
0.56	0.56	2.3	27.3 fg	189 c	130 e
0.56	0.84	2.3	29.2 efg	218 c	148 de
0.56	1.12	2.3	29.7 ef	238 c	152 de

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Figure 9. Percent moisture of redroot pigweed grown outside 10 days following treatment with acifluorfen and bentazon (solid lines) and in all possible combinations (dashed lines) with all treatments containing a crop oil concentrate versus the observed percent of control.



BNT
ACF
= .05
Δ =(ACF 0.28)
100
80
60
40
20
0
BNT 0
ACF 0
0.56
0.28
0.84
0.43
1.12
0.56
KG/HA
PERCENT OF CONTROL

Figure 9

Table 47. Colby's analysis using percent moisture of redroot pigweed grown outside with a crop oil concentrate present.

Acifluorfen	Bentazon	Actual Moisture	Observed (% of control)	Predicted Colby's value	Difference (observed - predicted)	Synergism/ antagonism	LSD
(kg/ha)	(kg/ha)	(%)	(%)				
0.00	0.00	77.60	100.0				
0.00	0.56	79.20	102.1				
0.00	0.84	80.47	103.7				
0.00	1.12	78.60	101.3				
0.28	0.00	27.93	36.0				
0.28	0.56	36.33	46.8	36.7	10.1*	ant	6.7
0.28	0.84	39.33	50.7	37.3	13.4*	ant	6.8
0.28	1.12	42.26	54.5	36.5	18.0*	ant	6.9
0.43	0.00	27.20	35.1				
0.43	0.56	35.07	45.2	35.8	9.4*	ant	6.6
0.43	0.84	31.27	40.3	36.3	3.9	ant	6.5
0.43	1.12	33.13	42.7	35.5	7.2*	ant	6.6
0.56	0.00	24.13	31.1				
0.56	0.56	27.33	35.2	31.7	3.5	ant	6.4
0.56	0.84	29.20	37.6	32.2	5.4	ant	6.5
0.56	1.12	29.67	38.2	31.5	6.7*	ant	6.5

*Significance at the .05 level.

The value of 't' = 1.981
The value of 'n' = 15
The mean square error = 42.165

Vel

aci
par
sig

ind
par
com
bent
fres

cont
bent
affe
acif
the
bent
the
Dry
less
less
dry
acif
sens

fresh
perfo

Velvetleaf:

Greenhouse: Velvetleaf grown in the greenhouse and treated with acifluorfen and bentazon showed a significant reduction to all measured parameters (Table 48). The interaction of acifluorfen and bentazon was significant only when percent moisture was considered.

The main effects of acifluorfen and bentazon averaged over rates, indicated that when grown in the greenhouse the measured velvetleaf parameters were significantly reduced by acifluorfen and bentazon compared to the control. Increasing the rates of acifluorfen and bentazon caused significant reductions in percent moisture but true when fresh or dry weights were compared (Table 49).

When averaged over individual treatments and compared to the controls (Table 50), percent moisture was significantly reduced by bentazon only at rates greater than 0.84 kg/ha and acifluorfen did not affect percent moisture significantly at any rate. All combinations of acifluorfen and bentazon significantly reduced the percent moisture below the value of each herbicide applied singly. Both acifluorfen and bentazon significantly reduced fresh weight values below the control but the combinations were generally lower than each herbicide applied singly. Dry weight measurements of acifluorfen and bentazon were significantly less than the control, but each combination rate was seldom significantly less than the single rate of bentazon present in the combination. All dry weights except the control were significantly less than any rate of acifluorfen applied singly. Thus, velvetleaf appears to be more sensitive to bentazon when grown in the greenhouse.

The acifluorfen and bentazon interaction was not significant when fresh or dry weights were compared so a Colby's analysis was not performed. Fresh weights appeared to be additive in their response to

Table 48. The analysis of variance of velvetleaf grown in the greenhouse on the measured parameters of percent moisture, fresh weight and dry weight.

Source	Degrees of freedom	Significance (* = .05, ** = .01) % Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	**	-	-

Table 49. The effects of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of velvetleaf grown in the greenhouse averaged over the main effects of herbicide.[a]

Rate	Moisture	Fresh weight	Dry weight
(kg/ha)	(%)	(mg)	(mg)
Acifluorfen			
0.00	71.4 a	236 a	58 a
0.28	58.3 b	151 b	50 b
0.43	57.3 bc	158 b	53 b
0.56	54.4 c	147 b	51 b
Bentazon			
0.00	75.8 a	312 a	72 a
0.56	64.3 b	170 b	50 b
0.84	52.5 c	110 c	45 c
1.12	48.9 d	100 c	45 c

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 50. The effect of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of velvetleaf grown in the greenhouse averaged over herbicide rates.[a]

Herbicide rate				
Acifluorfen	Bentazon	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	78.0 a	358 a	77 a
0.00	0.56	76.2 a	268 b	57 b
0.00	0.84	65.7 b	155 c	46 cd
0.00	1.12	65.9 b	162 c	51 bcd
0.28	0.00	75.6 a	286 b	69 a
0.43	0.00	75.2 a	297 b	71 a
0.56	0.00	74.2 a	309 b	72 a
0.28	0.56	61.4 bc	141 cd	46 cd
0.28	0.84	50.7 d	98 de	43 d
0.28	1.12	45.4 def	81 e	42 d
0.43	0.56	62.6 bc	156 c	53 bc
0.43	0.84	47.4 de	92 e	44 cd
0.43	1.12	43.8 ef	87 e	45 cd
0.56	0.56	56.8 c	116 cde	43 d
0.56	0.84	46.a def	95 e	47 cd
0.56	1.12	40.3 f	69 e	41 d

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

t
p
s
c
m
F
c
s

be
in

ef
si
Be
ra
ne
ra

not
Ben
bel
aci
rat
decr
sign
comb

the combinations when compared to each herbicide applied singly. When percent moistures were compared, however, the interaction term was significant. A Colby's analysis indicated acifluorfen and bentazon in combination significantly reduced velvetleaf percent moisture measurements below that of either herbicide applied singly (Table 51, Figure 10). This synergism was considered significant across all combinations. The model is considered to be multiplicative with a synergistic response.

Outside: Velvetleaf grown outside and treated with acifluorfen and bentazon showed a significant reduction in all measured parameter. The interaction of acifluorfen and bentazon was also significant (Table 52).

The effect of acifluorfen and bentazon, when averaged over the main effect of herbicide rates (Table 53) indicated that both herbicides significantly reduced all the measured parameters below the control. Bentazon significantly reduced percent moisture values with increasing rates, acifluorfen did not. When fresh and dry weights were compared, neither herbicide significantly reduced measured weights with increasing rates of herbicide.

When averaged over individual herbicide treatments, acifluorfen did not reduce percent moisture significantly below the control (Table 54). Bentazon significantly reduced percent moisture below the control and below all the single rates of acifluorfen. All combinations of acifluorfen and bentazon were reduced significantly below all the single rates of either herbicide and increasing rates of bentazon significantly decreased the percent moisture. No fresh or dry weight values were significantly lower than the rate of bentazon applied singly in the combination, although all combinations were lower than any rate of

Table 51. Colby's analysis using percent moisture of velvetleaf grown in the greenhouse

Table 51. Colby's analysis using percent moisture of velvetleaf grown in the greenhouse.

Acifluorfen	Bentazon	Actual Moisture	Observed (% of control)	Predicted Colby's value	Difference (observed - predicted)	Synergism/ antagonism	LSD
(kg/ha)	(kg/ha)	(%)	(%)				
0.00	0.00	78.00	100.0				
0.00	0.56	76.22	97.7				
0.00	0.84	65.67	84.2				
0.00	1.12	65.89	84.5				
0.28	0.00	75.56	96.9				
0.28	0.56	61.44	78.8	94.7	-15.9*	syn	9.6
0.28	0.84	50.67	65.0	81.5	-16.6*	syn	9.0
0.28	1.12	45.44	58.3	81.8	-23.6*	syn	8.8
0.43	0.00	75.22	96.4				
0.43	0.56	62.56	80.2	94.2	-14.0*	syn	9.7
0.43	0.84	47.44	60.8	81.2	-20.4*	syn	8.9
0.43	1.12	43.78	56.1	81.5	-25.3*	syn	8.7
0.56	0.00	74.22	95.2				
0.56	0.56	56.78	72.8	93.0	-20.2*	syn	9.4
0.56	0.84	46.11	59.1	80.1	-21.0*	syn	8.8
0.56	1.12	40.33	51.7	80.4	-28.7*	syn	8.5

*Significance at the .05 level.

The value of 't' = 1.9901
The value of 'n' = 9
The mean square error = 39.421

Figure 10. Percent moisture of velvetleaf grown in the greenhouse 10 days following treatment with acifluorfen and bentazon (solid lines) and in all possible combinations (dashed lines) versus the observed percent of control.

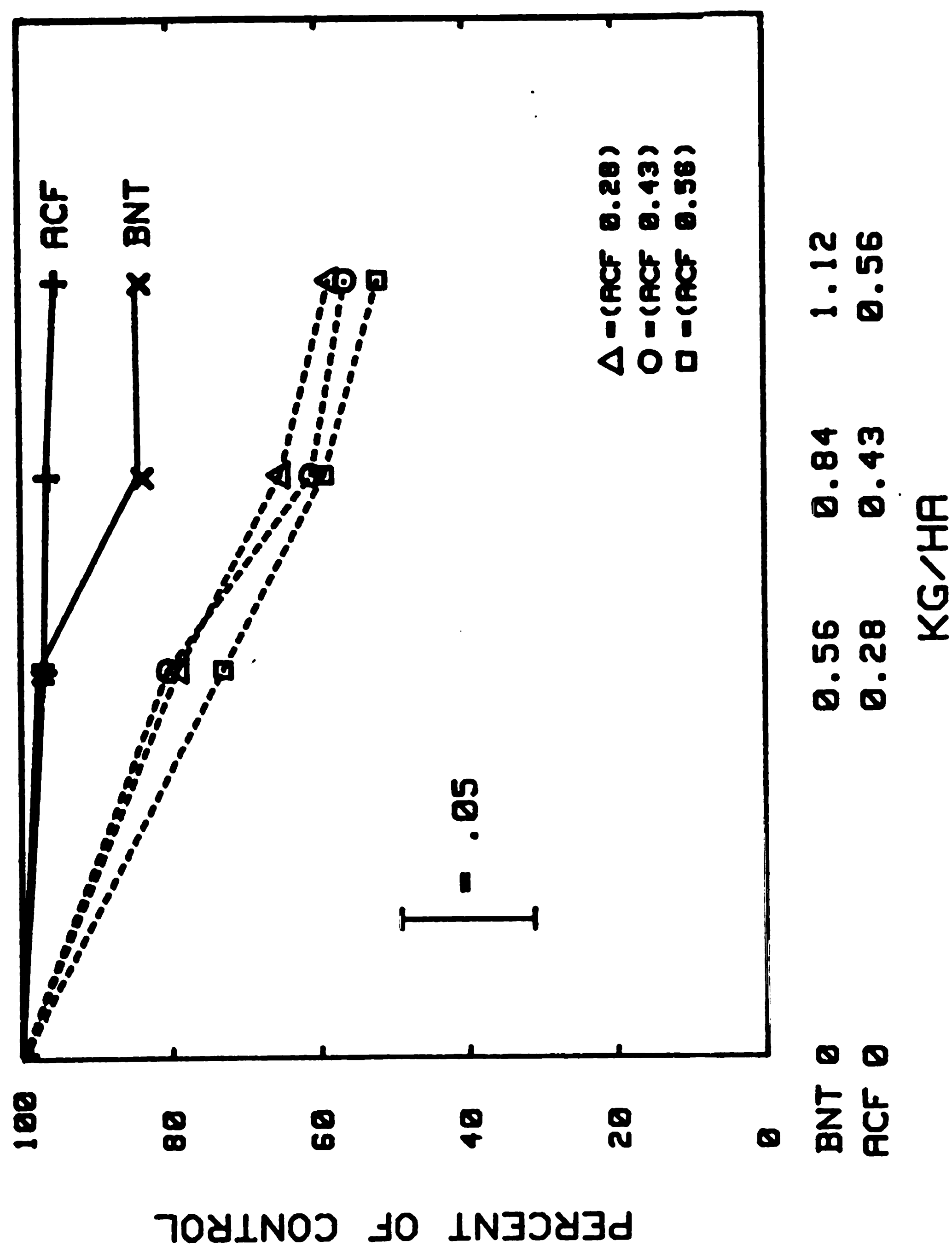

PERCENT OF CONTROL
100
80
60
40
20
0
BNT 0
ACF 0
0.56
0.28
0.84
0.43
1.12
0.56
KG/HA
ACF
BNT
= .05
Δ =(ACF 0.28)
O =(ACF 0.43)
□ =(ACF 0.56)

Figure 10

Table 52. The analysis of variance of velvetleaf grown outside on the measured parameters of percent moisture, fresh weight and dry weight.

Source	Degrees of freedom	Significance (* = .05, ** = .01) % Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	**	**	**

Table 53. The effects of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of velvetleaf grown outside averaged over the main effects of herbicide.[a]

Rate	Moisture	Fresh weight	Dry weight
(kg/ha)	(%)	(mg)	(mg)
Acifluorfen			
0.00	62.4 a	327 a	96 a
0.28	56.8 b	220 b	74 b
0.43	53.7 c	204 b	75 b
0.56	52.3 c	191 b	72 b
Bentazon			
0.00	75.3 a	532 a	127 a
0.56	53.5 b	154 b	65 b
0.84	49.9 c	132 b	62 b
1.12	46.5 d	124 b	62 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 54. The effect of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of velvetleaf grown outside averaged over herbicide rates.[a]

Herbicide rate				
Acifluorfen	Bentazon	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	76.3 a	819 a	184 a
0.00	0.56	61.9 b	187 d	69 d
0.00	0.84	58.3 bc	160 d	65 d
0.00	1.12	53.1 d	143 d	64 d
0.28	0.00	75.8 a	495 b	119 b
0.43	0.00	75.2 a	420 c	103 c
0.56	0.00	74.0 a	394 c	101 c
0.28	0.56	55.4 cd	151 d	62 d
0.28	0.84	48.7 e	115 d	56 d
0.28	1.12	47.3 e	118 d	508 d
0.43	0.56	48.6 e	139 d	65 d
0.43	0.84	47.7 e	137 d	67 d
0.43	1.12	43.3 f	121 d	63 d
0.56	0.56	48.0 e	137 d	65 d
0.56	0.84	45.0 ef	116 d	59 d
0.56	1.12	42.1 f	115 d	62 d

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

acifluorfen applied singly. Bentazon was more effective at reducing all parameters measured on velvetleaf grown outside than was acifluorfen.

Since the acifluorfen and bentazon interaction was significant over all the measured parameters, a Colby's analysis was performed. The Colby's analysis, however, was not performed on the fresh and dry weight measurements as the means of the combinations were not significantly different from the rate of bentazon applied singly and were considered confounded. The Colby's analysis of the percent moisture (Table 55) indicated that the combination of acifluorfen and bentazon was synergistic across all combined rates and considered significant (Figure 11). The correct model is considered to be multiplicative with a synergistic response to all combinations of acifluorfen and bentazon.

Greenhouse (oil): The analysis of variance of velvetleaf grown in the greenhouse with a crop oil concentrate added to acifluorfen and bentazon indicated all the measured parameters were significantly reduced (Table 56). Interactions of acifluorfen and bentazon were measured with fresh and dry weight measurements but not percent moistures.

Increasing rates of acifluorfen and bentazon significantly reduced all the measured parameters when averaged over the main effects of herbicide rates (Table 57). This decrease was generally larger for bentazon than for acifluorfen.

When averaged over individual herbicide rates (Table 58), acifluorfen plus a crop oil concentrate had no significant effect on percent moisture when compared to the control, although fresh and dry weights were significantly reduced but all values were significantly higher than any rate of bentazon applied singly or in combination. All combination treatments, however, never had significantly lower fresh or dry weight values than the bentazon in the combination applied singly.

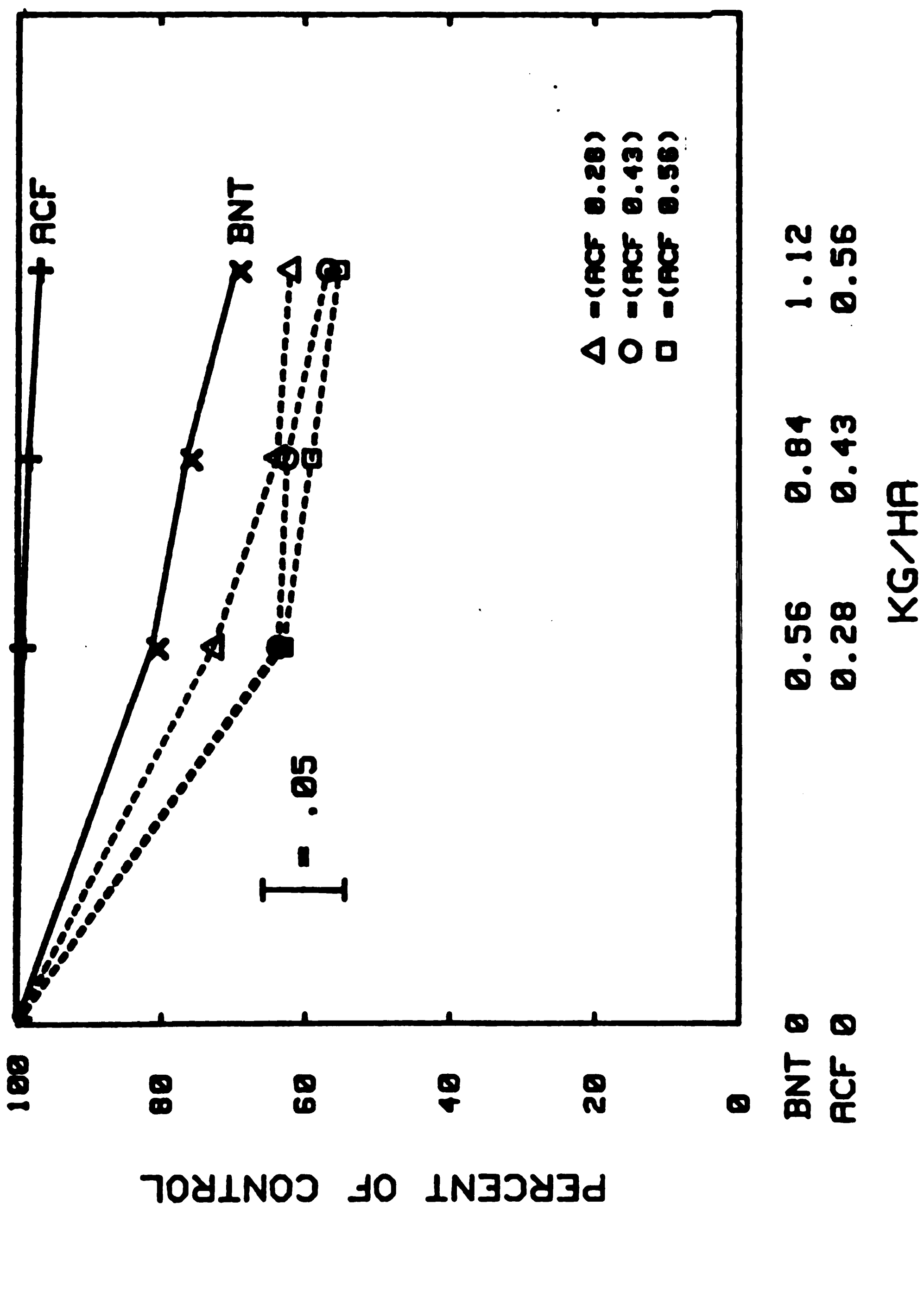
Table 55. Colby's analysis using percent moisture of velvetleaf grown outside.

Acifluorfen	Bentazon	Actual Moisture	Observed (% of control)	Predicted Colby's value	Difference (observed - predicted)	Synergism/ antagonism	LSD
(kg/ha)	(kg/ha)	(%)	(%)				
0.00	0.00	76.33	100.0				
0.00	0.56	61.89	81.1				
0.00	0.84	58.33	76.4				
0.00	1.12	53.11	69.6				
0.28	0.00	75.78	99.3				
0.28	0.56	55.44	72.6	80.5	-7.9*	syn	6.0
0.28	0.84	48.67	63.8	75.9	-12.1*	syn	5.8
0.28	1.12	47.33	62.0	69.1	-7.1*	syn	5.7
0.43	0.00	75.22	98.5				
0.43	0.56	48.56	63.6	79.9	-16.3*	syn	5.8
0.43	0.84	47.67	62.4	75.3	-12.9*	syn	5.7
0.43	1.12	43.33	56.8	68.6	-11.8*	syn	5.6
0.56	0.00	74.00	96.9				
0.56	0.56	48.00	62.9	78.6	-15.7*	syn	5.7
0.56	0.84	45.00	59.0	74.1	-15.1*	syn	5.6
0.56	1.12	42.11	55.2	67.5	-12.3*	syn	5.5

*Significance at the .05 level.

The value of 't' = 1.9901
The value of 'n' = 9
The mean square error = 26.15

Figure 11. Percent moisture of velvetleaf grown outside 10 days following treatment with acifluorfen and bentazon (solid lines) and in all possible combinations (dashed lines) versus the observed percent of control.



PERCENT OF CONTROL
100
80
60
40
20
0
BNT 0
ACF 0
0.56
0.28
0.84
0.43
1.12
0.56
KG/HA
ACF
BNT
= .05
Δ =(ACF 0.28)
O =(ACF 0.43)
□ =(ACF 0.56)

Figure 11

Table 56. The analysis of variance of velvetleaf grown in the greenhouse added on the measured parameters of percent moisture, fresh weight and dry weight as affected by acifluorfen and bentazon with a crop oil concentrate added.

		Significance (* = .05, ** = .01)		
Source	Degrees of freedom	% Moisture	Fresh weight	Dry weight
Replication	2	*	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	-	**	**

Table 57. The effects of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of velvetleaf grown in the greenhouse averaged over the main effects of herbicide.[a]

Rate	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(L/ha)	(%)	(mg)	(mg)
Acifluorfen				
0.00	2.3	62.6 a	336 a	86 a
0.28	2.3	58.3 ab	268 b	81 ab
0.43	2.3	55.6 bc	234 c	78 bc
0.56	2.3	52.6 c	205 c	73 c
Bentazon				
0.00	2.3	75.6 a	512 a	122 a
0.56	2.3	62.2 b	234 b	71 b
0.84	2.3	47.8 c	157 c	63 c
1.12	2.3	43.4 c	140 c	63 c

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 58. The effect of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of velvetleaf grown in the greenhouse averaged over herbicide rates.[a]

Herbicide rate					
Acifluorfen	Bentazon	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(L/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	0.0	78.1 a	641 a	125 a
0.00	0.00	2.3	77.6 a	636 a	142 a
0.00	0.56	2.3	67.0 bc	319 d	77 d
0.00	0.84	2.3	54.6 def	200 ef	62 de
0.00	1.12	2.3	51.1 efg	188 fg	63 de
0.28	0.00	2.3	76.6 ab	525 b	121 b
0.43	0.00	2.3	74.3 ab	493 b	125 b
0.56	0.00	2.3	73.9 ab	392 c	99 c
0.28	0.56	2.3	63.8 cd	264 de	77 d
0.28	0.84	2.3	44.0 gh	151 fg	68 de
0.28	1.12	2.3	48.9 fg	131 fg	60 e
0.43	0.56	2.3	60.8 cde	175 fg	61 de
0.43	0.84	2.3	48.6 fg	145 fg	61 de
0.43	1.12	2.3	38.8 h	123 g	64 de
0.56	0.56	2.3	57.2 def	178 fg	67 de
0.56	0.84	2.3	44.2 gh	131 fg	60 e
0.56	1.12	2.3	35.0 h	117 g	67 de

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Bentazon and combination treatments significantly reduced percent moisture below the control and below acifluorfen applied singly. Some combinations also had significantly lower percent moisture values than the rate of bentazon in the combination applied singly. However, this reduction was not consistent but random and acifluorfen and bentazon interaction was not significant. The significant interactions noted from the fresh and dry weight measurements were considered confounded as the combination rates were never significantly different from the single rate of bentazon. Therefore, a Colby's analysis was not performed. The response of velvetleaf grown in the greenhouse to acifluorfen and bentazon plus a crop oil concentrate was considered additive.

Outside (oil): Velvetleaf grown outside was affected by acifluorfen and bentazon plus a crop oil concentrate by significantly reducing the measured parameters. Interactions of acifluorfen and bentazon were considered highly significant with fresh and dry weight measurements but no interaction was measured with percent moisture (Table 59).

The overall effects of acifluorfen and bentazon plus a crop oil concentrate on velvetleaf grown outside indicated bentazon was more effective than was acifluorfen although all measured parameters were generally reduced significantly (Table 60).

When averaged over individual herbicide treatments, bentazon plus oil significantly reduced all measured parameters below those of acifluorfen plus oil (Table 61). Acifluorfen did not significantly reduce percent moisture values below the control but did significantly reduce fresh and dry weights. The fresh and dry weight values of the combination treatments, however, were always significantly lower than the single rates of acifluorfen but were never significantly lower than the single rate of bentazon in the mix. The only treatments that had

E

A
B

Ta

F

(kg

Aci

0.
0.
0.
0.

Bent.

0.0
0.5
0.8
1.1

aMeans
diffe

Table 59. The analysis of variance of velvetleaf grown outside on the measured parameters of percent moisture, fresh weight and dry weight as affected by acifluorfen and bentazon.

Source	Degrees of freedom	Significance (* = .05, ** = .01) % Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	-
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	-	**	**

Table 60. The effects of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of velvetleaf grown outside averaged over the main effects of herbicide.[a]

Rate	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(L/ha)	(%)	(mg)	(mg)
Acifluorfen				
0.00	2.3	61.6 a	432 a	163 ab
0.28	2.3	60.7 a	428 a	168 a
0.43	2.3	59.2 ab	388 b	156 b
0.56	2.3	57.5 b	380 b	178 ab
Bentazon				
0.00	2.3	64.3 a	647 a	226 a
0.56	2.3	59.9 b	270 b	151 b
0.84	2.3	59.5 b	338 b	143 b
1.12	2.3	55.2 c	274 c	125 c

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 61. The effect of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of velvetleaf grown outside averaged over herbicide rates.[a]

Herbicide rate					
Acifluorfen	Bentazon	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(L/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	0.0	68.1 a	784 a	260 a
0.00	0.00	2.3	66.0 a	771 a	255 a
0.00	0.56	2.3	60.3 bcde	348 def	143 def
0.00	0.84	2.3	63.7 abc	351 de	136 efg
0.00	1.12	2.3	56.2 efg	257 g	116 g
0.28	0.00	2.3	65.0 ab	671 b	233 b
0.43	0.00	2.3	64.9 ab	605 bc	214 bc
0.56	0.00	2.3	61.0 abcde	542 c	204 c
0.28	0.56	2.3	62.0 abcd	403 d	154 de
0.28	0.84	2.3	57.0 defg	333 defg	157 de
0.28	1.12	2.3	58.3 cdef	305 fg	129 fg
0.43	0.56	2.3	60.a bcde	352 de	145 def
0.43	0.84	2.3	58.9 cdef	336 defg	138 defg
0.43	1.12	2.3	52.0 g	260 g	127 fg
0.56	0.56	2.3	57.1 defg	379 de	160 d
0.56	0.84	2.3	58.3 cdef	331 defg	142 def
0.56	1.12	2.3	53.4 fg	270 fg	126 g

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

consistent lower percent moisture values were those that had 1.12 kg/ha of bentazon present, either in combination or alone. The interaction of acifluorfen and bentazon was considered significant when fresh and dry weights were evaluated but both were considered confounded as the combinations did not differ significantly from the single value of bentazon, therefore a Colby's analysis was not performed. The percent moisture values indicated no measured interaction. The response of velvetleaf grown outside to acifluorfen and bentazon with a crop oil concentrate was considered additive.

Soybeans:

Greenhouse: The analysis of variance of soybeans grown in the greenhouse indicated that percent moisture was significantly increased by acifluorfen and bentazon but fresh weights were not affected (Table 62). Acifluorfen significantly reduced dry weight values, where bentazon did not. No interactions were significant over the measured parameters.

When averaged over the main effects of herbicides (Table 63), both acifluorfen and bentazon had higher percent moisture values than the control. The fresh and dry weight values, however, were not significantly different from the control unless the highest rate of both herbicides was present, then the values were significantly reduced.

When averaged over individual herbicide rates, neither acifluorfen nor bentazon applied singly was significantly different from the control when any parameter was compared (Table 64). Fresh weight regardless of rate or combination was never significantly different from the control. Dry weight was significantly lowered only at the highest combined rate of both herbicides. All combined rates of acifluorfen had significantly higher percent moisture values than the control. Since no interaction

Table 62. The analysis of variance of soybeans grown in the greenhouse on the measured parameters of percent moisture, fresh weight and dry weight.

Source	Degrees of freedom	Significance (* = .05, ** = .01) % Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	-	*
Bentazon	3	**	-	-
Acifluorfen x Bentazon	9	-	-	-

Table 63. The effects of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of soybeans grown in the greenhouse averaged over the main effects of herbicide.[a]

Rate	Moisture	Fresh weight	Dry weight
(kg/ha)	(%)	(mg)	(mg)
Acifluorfen			
0.00	79.2 b	2743 a	583 a
0.28	80.4 a	2759 a	547 ab
0.43	80.7 a	2763 a	549 ab
0.56	80.5 a	2611 a	520 b
Bentazon			
0.00	79.1 b	2678 a	574 a
0.56	80.4 a	2784 a	557 ab
0.84	80.8 a	2731 a	536 ab
1.12	80.6 a	2684 a	531 b

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 64. The effect of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of soybeans grown in the greenhouse averaged over herbicide rates.[a]

Herbicide rate		Moisture	Fresh weight	Dry weight
Acifluorfen	Bentazon			
(kg/ha)	(kg/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	78.4 f	2668 a	583 ab
0.00	0.56	79.7 cdef	2919 a	617 a
0.00	0.84	80.0 bcdef	2703 a	552 ab
0.00	1.12	78.8 ef	2682 a	578 abc
0.28	0.00	79.2 def	2672 a	565 abc
0.43	0.00	79.3 def	2686 a	588 ab
0.56	0.00	79.3 def	2686 a	562 abc
0.28	0.56	80.7 abcd	2764 a	540 abc
0.28	0.84	80.6 abcd	2817 a	554 abc
0.28	1.12	81.3 ab	2785 a	530 abc
0.43	0.56	81.2 ab	2940 a	561 abc
0.43	0.84	81.6 a	2719 a	516 bc
0.43	1.12	80.9 abc	2708 a	530 abc
0.56	0.56	80.1 abcde	2512 a	508 bc
0.56	0.84	81.1 ab	2683 a	522 bc
0.56	1.12	81.3 ab	2563 a	487 c

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

was significant a Colby's analysis was not performed. The effect of acifluorfen and bentazon combination on soybeans grown in the greenhouse appears to be additive.

Outside: The analysis of variance of soybeans grown outside indicated that percent moisture was significantly increased by acifluorfen and bentazon but fresh and dry weights were not (Table 65). There were no significant interactions measured.

When averaged over the main effects of herbicides, both acifluorfen and bentazon had percent moistures significantly higher and dry weights significantly lower than the control. Fresh weights were significantly lower than the control only at the highest rates of both herbicides (Table 66).

When averaged over individual herbicide rates (Table 67), dry weight values of each herbicide applied singly were never significantly different from the control. The combination rates, however, significantly decreased dry weight values below the control once more than 0.43 kg/ha acifluorfen was present in the combination. Fresh weight values, regardless of herbicide rate, were significantly different from the control only at the higher combined rates. Percent moisture values were all significantly higher than the control values except for rates of acifluorfen applied singly. Since no interaction was significant, a Colby's analysis was not performed. The effect of acifluorfen and bentazon combination on soybeans grown in the greenhouse appears to be additive.

Greenhouse (oil): The analysis of variance of soybeans grown in the greenhouse treated with acifluorfen and bentazon plus a crop oil concentrate significantly increased percent moisture values (Table 68).

Table 65. The analysis of variance of soybeans grown outside on the measured parameters of percent moisture, fresh weight and dry weight

		Significance (* = .05, ** = .01)		
Source	Degrees of freedom	% Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	**	**
Acifluorfen x Bentazon	9	-	-	-

Table 66. The effects of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of soybeans outside averaged over the main effects of herbicide.[a]

Rate	Moisture	Fresh weight	Dry weight
(kg/ha)	(%)	(mg)	(mg)
Acifluorfen			
0.00	76.9a	2953 a	685 a
0.28	77.6 a	2788 ab	626 b
0.43	77.6 a	2685 bc	601 b
0.56	77.5 a	2594 c	587 b
Bentazon			
0.00	76.1 b	2945 a	709 a
0.56	77.7 a	2821 ab	628 b
0.84	77.9 a	2671 ab	591 bc
1.12	77.9 a	2583 b	571 c

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Ta

Aci
(kg
0
0
0
0.
0.
0.
0.
0.
0.2
0.2
0.4
0.4
0.4
0.5
0.56
0.56

[a]Means
differ

Table 67. The effect of acifluorfen and bentazon on the measured parameters of percent moisture, fresh weight and dry weight of soybeans grown outside averaged over herbicide rates.[a]

Herbicide rate				
Acifluorfen	Bentazon	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	75.6 d	2926 abc	722 a
0.00	0.56	77.1 c	2918 abc	668 abc
0.00	0.84	77.3 bc	2904 abc	689 abcd
0.00	1.12	77.6 abc	3063 a	692 ab
0.28	0.00	76.2 d	2952 ab	707 a
0.43	0.00	76.2 d	2951 ab	704 a
0.56	0.00	76.3 d	2950 ab	701 a
0.28	0.56	78.0 ab	2965 ab	653 abcd
0.28	0.84	78.2 a	2703 abcde	587 cd
0.28	1.12	78.0 ab	2533 cde	556 e
0.43	0.56	77.9 abc	2748 abcd	604 bcde
0.43	0.84	78.2 a	2636 bcde	574 de
0.43	1.12	78.2 a	2404 de	520 e
0.56	0.56	77.9 abc	2651 bcde	585 cde
0.56	0.84	77.8 abc	2441 de	542 e
0.56	1.12	77.9 abc	2333 e	518 e

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

A

T

a

a

app

mo

(Ta

the

Fres

highe

combi

Aciflu

bentaz

interac

effect

concentr

Out

outside w

indicated

71). Acif

dry weight

When a

the percent

increased ra

moisture but

values (Table

Acifluorfen also significantly decreased fresh and dry weight values. There were no significant interactions.

When averaged over main effects of herbicide rates (Table 69), acifluorfen significantly increased average percent moisture values over all rates and bentazon only where 0.84 kg/ha was present.

When averaged over individual herbicide treatments, both herbicides applied singly and all combinations had significantly higher percent moisture values than the control except the lowest rate of bentazon (Table 70). The combinations were seldom significantly different than the components of the combinations when percent moistures were compared. Fresh weight values were significantly less than the control only at the highest rate of acifluorfen and bentazon. All acifluorfen rates and combinations reduced dry weight values significantly below the control. Acifluorfen appears to have a greater effect on soybeans than does bentazon as evidenced by reduced fresh and dry weight values. No interaction was significant so a Colby's analysis was not performed. The effect of acifluorfen and bentazon combinations plus a crop oil concentrate on soybeans grown in the greenhouse appears to be additive.

<u>Outside (oil)</u>: The analysis of variance of soybeans grown outside with a crop oil concentrate present on the measured parameters indicated that percent moisture was influenced only by acifluorfen (Table 71). Acifluorfen and bentazon both had a significant effect on fresh and dry weight measurements as well as a significant interaction terms.

When averaged over main effects, acifluorfen significantly reduced the percent moisture and fresh weight values below the control. Increased rates did not continue to significantly decrease percent moisture but at the highest rate there was reduced fresh and dry weight values (Table 72). Bentazon had no significant effect on percent

Table 68. The analysis of variance of soybean grown in the greenhouse on the measured parameters of percent moisture, fresh weight and dry weight as affected by acifluorfen and bentazon with a crop oil concentrate added.

Source	Degrees of freedom	Significance (* = .05, ** = .01) % Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	**	-	-
Acifluorfen x Bentazon	9	-	-	-

Table 69. The effects of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of soybeans grown in the greenhouse averaged over the main effects of herbicide.[a]

Rate	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(L/ha)	(%)	(mg)	(mg)
Acifluorfen				
0.00	2.3	74.4 b	3398 a	877 a
0.28	2.3	76.3 a	3046 b	727 b
0.43	2.3	76.1 a	2985 b	720 b
0.56	2.3	76.4 a	2906 b	695 b
Bentazon				
0.00	2.3	74.8 b	3093 a	784 a
0.56	2.3	75.3 b	3121 a	779 a
0.84	2.3	76.5 a	3120 a	743 a
1.12	2.3	76.5 a	3000 a	713 a

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 70. The effect of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of soybeans grown in the greenhouse averaged over herbicide rates.[a]

Herbicide rate					
Acifluorfen	Bentazon	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(L/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	0.0	73.8 ef	3430 ab	909 a
0.00	0.00	2.3	73.2 f	3411 ab	945 a
0.00	0.56	2.3	73.7 ef	3531 a	938 a
0.00	0.84	2.3	75.4 bcd	3391 abc	842 b
0.00	1.12	2.3	75.2 cde	3258 abc	813 ab
0.28	0.00	2.3	75.6 bcd	3126 abcd	762 bc
0.43	0.00	2.3	75.1 de	2870 cd	716 bc
0.56	0.00	2.3	75.3 bcd	2966 bcd	741 bc
0.28	0.56	2.3	76.0 abcd	2990 bcd	719 bc
0.28	0.84	2.3	76.9 abc	3049 abcd	705 bc
0.28	1.12	2.3	76.6 abcd	3018 bcd	727 bc
0.43	0.56	2.3	75.9 abcd	3014 bcd	734 bc
0.43	0.84	2.3	76.6 abcd	3053 abcd	728 bc
0.43	1.12	2.3	76.7 abcd	3.004 bcd	702 bc
0.56	0.56	2.3	75.8 bcd	2.951 bcd	727 bc
0.56	0.84	2.3	77.0 ab	2.987 bcd	699 bc
0.56	1.12	2.3	77.6 a	2719 d	614 c

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 71. The analysis of variance of soybeans grown outside on the measured parameters of percent moisture, fresh weight and dry weight as affected by acifluorfen and bentazon with a crop oil concentrate added.

		Significance (* = .05, ** = .01)		
Source	Degrees of freedom	% Moisture	Fresh weight	Dry weight
Replication	2	-	-	-
Acifluorfen	3	**	**	**
Bentazon	3	-	**	**
Acifluorfen x Bentazon	9	-	**	**

Table 72. The effects of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of soybeans grown outside averaged over the main effects of herbicide.[a]

Rate	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(L/ha)	(%)	(mg)	(mg)
Acifluorfen				
0.00	2.3	76.9 a	3091 a	720 a
0.28	2.3	75.3 b	2813 b	714 a
0.43	2.3	76.4 b	2804 b	703 a
0.56	2.3	76.0 b	2519 c	626 b
Bentazon				
0.00	2.3	75.6 a	3156 a	788 a
0.56	2.3	75.6 a	2846 b	701 b
0.84	2.3	76.0 a	2617 c	641 c
1.12	2.3	76.3 a	2609 c	634 c

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

mo

be

the

red

no

than

for

valu

excep

signi

herbi

weight

differ

calcul

crop o

Velvetl

A

the cont

material

rated (Ta

over all

bentazon.

three way

periods.

The re

indicated v

moisture values but significantly reduced fresh and dry weight values below the control. When rates of 0.84 kg/ha of bentazon were present, the average fresh and dry weight values were no longer significantly reduced by increasing the rate of bentazon.

When averaged over the individual herbicide treatments (Table 73), no herbicide applied singly or in combination was significantly lower than the control when percent moistures were compared. Fresh weights for the combinations generally had significantly lower fresh weight values than the control and each herbicide applied singly. The exceptions were random and not consistent. Dry weights were significantly less than the control only at the highest rates of both herbicides applied in combination. The interaction of fresh and dry weight values was considered confounded as they were never significantly different than the components applied singly. Colby's analysis was not calculated. The effect of acifluorfen and bentazon combinations plus a crop oil concentrate on soybeans grown outside was considered additive.

Velvetleaf field study:

A field study using the same combination of treatments utilized in the containers was initiated at Sunfield, Michigan as described in the materials and methods section on velvetleaf. The plots were visually rated (Table 74). The presence of a crop oil had a significant effect over all three rating periods as did the main effects of acifluorfen and bentazon. The interactions between acifluorfen and bentazon and the three way interaction with crop oil was significant at all three rating periods.

The results averaged over the three replications and rating periods indicated velvetleaf was more sensitive to bentazon than acifluorfen with

Table 73. The effect of acifluorfen and bentazon plus a crop oil concentrate on the measured parameters of percent moisture, fresh weight and dry weight of soybeans grown outside averaged over herbicide rates.[a]

Herbicide rate					
Acifluorfen	Bentazon	Crop oil	Moisture	Fresh weight	Dry weight
(kg/ha)	(kg/ha)	(L/ha)	(kg/ha)	(mg)	(mg)
0.00	0.00	0.0	76.5 ab	3228 abc	741 abc
0.00	0.00	2.3	77.1 ab	3226 abc	739 abc
0.00	0.56	2.3	76.9 ab	3287 ab	769 ab
0.00	0.84	2.3	76.9 ab	2885 bcde	671 bc
0.00	1.12	2.3	76.5 abc	2966 bcd	703 bc
0.28	0.00	2.3	74.6 bc	2971 bcd	783 bc
0.43	0.00	2.3	75.3 bc	3428 a	866 a
0.56	0.00	2.3	75.3 bc	2998 bcd	762 abc
0.28	0.56	2.3	75.2 bc	2759 de	686 bc
0.28	0.84	2.3	75.8 abc	2798 cde	693 bc
0.28	1.12	2.3	75.4 abc	2726 de	696 bc
0.43	0.56	2.3	75.1 bc	2484 ef	627 cd
0.43	0.84	2.3	75.6 abc	2669 de	665 bc
0.43	1.12	2.3	75.8 abc	2635 de	655 bcd
0.56	0.56	2.3	75.4 abc	2852 cde	722 bc
0.56	0.84	2.3	75.7 abc	2115 f	537 de
0.56	1.12	2.3	77.4 a	2109 f	482 e

[a]Means in the same column with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Tab

COC
BNT[1]
ACF[1]
BNT[1]
COC

[1]DAT
crop

Table 74. Velvetleaf control at Sunfield using combinations of acifluorfen and bentazon with and without a crop oil concentrate. Ratings were taken 3, 10, 21 days after treatment.

	Statistics		
	3 DAT[1]	10 DAT[1]	21 DAT[1]
COC[1]	**	**	**
BNT[1]	**	**	**
ACF[1]	**	**	**
BNT[1] X ACF[1]	**	**	**
COC X BNT X ACF[1]	**	**	**

[1]DAT = Days after treatment, BNT = bentazon, ACF = acifluorfen, COC = crop oil concentrate.

c

c

c

ac

be

ber

the

sign

acif

than

when

acifl

rate o

highest

control

The

containe

increased

significa

velvetlea

alone but

and without a crop oil concentrate (Table 75). Increasing rates of acifluorfen and bentazon increased phytotoxicity. Combinations at the early ratings were not significantly different from the single rate of bentazon present in the mix regardless of whether or not a crop oil was present.

The results 10 days after application indicated that a crop oil concentrate significantly influenced control overall. Increasing rates of both herbicides generally increased control with or without a crop oil concentrate. Velvetleaf was more sensitive to bentazon than to acifluorfen. The combinations were generally not rated significantly better than the single rate of bentazon in the mix. The lower rates of bentazon (0.56 kg/ha) were more often helped by the combination than were the higher rates of bentazon.

The results 21 days after treatment indicated that crop oil significantly increased herbicide activity on velvetleaf, although acifluorfen appeared to be more influenced by the crop oil concentrate than did bentazon. Bentazon was rated more effective than acifluorfen when applied singly. The combinations were consistently better than acifluorfen applied singly, but generally were not much better than the rate of bentazon in the mix applied singly. The exception was the highest rate of both acifluorfen and bentazon gave the highest consistent control.

The results from the field test were similar to those in the container grown plants in that the addition of a crop oil concentrate increased control over no crop oil concentrate. Bentazon also was significantly more effective than was acifluorfen in controlling velvetleaf. The combinations were generally better than acifluorfen alone but not always better than rate of bentazon in the mix. The

Ta

He

Ac
0
.28
.43
.56
0
0
0
.28
.28
.28
.43
.43
.43
.56
.56
.56
0
.28
.43
.56
0
0
0
.28
.28
.28
.43
.43
.43
.56
.56
.56

Table 75. Velvetleaf contraol at Sunfield using combinations of acifluorfen and bentazon with and without a crop oil concentrate. Ratings were at 3, 10 21 DAT (days after treatment) where 0 = no control and 100 = total plant death.

Herbicide rate (kg/ha)		Crop Oil	% Control - Visual Ratings		
Acf	Bnt	(L/ha)	3 DAT	10 DAT	21 DAT
0	0	0	0 k	0 l	0 i
.28	0	0	18.3 j	23.3 k	13.3 i
.43	0	0	36.7 i	35.0 j	16.7 i
.56	0	0	48.3 gh	40.0 ij	16.7 i
0	.56	0	70.0 f	50.0 ghi	40.0 h
0	.84	0	82.7 cde	55.0 efgh	43.3 fgh
0	1.12	0	82.7 cde	70.0 abcd	52.7 defgh
.28	.56	0	80.0 de	65.0 cdef	50.0 defgh
.28	.84	0	85.0 bcde	65.0 cdef	60.0 cdefg
.28	1.12	0	86.7 abcde	70.0 abcde	48.3 defgh
.43	.56	0	78.3 e	50.0 ghi	45.0 efgh
.43	.84	0	83.3 cde	66.7 bcdef	50.0 defgh
.43	1.12	0	86.7 abcde	70.0 abcd	40.0 h
.56	.56	0	80.0 de	65.0 cdef	50.0 defgh
.56	.84	0	82.7 cde	65.0 cdefe	40.0 h
.56	1.12	0	87.7 abcd	65.0 cdef	56.7 defgh
0	0	2.3	0 k	0 l	0 i
.28	0	2.3	41.7 hi	46.7 hij	41.7 hi
.43	0	2.3	50.0 g	53.3 fgh	41.7 hi
.56	0	2.3	70.0 f	40.0 ij	45.0 efgh
0	.56	2.3	80.3 abcd	60.0 defgh	42.7 gh
0	.84	2.3	85.0 bcde	66.7 bcdef	50.0 defgh
0	1.12	2.3	92.7 abc	75.0 abc	60.0 cdefg
.28	.56	2.3	80.0 de	65.0 cdef	46.7 efgh
.28	.84	2.3	88.3 abcd	73.3 abcd	56.7 defgh
.28	1.12	2.3	90.0 abc	75.0 abc	63.3 bcde
.43	.56	2.3	90.0 abc	77.7 abc	67.7 bcd
.43	.84	2.3	90.0 abc	78.3 abc	76.7 abc
.43	1.12	2.3	92.7 ab	80.0 ab	67.7 bcd
.56	.56	2.3	92.7 ab	68.3 bcde	62.0 bcdef
.56	.84	2.3	95.0 ab	80.0 ab	80.0 ab
.56	1.12	2.3	95.0 a	83.3 a	86.7 a

comb

incr

comb

combinations helped bentazon only at the lowest rates and decreased with increasing rates of bentazon. The highest rates of both herbicides in combination plus a crop oil concentrate were always the most effective.

la

sou

the

of

cro

inc

for

All

expo

0.28,

conce

redro

random

recomm

plant.

simula

CHAPTER 3

DROPLET SIZE AS INFLUENCED BY ACIFLUORFEN, BENTAZON AND CROP OIL

INTRODUCTION

To determine whether the interactions measured on common lambsquarters, redroot pigweed, jimsonweed and velvetleaf were due to some internal physiological factor or to some external factor caused by the herbicide combinations, a comparison was made measuring the effects of acifluorfen and bentazon alone and in combination with and without a crop oil concentrate on the physical diameter of a 2 μl droplet. An increased surface area induced by the herbicide or herbicides would allow for more surface-herbicide contact and thus, increase the treated area. All things being equal, it would be logical to assume that a herbicide exposing the greatest plant area would be more effective.

MATERIALS AND METHODS

The experiment was a four factor factorial with acifluorfen (0, 0.28, 0.43, 0.56 kg/ha), bentazon (0, 0.56, 0.83, 1.12 kg/ha), crop oil concentrate (0, 2.3 L/ha), and weed species (common lambsquarters, redroot pigweed, jimsonweed and velvetleaf) arranged in a completely randomized factorial design. The plants were grown to maximum height recommended by the label and leaves were selected at random from each plant. Herbicides were mixed in equivalent application volumes to simulate the previous interaction study application rate of 355 L/ha of water. A microliter syringe was used to apply a 2 µl droplet to two locations on each leaf. Two fully expanded leaves were selected at random from each plant and 2 random plants from each of the four weed species. The droplets were allowed to spread approximately 30 seconds after the application and then the diameter of the droplet was measured through a dissecting light microscope using an ocular micrometer.

RESULTS AND DISCUSSION

The effect of acifluorfen when averaged over each rate indicated a significant increase in droplet size from the lowest to the highest rate of acifluorfen compared to when no acifluorfen was present as measured by Duncan's Multiple Range Test (Table 76). When overall mean rates of bentazon were compared they were significantly less than the control but also increased in diameter from lowest to highest rate as compared by the Duncan's multiple range test. These overall averages are used for comparison only as they are gross averages over all rates of herbicide, oil and weed species. The interaction of acifluorfen x bentazon appeared to be confounded as no single rate or combination of rates significantly increased the droplet size more than any other except for acifluorfen at 0.28 and 0.56 kg/ha applied singly.

The calculated significant effect of acifluorfen was closely analyzed. Individual analysis of variances were run with each weed species at each rate to try to determine where the significant effect of acifluorfen occurred. The individual analysis of variance showed the effect of acifluorfen on droplet size was a random variable occurring at random rates across weed species and never in consistent order or rate. The significant effect of acifluorfen measured in the analysis of

Table

Source
Replic
Aciflu
Bentaz
A x B
Crop o
A x O
B x O
A x B
Weed s
S x A
S x B
S x A
S x O
S x A
S x B
S x A
Error

Table 76. The analysis of variance summary of the effect of herbicide, crop oil and weed species on droplet spreadability.

Source	Degrees of freedom	Mean Square	95%	99%
Replications	1	.32		
Acifluorfen (A)	3	14.1	*	**
Bentazon (B)	3	4.44		
A x B	9	9.71	*	**
Crop oil (O)	1	14235	*	**
A x O	3	1.26		
B x O	3	5.57		
A x B x O	9	4.6		
Weed species (S)	3	816.8	*	**
S x A	9	23.6	*	**
S x B	9	6.0		
S x A x B	27	5.6	*	
S x O	3	124.1	*	**
S x A X O	9	2.4		
S x B x O	9	9.37	*	**
S x A x B x O	27	7.10	*	**
Error	127	3.16		

variance was considered confounded and therefore, not considered significant.

Crop oil had a significant effect on droplet diameter. The average increase over all species and rates when a crop oil concentrate was 34 percent. Each individual plant species responded differently to the crop oil but all had a significant increase in droplet size regardless of herbicide rate or combination. The increase in droplet diameter averaged over all herbicide rates for common lambsquarters, redroot pigweed, jimsonweed and velvetleaf was 53, 27, 28, and 41 percent respectively when a crop oil concentrate was added.

Plant species had a significant effect on droplet size. When overall averages were compared droplet size increased significantly from common lambsquarters > redroot pigweed > jimsonweed > velvetleaf.

A species x acifluorfen interaction was significant but was considered confounded as the only consistent pattern was that common lambsquarters had the smallest droplet diameters regardless of acifluorfen rate. The response of the other species was more or less random. The large effect due to species may have added to the term being considered significant.

Species x oil interaction was considered significant. There was a change in the species order when overall averages were compared. When no oil was present droplet size increased from common lambsquarters > redroot pigweed > jimsonweed > velvetleaf. If a crop oil concentrate was present the overall increase in droplet size was from redroot pigweed > common lambsquarters = jimsonweed > velvetleaf.

The three way interaction of species x bentazon x oil was significant. This interaction was considered confounded as the individual ANOVA's indicated droplet size was not significantly different

a

e

c

Th

su

ir

cr

in

in

he

to

cor

inc

not

spe

The

size

It ap

the f

with increasing rates of herbicides within weed species. Oil consistently increased the droplet size regardless of species but never significantly within herbicide or herbicide rate combinations. Since there was a size difference in droplet diameter from species to species and from no oil to oil a large portion of this three way error can be explained as there was no significance difference noted due to bentazon or acifluorfen rates singly or in combination.

CONCLUSION

Crop oil concentrate significantly increased droplet diameter. The increased diameter of the droplet increased the amount of plant surface exposed to the herbicide and this increase was measured in increased herbicide damage over all weed species tested compared to no crop oil concentrate present. Crop oil concentrate may influence an interaction measured between two herbicides if the interaction occurred internally in the plant and uptake was increased by increased exposure to herbicide through larger droplets. If the weed species is more sensitive to one herbicide in the combination than the other, then a crop oil concentrate could increase the uptake of the more sensitive herbicide by increasing the exposure area and the interaction would be less noticeable.

Species influenced droplet size due to physical plant features. All species tested had an increase in droplet size with the addition of oil. The droplet size increase varied with plant species.

Acifluorfen and bentazon had no significant influence on droplet size regardless of rate or combinations used or weed species involved. It appears likely that the measured interactions are not likely due to the impact of acifluorfen and bentazon on the physical size and diameter of the droplets. Crop oil concentrate does affect the interactions measured and it appears to have its action by exposing more plant surface to the herbicide or increasing droplet size. A plant species physical features may also be a factor as each species responds differently to whether or not a crop oil is present.

1
a
c
((
s
ap
ef
no
wo
on
ph
to
by
car
3)

Pigw
been

CHAPTER 4

RADIOLABELED UPTAKE STUDY

INTRODUCTION

An interaction was measured when four weed species i.e. common lambsquarters, jimsonweed, redroot pigweed, and velvetleaf, were grown in a greenhouse situation. The interaction was measured over all the combined rates of acifluorfen (0, 0.28, 0.43, 0.56 kg/ha) and bentazon (0, 0.56, 0.84, 1.12 kg/ha). The herbicides were shown to have no significant effect on the physical diameter of a 2 μl droplet either applied singly or in any herbicide combination. This lack of physical effect on droplet diameter, indicates that the combined application would not expose a greater surface area of the plant to the herbicide than would each herbicide applied alone. A possible explanation may be that one herbicide influences the uptake of the other due to some physiological aspect in the plant system. The purpose of this study was to determine 1) if uptake of acifluorfen and bentazon can be influenced by combinations over each herbicide applied alone, 2) if translocation can be influenced by a combination over each herbicide applied singly and 3) if interactions can be explained on the basis of uptake differences.

MATERIALS AND METHODS

The weed species common lambsquarters, jimsonweed, redroot pigweed, and velvetleaf were grown in the greenhouse. An interaction had been measured with each weed species grown in that situation. Each weed species was grown under conditions similar to those for the interaction study described in Chapter 2.

The labeled acifluorfen was obtained from Rohm and Haas Company. It was uniformly labeled on the second benzene ring or the ring containing the nitrogen group. The acifluorfen was formulated in a 10.75 percent aqueous solution with a specific activity of 3.32 mCi/g. In order to apply the equivalent of 0.28 kg/ha of acifluorfen equivalent, the radiolabeled acifluorfen was diluted to .00931 microcuries per dose or approximately 20,670 d.p.m. (disintegration per minute).

The labeled bentazon was obtained from BASF Company. It was labeled uniformly on the phenyl ring. The specific activity of the bentazon was 13.7 mCi/mMole and was prepared by dissolving the labeled material in a 0.02 molar solution of NaOH to form the Na salt of bentazon. In order to apply the equivalent of 0.56 kg/ha of bentazon, the radiolabeled bentazon was diluted to .1599 microcuries per dose or approximately 350,000 d.p.m. The combined applications were made by mixing one labeled herbicide with the technical grade of the other, both in ratios to equal field applications and brought up to the equivalent field volume by adding water. This mixture was then applied to the one square centimeter area in 4 microliters to approximate the kg/ha use rate in 400 L/ha of diluent. The technical grade herbicide will be referred to as the cold or non-labeled treatment.

The experimental design was a completely randomized three factor factorial with a split. The main factors acifluorfen and bentazon were split by time. Each experimental unit was a weed species, with four treatments and four replications. Each experiment was repeated twice. The four treatments were 1) ^{14}C acifluorfen (0.28 kg/ha equivalent), 2) ^{14}C acifluorfen (0.28 kg/ha equivalent) plus cold-bentazon (0.56 kg/ha),

[illegible]

f

r

p

m

t

mi

le

le

ba

at

the

tre

(be

3) ^{14}C bentazon (0.56 kg/ha equivalent), 4) ^{14}C bentazon (0.56 kg/ha) equivalent) plus cold-acifluorfen (0.28 kg/ha) equivalent). Each plant had one treated leaf and was considered one replication. The leaf treated on each species was the first fully expanded leaf below the shoot apex. The treated area was about three-quarters of the distance from the leaf base to the leaf tip and was an area one centimeter square. Each treatment was applied in eight one-half microliter drops within the square centimeter. Following treatment, the plants were placed under sodium-halide lights emitting 250 $\mu E\ m^{-2}\ sec^{-1}$ and rerandomized daily for five days before harvest. The plants were also exposed to the natural sunlight available after the treatment time.

The plants at treatment were at the maximum leaf and growth stage as recommended by the herbicide label and similar to those grown in the interaction study (Chapter 2). The plants were rated for visual herbicide damage and harvested five days following treatment.

At harvest, the centimeter square treated area was excised and placed in ten milliliters of a 90:10 distilled water:methanol wash for one minute. The excised leaf was allowed to air dry for approximately four to five minutes before being washed in a 10 chloroform wash for one minute. The plant was divided into five sections: 1) the leaf tip or all leaf tissue remaining from the treated area to the tip of the treated leaf (tip), 2) the treated area or the centimeter square (cm^2), 3) leaf base or remaining tissue from the treated area to where the petiole attached to the plant main stem (base), 4) above the treated leaf or from the point of petiole attachment to the growing apex (above), 5) below the treated leaf or from the point of petiole attachment to the soil surface (below). All harvested parts were placed in a freezer at -18°C for 48 h.

The samples were then freeze dried for 48 h and kept in the freezer until analyzed.

The water:methanol and chloroform washes were placed on a N-vaporator and evaporated to dryness by compressed air, filtered through an activated charcoal and an anhydrous $CaSO_4$ filter. After being completely dried each wash was redissolved with water:methanol or chloroform using one or one-half ml respectively. After a one minute shaking period to redissolve the label, 15 ml of Safety-Solve scintillation cocktail was added to the redissolved washes and the vials were again shaken for one minute. The vials were immediately counted on a LS-100 scintillation counter.

The plant parts were individually oxidized in an OX-200 biological oxidizer made by R.J. Harvey Instrument Company. The combustion furnace was maintained between 750 to 900°C and the CO_2 gas was trapped in a 2:1 mixture of Safety-Solve scintillation cocktail and Carbo Sorb II organic amine CO_2 trapper. The combustion period was for four minutes. An efficiency test was performed at the beginning and end of each oxidation period with an average efficiency of about 93 percent.

The samples were counted on a Beckman LS-100 scintillation counter. Each sample was counted once for a maximum of 10 minutes.

During the first experiment in January and February, plants received light mainly from the high pressure sodium-halide lamps. The light was measured at 250 $\mu E\ m^{-2}\ sec^{-1}$ for a 15 h photoperiod. During the second experiment on common lambsquarters and redroot pigweed, in addition to the halide lamps, the plants received increased natural sunlight a maximum of 450 $\mu E\ m^{-2}\ sec^{-1}$ for approximately a four to five h period and an increased day length. The normal greenhouse temperature was also increased above the normal 23° to 29°C.

The total amount of recovered label from all washes and plant parts was generally 90-94 percent. Each analysis of variance was run using the arc-sine transformation of the percent total recovered label.

Each weed species will be discussed individually. Within each weed species the results of the ANOV will be discussed as it relates to each labeled herbicide individually and the effect on the labeled herbicide by the combination. A summary will be included at the end of each weed species.

RESULTS AND DISCUSSION

A preliminary uptake study was completed to determine the amount of time required for maximum uptake and translocation of acifluorfen and bentazon. Uptake and translocation of labeled material found in the leaf base, tip, and chloroform wash generally did not increase with time regardless of herbicide used. The treated area, regardless of species or herbicide used, increased the amount of radiolabeled herbicide taken up with time, generally about 2 percent per day. The recovered label in the water:methanol wash, decreased with time proportionally to that which was recovered in the treated area. Five days appeared to be a suitable time period that would provide for maximum uptake of both herbicides.

Common lambsquarters:

The analysis of variance indicated a significant response due to the main effects of treatment and plant part. Significant interactions were also measured for time x treatment, time x plant part, plant part x treatment, and time x treatment x plant part.

The time x treatment interaction showed an increase of ^{14}C acifluorfen uptake from time 1 to time 2 when applied singly but no effect when bentazon was added.

^{14}C acifluorfen: The time x plant part interaction indicated that when time 1 was compared to time 2 no significant change occurred with respect to the amount of herbicide label recovered in the leaf tip, base, tissue above or below the treated leaf, nor in the chloroform wash. The amount of label recovered in the water: methanol wash, however, decreased from 60 to 32 percent and the amount recovered in the treated area increased from 35 to 56 percent. This increase in uptake from time 1 to time 2 is attributed to the bright sunny days and increased greenhouse temperature that occurred during the second experimental period. The treatment x plant part interaction means indicated, when bentazon was added to the ^{14}C acifluorfen, movement of the labeled acifluorfen did not change significantly in the leaf tip, base, above or below the treated leaf nor did the amount recovered by the chloroform wash increase (Table 77). However, the amount of ^{14}C-labeled acifluorfen that was recovered in the treated area was significantly reduced when bentazon was added to the ^{14}C acifluorfen compared to the ^{14}C acifluorfen applied alone and the amount of label recovered by the water:methanol wash was increased proportionally.

The 3-way interaction of time x treatment x plant part, which was also significant, indicated that when the experiment was performed under lower light and temperature values (time 1) the uptake differences between ^{14}C acifluorfen and ^{14}C acifluorfen with bentazon were not significantly different when the treated areas or the water:methanol washes were compared. However, under the higher light and temperature values of the second experiment, the uptake of the ^{14}C acifluorfen applied alone in the treated area was significantly increased by 28 percent over the ^{14}C acifluorfen plus bentazon. The ^{14}C acifluorfen uptake in the treated area when bentazon was present under the higher

p
a
a
r
a

th
tr
th
ch
ac
tre
app

light and temperature values was not significantly different from those of the lower light values of the first experiment. The only significant change in label recovery from time 1 to time 2 was an increase in uptake of ^{14}C acifluorfen in the treated area and the proportional decrease of ^{14}C acifluorfen in the water:methanol wash.

The effect of treatments was significant and indicated that there was a significant decrease in uptake of ^{14}C labeled acifluorfen when bentazon was added.

^{14}C Bentazon: The time x treatment interaction indicated that the ^{14}C bentazon and ^{14}C bentazon plus acifluorfen did not change significantly from time 1 to time 2 when overall means are compared. However, the amount of ^{14}C bentazon that was measured was significantly reduced by 3 percent in both time periods when acifluorfen was added to the labeled bentazon treatment.

The plant part x treatment interaction showed a significant 5 percent increase in uptake of ^{14}C bentazon in the treated area when acifluorfen was present (Table 77). The plant parts i.e. leaf tip, base and above or below the treated leaf, were not significantly changed with respect to the amount of ^{14}C bentazon recovered when acifluorfen was added.

The three way interaction of time x treatment x plant part indicated that there was a 36 percent increase in ^{14}C bentazon taken up in the treated area with a proportional decrease in the water:methanol wash with the increase in light from time 1 to time 2. All other plant parts and chloroform wash did not change significantly from time 1 to time 2. When acifluorfen was present, the increase in ^{14}C bentazon uptake in the treated area from time 1 to time 2 was a significant 12 percent. If applied alone, the uptake increased a significant 35 percent and there

Table 77. The treatment x plant part interaction means of percent recoverable labeled acifluorfen and bentazon as separated by Duncan's multiple range test on common lambsquarters.

Treatment[1]	Plant Part[2]	Percent Recovered	Arc-Sine	Duncan's
^{14}C Acf	Tip	1	.75	e
"	H_2O	39	22.79	d
"	Chl	3	1.96	e
"	Cm^2	56	34.38	a
"	Base	1	.78	e
"	Above	1	.35	e
"	Below	1	.35	3
^{14}C Acf + Bnt	Tip	2	1.00	e
"	H_2O	54	32.59	a
"	Chl	3	1.46	e
"	Cm^2	41	24.21	bcd
"	Base	1	.31	e
"	Above	.4	.25	e
"	Below	.4	.24	e
^{14}C Bnt	Tip	6	3.38	e
"	H_2O	47	28.15	b
"	Chl	1	.80	e
"	Cm^2	45	27.04	bc
"	Base	1	.70	e
"	Above	1	.63	e
"	Below	1	.45	e
^{14}C Bnt + Acf	Tip	7	3.88	e
"	H_2O	46	27.41	bc
"	Chl	2	1.0	e
"	Cm^2	40	23.53	cd
"	Base	2	1.35	e
"	Above	2	1.25	e
"	Below	2	1.09	e

[1]Treatments: ^{14}C Acf = ^{14}C labeled acifluorfen
^{14}C Acf + Bnt = ^{14}C labeled acifluorfen + unlabeled bentazon
^{14}C Bnt = ^{14}C labeled bentazon
^{14}C Bnt + Acf = ^{14}C labeled bentazon + unlabeled bentazon

[2]Plant parts:
Tip = Tip of treated leaf
H_2O = Water:methanol wash
Chl = Chloroform wash
Cm^2 = Treated area
Base = Base of treated leaf
Above = Plant tissue above the treated leaf
Below = Plant tissue below the treated leaf

was proportional decrease in the water:methanol wash. There was no significant change in the other plant parts or chloroform wash. The comparison of treatments indicated that there was no significant effect of acifluorfen on ^{14}C bentazon uptake in time 1. However, there was a significant decrease in ^{14}C bentazon uptake when acifluorfen was present in time 2.

The main effect of treatments was significant. The overall means indicated that there was a significant decrease in uptake of ^{14}C bentazon when acifluorfen was present.

Conclusion: The increase in light from time 1 to time 2 significantly increased the uptake of both labeled herbicides applied singly. Both herbicides showed reduced label uptake whenever used in combination with the other regardless of light intensity. The uptake differences were restricted to the treated area.

Jimsonweed:

The analysis of variance indicated a highly significant response of the main effects treatment and plant part. The interactions that were highly significant included time x treatment, time x plant part, treatment x plant part and time x treatment x plant part. The time x plant part interaction indicates that there was a significant increase in the uptake of herbicide from time 1 to time 2. The amount recovered in the water:methanol wash also decreased proportionally to the increased uptake of the treated area.

^{14}C acifluorfen: The time x treatment interaction showed a significant increase in the amount of ^{14}C acifluorfen recovered when bentazon is added compared to ^{14}C acifluorfen applied alone over both time periods.

The treatment x plant part means indicated there was an increase in the amount of ^{14}C acifluorfen recovered in the water:methanol wash when bentazon was added and a concurrent increase in ^{14}C acifluorfen recovered in the treated area when acifluorfen was applied singly as compared to the treatment when bentazon was added but the difference was not significant.

The three-way interaction of time x treatment x plant part shows that the amount of ^{14}C acifluorfen being recovered in the water:methanol wash increased whenever bentazon was added. There was also a corresponding increase in measured uptake of ^{14}C acifluorfen in the treated area when no bentazon was present, but the increase was never significant.

<u>^{14}C bentazon:</u> The time x treatment interaction indicated that the ^{14}C bentazon recovered did not change significantly if acifluorfen was added in time 1. In time 2 the amount of ^{14}C bentazon significantly increased when acifluorfen was present. This was probably due to the higher amount of ^{14}C bentazon recovered in the water:methanol wash and not an increase in uptake.

The treatment x plant part means indicated there was a significant increase in the amount of ^{14}C bentazon in the water:methanol wash when acifluorfen was present (Table 78). Conversely, there was a significant increase in ^{14}C bentazon recovered from the treated area when no acifluorfen was present.

The three way interaction of time x treatment x plant part shows that the amount of ^{14}C bentazon in the water:methanol wash significantly decreased from time 1 to time 2. There was a corresponding increased ^{14}C bentazon uptake measured in all plant parts, the increase, however, was not significant. The increase in uptake in time 2 was probably due to the increase in light intensity and temperature over time 1. The uptake

Table 78. The treatment x plant part interaction means of percent recoverable labeled acifluorfen and bentazon as separated by Duncan's multiple range test on jimsonweed.

Treatment[1]	Plant Part[2]	Percent Recovered	Arc-Sine	Duncan's
^{14}C Acf[1]	Tip	.26	.15	e
"	H_2O	94	69.79	b
"	Chl	2	1.35	e
"	Cm^2	4	2.13	de
"	Base	.35	.20	e
^{14}C Acf + Bnt	Tip	1	.58	e
"	H_2O	97	75.74	a
"	Chl	1	.45	e
"	Cm^2	2	1.1	e
"	Base	.46	.26	e
^{14}C Bnt	Tip	2	1.09	e
"	H_2O	92	67.31	c
"	Chl	1	.40	e
"	Cm^2	7	3.78	d
"	Base	1	.68	e
^{14}C Bnt + Acf	Tip	1	.53	e
"	H_2O	95	71.25	b
"	Chl	1	.7	e
"	Cm^2	3	1.61	e
"	Base	1	.61	e

[1]Treatments: ^{14}C Acf = ^{14}C labeled acifluorfen
^{14}C Acf + Bnt = ^{14}C labeled acifluorfen + unlabeled bentazon
^{14}C Bnt = ^{14}C labeled bentazon
^{14}C Bnt + Acf = ^{14}C labeled bentazon + unlabeled bentazon

[2]Plant parts:
Tip = Tip of treated leaf
H_2O = Water:methanol wash
Chl = Chloroform wash
Cm^2 = Treated area
Base = Base of treated leaf

s

a

f

R

tr

x

we

ti

in the treated area was significantly greater when bentazon was applied singly.

The main effects of treatments was highly significant. The means indicated that the combinations had higher uptake values than either herbicide applied singly. This is somewhat a misnomer as the higher values of the water:methanol washes are reflected in the averages. Decreases in water:methanol wash values were not offset by increases in the uptake of labeled material into plant parts. There was no significant difference measured in any plant part except ^{14}C bentazon applied alone to the treated area had a significantly higher value than when acifluorfen was present.

Conclusion: The uptake of labeled herbicide by jimsonweed was extremely limited as most (94 percent) was recovered in the water: methanol wash. Acifluorfen uptake did not appear to be influenced by the presence of bentazon although bentazon did increase the amount of acifluorfen label in the water:methanol wash if it were present. The ^{14}C acifluorfen recovered from all plant parts was not significantly changed if bentazon were present. Labeled bentazon uptake, however, was significantly influenced by the presence of acifluorfen. When no acifluorfen was present the uptake of ^{14}C bentazon was significantly increased (4 percent) compared to when acifluorfen was added.

Redroot pigweed:

The analysis of variance indicated that the main effects of treatment and plant part were highly significant. The interactions time x treatment, treatment x plant part, and time x treatment x plant part were also highly significant. There was a significant difference between time 1 and time 2, due probably to the intensity of the sunlight and

a

t
1

f

b

79

pr

pa

inf

ben

aci

hig

acif

bent

wate

benta

temperature that was present following the herbicide treatments in time 2. The only plant parts or washes significantly different from time 1 to time 2 were the water:methanol wash and the treated area (cm^2).

<u>^{14}C acifluorfen</u>: The time x treatment interaction indicated that there was a significant decrease in overall ^{14}C acifluorfen measured when bentazon was present under the lower light and temperature of time 1. Conversely, There was a mean increase in overall ^{14}C acifluorfen measured if bentazon was present under the higher light and temperature values of time 2. This is probably due to the increased uptake in label in all plant parts. However, only the water:methanol wash and treated area was significantly changed.

The treatment x plant part interaction indicated that when treatments were averaged over time there was a significant decrease in ^{14}C acifluorfen recovered in the treated area and a corresponding increase of ^{14}C acifluorfen recovered in the water:methanol wash if bentazon was present compared to ^{14}C acifluorfen applied alone (Table 79). No other plant part or wash was significantly influenced by the presence of bentazon.

The time x treatment x plant part interaction showed that no plant part or wash other than the treated area and the water:methanol wash was influenced by the addition of bentazon. In time 1 the addition of bentazon significantly increased by 10 percent the amount of ^{14}C acifluorfen recovered in the treated area. However, in time 2 under higher light intensities the converse was true, the amount of ^{14}C acifluorfen recovered in the treated area decreased by 23 percent when bentazon was present. The amount of ^{14}C acifluorfen recovered in the water:methanol washes were respectively decreased and increased when bentazon was added to the ^{14}C acifluorfen proportionally to the amount

Table 79. The treatment x plant part interaction means of percent recoverable labeled acifluorfen and bentazon as separated by Duncan's multiple range test on redroot pigweed.

Treatment[1]	Plant Part[2]	Percent Recovered	Arc-Sine	Duncan's
^{14}C Acf[1]	Tip	1	.44	g
"	H_2O	67	42.45	b
"	Chl	6	3.48	g
"	Cm^2	29	17.15	e
"	Base	.3	.19	g
"	Above	.4	.24	g
"	Below	1	.36	g
^{14}C Acf + Bnt	Tip	1	.32	g
"	H_2O	78	48.54	a
"	Chl	2	1.00	g
"	Cm^2	22	12.91	f
"	Base	.3	17.50	g
"	Above	.4	.20	g
"	Below	.5	.26	g
^{14}C Bnt	Tip	5	2.71	g
"	H_2O	53	31.90	c
"	Chl	1	.29	g
"	Cm^2	40	23.44	d
"	Base	1	.79	g
"	Above	1	.61	g
"	Below	1	.60	g
^{14}C Bnt + Acf	Tip	6	3.71	g
"	H_2O	33	19.45	e
"	Chl	1	.63	g
"	Cm^2	51	30.40	c
"	Base	4	2.1	g
"	Above	32	1.44	g
"	Below	2	1.39	g

[1]Treatments: ^{14}C Acf = ^{14}C labeled acifluorfen
^{14}C Acf + Bnt = ^{14}C labeled acifluorfen + unlabeled bentazon
^{14}C Bnt = ^{14}C labeled bentazon
^{14}C Bnt + Acf = ^{14}C labeled bentazon + unlabeled bentazon

[2]Plant parts:
Tip = Tip of treated leaf
H_2O Water:methanol wash
Chl = Chloroform wash
Cm^2 = Treated area
Base = Base of treated leaf
Above = Plant tissue above the treated leaf
Below = Plant tissue below the treated leaf

recovered in the treated area. No other wash or plant part was significantly influenced by the addition of bentazon as measured by ^{14}C acifluorfen recovery.

^{14}C bentazon: The time x treatment interaction indicated that there was a significant decrease in the overall amount of ^{14}C bentazon measured when acifluorfen is present in time 1. In time 2 the presence of acifluorfen had no significant effect on ^{14}C bentazon.

The treatment x plant part interaction indicated when treatments were averaged over time, there was a significant 11 percent increase in the amount of ^{14}C bentazon measured in the treated area and a proportional decrease in the water:methanol wash if acifluorfen were present, as compared to when ^{14}C bentazon was applied alone. No other plant part or wash was significantly influenced by the presence of acifluorfen.

The time x treatment x plant part interaction indicated that only the water:methanol wash and the treated area (cm^2) were significantly influenced by treatment or time. In time 1 under lower light values and in time 2 under higher light values, there was a significant, 10 and 12 percent respective increase of ^{14}C bentazon and a corresponding decrease in the water:methanol wash in the treated area when acifluorfen was .pa present. No other plant part or wash was significantly influenced by the addition of acifluorfen to the ^{14}C bentazon.

The main effect of treatments indicated that ^{14}C acifluorfen recovery was significantly decreased when bentazon was present. This overall average may be somewhat misleading. At higher light and temperature values it appears that the presence of bentazon does reduce uptake of ^{14}C acifluorfen. However, at lower temperatures and light values the uptake of ^{14}C acifluorfen was increased by the presence of bentazon. The uptake of ^{14}C bentazon in the treated area was significantly increased by the presence of acifluorfen regardless of light or temperature when compared to uptake values of ^{14}C bentazon applied alone.

Conclusion: Light and temperature appear to have more influence on ^{14}C acifluorfen uptake than that of ^{14}C bentazon. At lower light and temperature values bentazon increased the uptake of ^{14}C acifluorfen in the treated area. Under higher light and temperature values, however, bentazon decreased the amount of ^{14}C acifluorfen recovered in the treated area. The uptake of ^{14}C bentazon in the treated area was significantly increased when acifluorfen was present regardless of temperature or light values. Neither light, temperature, or herbicide had any significant effect on ^{14}C acifluorfen or ^{14}C bentazon movement or recovery in any plant part or wash other than the treated area and the water:methanol wash in redroot pigweed.

Velvetleaf:

The analysis of variance indicated that the main effects of treatment and plant part were highly significant. The interactions, treatment x plant part, and time x treatment x plant part were all highly significant. The leaf tip and base of the treated leaf were not significantly influenced by time or treatment. Concerning plant parts, most of the labeled herbicide, 95 percent, was recovered in the water:methanol wash. The overall recovery averages for the chloroform wash and the treated area were 3 and 2 percent respectively, and were not significantly different from each other but had significantly greater label recovery than the other plant parts measured.

<u>^{14}C Acifluorfen</u>: The treatment x plant part interaction indicated (Table 80) that the addition of bentazon to the ^{14}C acifluorfen had no significant effect on the amount of ^{14}C acifluorfen that was recovered from the treated area. When ^{14}C acifluorfen was added alone, a significant increase (7 percent) in label was recovered in the chloroform wash compared to when bentazon was present (2 percent). If bentazon was present, the amount of ^{14}C acifluorfen recovered in the water:methanol wash also significantly increased. The addition of bentazon had no effect on the amount of ^{14}C acifluorfen recovered in the other plant part areas.

The time x treatment x plant part interaction indicated that the presence of bentazon had no significant effect on the amount of ^{14}C acifluorfen recovered in the treated area but increased the recovered amount in the water:methanol wash and decreased the amount in the chloroform wash. The amount of ^{14}C acifluorfen recovered in leaf tip or base of the treated leaf was not significantly influenced by the addition of bentazon.

<u>^{14}C bentazon</u>: The treatment x plant part interaction indicated (Table 80) that the addition of acifluorfen had no significant effect on the amount of ^{14}C bentazon recovered in any plant part or wash.

The time x treatment x plant part interaction indicated that in both time periods ^{14}C bentazon was not significantly influenced by acifluorfen as measured by recovery of ^{14}C bentazon in any plant part or wash.

The overall main effect of treatments indicated that there was an increase in ^{14}C acifluorfen when bentazon was present. This is probably confounded in that the only consistent increase of ^{14}C acifluorfen recovery was in the chloroform wash when bentazon was absent. Acifluorfen had no significant effect on ^{14}C bentazon.

Table 80. The treatment x plant part interaction means of percent recoverable labeled acifluorfen and bentazon as separated by Duncan's multiple range test on velvetleaf.

Treatment[1]	Plant Part[2]	Percent Recovered	Arc-Sine	Duncan's
^{14}C Acf[1]	Tip	.14	.08	f
"	H_2O	90	63.61	c
"	Chl	7	3.85	d
"	Cm^2	4	2.21	e
"	Base	.3	.17	f
^{14}C Acf + Bnt	Tip	.4	.20	f
"	H_2O	96	73.79	b
"	Chl	2	.94	ef
"	Cm^2	2	1.25	ef
"	Base	.13	.08	f
^{14}C Bnt	Tip	1	.51	ef
"	H_2O	97	76.05	a
"	Chl	1	.40	ef
"	Cm^2	1	.75	ef
"	Base	.22	.13	f
^{14}C Bnt + Acf	Tip	1	.30	f
"	H_2O	97	75.83	a
"	Chl	1	.60	ef
"	Cm^2	1	.76	ef
"	Base	.24	.14	f

[1]Treatments: ^{14}C Acf = ^{14}C labeled acifluorfen
^{14}C Acf + Bnt = ^{14}C labeled acifluorfen + unlabeled bentazon
^{14}C Bnt = ^{14}C labeled bentazon
^{14}C Bnt + Acf = ^{14}C labeled bentazon + unlabeled bentazon

[2]Plant parts:
Tip = Tip of treated leaf
H_2O = Water:methanol wash
Chl = Chloroform wash
Cm^2 = Treated area
Base = Base of treated leaf
Above = Plant tissue above the treated leaf
Below = Plant tissue below the treated leaf

Conclusion: Bentazon had no significant influence on the uptake or movement of ^{14}C acifluorfen in any plant part. There was a significant increase in ^{14}C acifluorfen that was recovered in the chloroform wash and conversely an increase in the water:methanol wash when bentazon was present. Acifluorfen had no significant effect on ^{14}C bentazon measurement in any plant part or wash on velvetleaf.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The greenhouse and outside grown plants and a comparison field study indicated that an interaction exists between acifluorfen and bentazon when used in combination. The interactions were measured using percent moisture as an indicator of herbicidal action. Percent moisture appeared to be more consistent and accurate than were visual ratings of fresh and dry weight measurements in estimating actual herbicide damage. Visual ratings were too variable and easily subject to bias. Fresh weight was fairly consistent when compared to percent moisture but in cases where plants had been heavily damaged by herbicide treatments and yet recovering, this weight did not reflect the present recovery condition and false conclusions could be drawn. This was especially true because of the short 10 day period used between herbicide treatment and harvest. Dry weight differences were simply not great enough to detect interactions because if extensive herbicide damage had stunted growth, but regrowth was evident during the 10 day period following herbicide treatment, this lack of herbicidal activity was not reflected in the dry weight measurements of a recovering plant. A dead plant was not significantly different from a recovering plant when only dry weight masses were compared. Percent moisture reflected herbicide damage and the percent recovery that may have occurred. This method of measurement is especially true for the contact-type herbicides used in this study.

The measured interactions when acifluorfen and bentazon were used in combination occurred across all tested rates unless noted (Table 81). The type of interaction listed was measured by use of a Fishers ANOV and if appropriate, a Colby's analysis.

Common lambsquarters response to the combinations was considered synergistic at all combined levels of acifluorfen and bentazon when no crop oil was added to the combination regardless of where the plants were grown. If a crop oil concentrate was added, the interaction was no longer significant and synergism was no longer measured but the results were considered additive.

Jimsonweed response to the combination was considered antagonistic at all the combined levels of acifluorfen and bentazon when plants were grown in the greenhouse and no crop oil was added. When grown outside, the results of the interaction was no longer significant and the response was considered additive. If a crop oil concentrate was present regardless of location, both herbicides were equally effective on jimsonweed and the combinations were no better than either herbicide applied singly. Even though the herbicides appear to act independently, they are considered part of the additive response.

Redroot pigweed grown in the greenhouse was antagonistic across all the combined rates of acifluorfen and bentazon whether or not a crop oil concentrate was present. Pigweed response to the combinations was significantly antagonistic when grown outside if a crop oil concentrate was present and synergistic if grown outside when no crop oil concentrate was present, only at the lowest rate of acifluorfen (0.28 kg/ha) across all the combined rates of bentazon. Once the rate of acifluorfen was increased to 0.43 kg/ha the interaction was no longer significant and was considered additive.

Table 81. A summary of measured interactions using combinations of acifluorfen and bentazon with and without a crop oil concentrate in plants grown inside and outside a greenhouse.

Weed species	No oil present		Crop oil present	
	Greenhouse	Outside	Greenhouse	Outside
Lambsquarter	Syn	Syn	Add	Add
Jimsonweed	Ant	Add	Add*	Add*
Redroot pigweed	Ant	(Syn)[1]	Ant	(Ant)[1]
Velvetleaf	Syn	Syn	Add	Add
Soybeans	Add	Add	Add	Add

Add = Additive
Ant = Antagonistic
Syn = Synergistic

*Results indicated herbicides acted independently but are considered as additive.

[1]The () indicates the interaction was measured only at the lowest rate of acifluorfen across all rates of bentazon. All other rate combinations of acifluorfen plus bentazon were considered additive.

Velvetleaf response to the combinations was significantly synergistic at all the combined rates of acifluorfen and bentazon if no oil was present regardless of where the plants were grown. The addition of a crop oil concentrate caused the interaction term to no longer be significant and the combinations were considered additive. A field study on velvetleaf, which was visually rated, showed results similar to those of the outside container grown plants.

Soybeans, regardless of location or crop oil concentrate present, never had a significant interaction term when combinations were compared. The combinations are considered to cause additive damage to the soybeans.

The cause of the interactions was not considered to be due to the effect of either herbicide or combinations of herbicides on the physical diameter of a water droplet. Neither acifluorfen nor bentazon nor any combination had any significant effect on droplet size. Crop oil significantly increased the droplet diameter regardless of weed species used. Weed species also influenced droplet size due to plant physical features.

The use of ^{14}C labeled acifluorfen and bentazon allowed a method of measuring whether one herbicide influenced the uptake of the other. Neither herbicide significantly influenced the movement of the other outside of the treated area regardless of weed species used. There was also no relation to the amount of herbicide taken up and sensitivity of the plant to the herbicide.

The amount of ^{14}C acifluorfen recovered in the treated area of lambsquarters was reduced a significant 15 percent by the addition of bentazon. If the combination occurred under low light intensity then bentazon had no effect on the ^{14}C acifluorfen uptake. Under higher light intensities and temperatures bentazon reduced ^{14}C acifluorfen uptake by a significant 28 percent over ^{14}C acifluorfen applied alone. The ^{14}C bentazon was not significantly influenced by the addition of acifluorfen unless under the conditions of higher light intensities and temperatures. Under these increases acifluorfen decreased ^{14}C bentazon uptake by a significant 17 percent.

The uptake of ^{14}C acifluorfen was not affected by the addition of bentazon in jimsonweed. With ^{14}C bentazon, however, the presence of acifluorfen reduced the uptake of labeled bentazon by a significant 4 percent compared to when no acifluorfen was present. Most (94 percent) of the labeled acifluorfen and bentazon was recovered in the water:methanol wash.

The amount of ^{14}C acifluorfen that was taken up by redroot pigweed was reduced a significant 7 percent when bentazon was added. If treated plants were placed under lower lights and temperatures after treatment, however, a significant 10 percent increase in ^{14}C acifluorfen uptake was measured if bentazon was present. Under higher lights and temperatures a significant 23 percent decrease in ^{14}C acifluorfen was measured when bentazon was present compared to ^{14}C acifluorfen applied alone. The ^{14}C bentazon showed a significant 10 percent increase in uptake values under both light and temperature conditions if acifluorfen was present.

Velvetleaf treated with ^{14}C acifluorfen did significantly change uptake values with the addition of the bentazon. Neither did the ^{14}C bentazon uptake values change with the addition of acifluorfen. Neither herbicide was significantly influenced by the addition of the other.

The measured synergism of acifluorfen and bentazon when applied in combination to lambsquarters, jimsonweed and velvetleaf when no crop oil was used may occur because of the different site of actions of both herbicides. Bentazon inhibits in the photosynthetic area where acifluorfen action is with the carotenoids. Both are activated in the presence of light and are inactive in the dark. This dual site of action also helps explain why synergism may occur with the combination as two sites of action are indicative of the multiplicative model. The addition of a crop oil concentrate increased the droplet size and hence more surface area for uptake. The addition of the crop oil tended to mask the measured interactions due probably to increased uptake of both herbicides or at least increased the uptake of the more sensitive herbicide. The measured decrease in uptake of both labeled herbicides as measured in lambsquarters when used in combination may explain why the response to the combination although greater than either herbicide applied singly is not as great as when as crop oil concentrate was present.

The antagonism measured in jimsonweed occurred only in the greenhouse grown plants. The labeled work indicated that ^{14}C bentazon uptake was reduced when acifluorfen was present. Jimsonweed was also more sensitive to bentazon.

The antagonism measured when combinations of acifluorfen and bentazon were used on redroot pigweed, occurred in every situation except when the plants were grown outside and no crop oil concentrate was used. The labeled uptake study indicated that the uptake of both herbicides was significantly reduced by the presence of the other. Redroot pigweed is much more sensitive to acifluorfen than to bentazon and a decrease in the uptake of acifluorfen could result in a reduced or antagonistic response. When grown outside with no crop oil concentrate applied with the combination, redroot pigweed responded synergistically only when the lowest rate of acifluorfen was used across all rates of bentazon. This synergism may have occurred because at lower light levels and temperatures ^{14}C acifluorfen uptake was increased in the presence of bentazon. The amount of labeled bentazon was always increased in the presence of acifluorfen and that increase may have had a significant herbicidal impact on redroot pigweed. The plants were grown outside during September and October when cooler temperatures and short days were present. The rate of 0.43 kg/ha of acifluorfen, however, seemed to overcome whatever interaction may have occurred when the plants were grown outside by supplying enough acifluorfen to mask whatever interactions may have occurred at the lower acifluorfen rates. The measured interactions were not due to uptake differences, however, but more likely because of the different sites of action of these two herbicides.

Further suggested studies into the effect of acifluorfen and bentazon might include: 1) More detailed data on the effect of light intensity and temperature on the interaction, 2) the causes of the uptake interactions (internal, external, physiological), 3) the effects of environment i.e. greenhouse versus outside grown plants on the interaction and what causes these differences, 4) the effect of increasing rates on the uptake of labeled herbicides, 5) do the labeled uptake values continue to explain responses if used outside or with crop oil concentrate.

LITERATURE CITED

1. Abernathy, J. R. and L. M. Wax. 1973. Bentazon mobility and adsorption in twelve Illinois soils. Weed Sci. 21: 224-227.

2. Anderson, R. N., W. E. Lueschen, D. D. Warnes, and W. W. Nelson. 1974. Controlling broadleaf weeds in soybean with bentazon in Minnesota. Weed Sci. 22: 136-142.

3. Anderson, W. P. 1983. Weed Science: Principles, second edition. West Publishing Co. pp 655.

4. Ashton, F. M. and A. S. Crafts. 1981. Mode of action of herbicides. Wiley-Interscience. pp. 523.

5. Allen, W. W., F. M. Ashton, R. Behrens, R. A. Darrow, W. C. Shaw, Chairman. 1961. Report of the Terminology Committee Weed Science Society of America. Weed Sci. 10:252-273.

6. Akobundu, I. O., W. B. Duke, R. D. Sweet, and P. L. Minotti. 1975. Basis for synergism of atrazine and alachlor combinations on Japanese millet. Weed Sci. 23: 20-25.

7. Akobundu, I. O., R. D. Sweet, and W. B. Duke. 1975. A method of evaluating herbicide combinations and determining herbicide synergism. Weed Sci. 23: 20-25.

8. American Heritage Dictionary. 1980. William Morris, Editor. Houghton Mifflin Company. pp 1550.

9. Anonymous. 1964. Report of the terminology committee. Weeds. 12: 331-332.

10. Beste, C. E., Chairman. 1983. Herbicide Handbook of the Weed Science Society of America. pp. 515.

11. Bugg, M. W., C. E. Rieck and W. W. Witt. 1980. Herbicidal activity of benazolin on broadleaf weeds in soybeans. Proceedings SWSS. 33: 214.

12. Bugg, M. W., J. Whitmarch, C. E. Rieck, and W. S. Cohen. 1980. Inhibition of photosynthesis electron transport by diphenyl ether herbicides. Plant Physiol. 65:47.

13. Burchfield, H. P. and F. Wilcoxon. 1954. Comparison of dosage-response and time-response methods for assessing the joint action of anti-metabolites. Contr. Boyce Thompson Inst. 18: 79-82.

14. Campbell, T. A., W. A. Gentner, and L. L. Danielson. 1981. Evaluation of herbicide interactions using linear regression modeling. Weed Sci 29: 378-831.

15. Campbell, J. R. and D. Penner. 1982. Compatability of diclofop and BAS 9052 with bentazon. Weed Sci. 30: 458-462.

16. Colby, S. R. 1967. Calculating synergistic and antagonistic response of herbicide combinations. Weeds. 15: 20-22.

16. Copping, L. G. and J. F. Garrod. 1980. Interactions between benazolin and other herbicides for broad-leaf weed control in soybeans. Proceedings British Crop Protection Conference. 177: 184.

17. Crafts, A. S. and C. W. Cleary. 1936. Toxicity of arsenic, borax, chlorate, and their combinations in three California soils. Hilgardia 10, 401.

18. Cress, C. R. 1984. Personal communication. Department of Crop and Soil Science, Michigan State University, East Lansing, MI.

19. Davis, L. G., A. H. Cobb and F. E. Taylor. 1979. The susceptibility of Chenopodium album to bentazon under different environmental conditions. Proceedings EWRS Symposium 1979. 94-107.

20. Devlin, R. M., S. J. Karczmarczyk and I. I. Zbiec. 1983. Influence of norflurazon on the activation of substituted diphenylether herbicides by light. Weed Sci. 31: 109-112.

21. Doran, D. L. and R. N. Anderson. 1975. Effects of simulated rainfall on bentazon activity. Weed Sci. 23: 105-109.

22. Drury, R. E. 1980. Physiological interaction, its mathematical expression. Weed Sci. 28: 573-579.

23. Dunleavy, P. J., A. H. Cobb, K. E. Pallett, L. G. Davies. 1982. The involvement of stomata in bentazone action in Chenopodium album L. Proceeding 1982 British Crop Protection Conference. Weeds. 1: 187-191.

24. Eshel, Y., R. L. Zimdahl, and E. E. Schweizer. 1976. Basis for interactions of ethofumesate and desmedipham on sugarbeets and weeds. Weed Sci. 24: 619-626.

25. Fadayomi, O. and G. F. Warren. 1976. The light requirement for herbicidal activity of diphenyl ethers. Weed Sci. 598-600.

26. Finney, D. J. 1952. Probit Analysis. Third Ed. University Press, Cambridge. pp. 333.

27. Frear, D. S., H. R. Swanson, and E. R. Mansager. 1983. Acifluorfen metabolism in soybean: Diphenylether bond cleavage and the formation of homoglutathion, cysteine, and glucose conjugates. Pestic. Biochem. and Physiol. 20: 299-310.

28. Gates, D. W. 1983. Influence of mefluidide on the activity of other herbicides. Proceedings WSSA 36: 30.

29. Gentner, W. A. 1966. The influence of EPTC on external foliage wax depostion. Weeds 14: 27-31.

30. Gorske, S. F. and H. J. Hopen. 1978. Effects of two diphenylether herbicides on common purslane (Portulaca oleracea). Weed Sci. 26: 585-588.

31. Gowing, D. P. 1959. A method of comparing herbicides and assessing herbicide mixtures at the screening level. Weeds. 7: 66-76.

32. Gowing, D. P. 1960. Comments on tests of herbicide mixtures. Weeds 8: 379-391.

33. Hayes, R. M. and L. M. Wax. 1975. Differential intraspecific responses of soybean cultivars to bentazon. Weed Sci. 23: 516-521.

34. Hagimoto, H. and H. Yoshikawa. 1972. Synergistic interactions between inhibitors of growth and photosynthesis. Weed Res. 12: 21-30.

35. Hamill, A. S. and D. Penner. 1973. Interactions of alacholor and carbofuran. Weed Sci. 21: 330-335.

36. Hartzler, R. G. and C. L. Foy. 1983. Compatability of BAS 9052 with acifluorfen and bentazon. Weed Sci. 31:597-599.

37. Hatzios, K. K. 1981. Synergistic interactions of tebuthiuron with EPTC + R-25788 and butylate + R-25788 in corn (Zea mays). Weed Sci. 29: 601-604.

38. Hatzios, K. K. and D. Penner. 1982. Metabolism of herbicides in higher plants. Burgess Publishing Co. Minneapolis, Mn. 142 pp.

39. Hatzios, K. K. and D. Penner. 1984. Pesticide interactions. In press.

40. Hewlett, P. S. 1960. Joint action in pesticides. Pages 27-74 in R.L. Metcalf, ed. Advances in Pest Control Research. John Wiley and Sons, Inc., New York.

41. Hook, B. J. and S. Glenn. 1984. Mefluidide and acifluorfen interactions on ivyleaf morningglory (Ipomoea hederacea), velvetleaf (Abutilon theophrasti), and common cocklebur (Xanthium pensylvanicum). Weed Sci. 32:198-201.

42. Irons. S. M. and O. C. Burnside. 1982. Absorbtion, translocation and metabolism of bentazon in sunflower (Heliathus annuus). Weed Sci. 30: 255-259.

43. Irons, S. M., and O. C. Burnside. 1982. Selective control of sunflower in soybean. Agron. Journal 74: 291-296.

44. Kells, J. J., W. F. Meggitt, D. Penner. 1981. Factors influencing grass control with selective postemergence herbicides. Proc. NCWCC. 36: 21-22.

45. Komives, T., J. E. Casida. 1983. Acifluorfen increases the leaf content of phytoalexins and stress metabolites in several crops. J. Agric. Food Chem. 31: 751-755.

46. Lambert, W. D. and E. Basler. 1983. Absorbtion, translocation and metabolism of acifluorfen in weed and crop plants. WSSA Abst. 1983: 82-93.

47. Lee, S. D. and Oliver. 1982. Efficacy of acifluorfen on broadleaf weeds. Times and methods for application. Weed Sci. 30: 520-526.

48. Leong, T.Y. and W. R. Briggs. 1982. Evidence from studies with acifluorfen for participation of a flavin-cytochrome complex in blue light photoreception for phototropism of oat coleoptiles. Plant. Physio. 70: 875-881.

49. Lockhart, J. A. 1965. The analysis of interactions of physical and chemical factors on plant growth. Annual Review of Plant Physiology. 16:37-52.

50. Loewe, S. 1963. The problem of synergism and antagonism of combined drugs. ArzneimittForsch. 3: 285-290.

51. Mahoney, M. D. and D. Penner. 1975. Bentazon translocation and metabolism in soybean and navy bean. Weed Sci 23: 265-270.

52. Mann, R. K. and C. E. Rieck. 1979. Effect of soil moisture on hebericidal action of foliar applied herbicides. Proceedings SWSS. 32:31.

53. Martin, J. R., C. E. Rieck and B. L. Mangeot. 1978. The movement of bentazon in cocklebur and giant ragweed. Proceedings of SWSS. 31: 241.

54. Matsunaka, S. 1969. Acceptor of light energy in photoactivation of diphenyl ether herbicides. J. Agric. Food Chem. 17: 171.

55. Meier, D., G. K. Lichtenthaler, and G. Burkard. 1980. Change of cholorplast ultrasturcture in radish seedlings under the influence of the photosystem II - herbicide bentazon. Zeitschrift fur Naturforschung. 35: 656-664.

56. Mine, A. and S. Matsunaka. 1975. Mode of action of bentazon: Effect on photosynthesis. Pest. Biochem. Physiol. 5: 444-450.

57. Mine, A., M. Miyakada, and S. Matsunaka. 1975. The mechanism of bentazon selectivity. Pestic. Biochem. and Physiol. 5: 566-574.

58. Moreland, D., W. Blackman, H. Todd and F. Farmer. 1970. Effects of diphenyl ether herbicides on reactions of chloroplasts and mitochondria. Weed Sci. 18: 636.

74. Prendeville, G. N., C. S. James, G. F. Warren, and M. M. Schreiber. 1969. Antagonistic responses with combinations of carbamate and growth regulator herbicides. Weed Sci. 17: 307-309.

75. Prendeville, G. N. and G. F. Warren. 1977. Effect of four herbicides and two oils on leaf-cell membrane permeability. Weed Res. 17: 251.

76. Pritchard, M. K., G. F. Warren and R. A. Dilley. 1980. Site of action of oxyfluorfen. Weed Sci. 28: 640.

77. Putnam, A. R. and D. Penner. 1974. Pesticide interactions in higher plants. Residue Reviews. Editor, F. A. Gunther, Vol. 50: 73-110.

78. Rao, S. R. and T. R. Harger. 1981. Mefluidide-bentazon interactions on Soybeans (Glycine max) and Red Rice (Oryza sativa). Weed Sci. 29: 298-212.

79. Renner, K. A. and R. G. Harvey. 1983. Postemergence control of giant foxtail (Setaria faberii Herm.) and wild proso millet (Panicum miliaceum L.) in soybeans. WSSA Abstract 748.

80. Retzlaff, G. and R. Hamm. 1977. Current knowledge on the mode of action of 3-isopropyl-2,1,3-thiadiazin-4-one-2,2-dioxide (bentazon). Mitteilungen aus der Biologischen Bundesanstait fur Land und Forstwirtschaft, Berlin-Dahlem. No. 178: 220-221.

81. Ritter, R. L. 1980. Influence of temperature and relative humidity on the herbicide activity of acifluorfen. Proceedings NWSS 34: 4.

82. Ritter, R. L. and H. D. Coble. 1981. Penetration, translocation and metabolism of acifluorfen in soybean (Glycine max), common ragweed (Ambrosia artemisiifolia) and common cockleburr (Xanthium pensylvanicum). Weed Sci. 29: 474-480.

83. Ritter, R. L. and H. D. Coble. 1981. Influence of temperature and relative humidity on the activity of acifluorfen. Weed Sci. 29: 480-485.

84. Rummens, F. H. A. 1974. An improved definition of synergistic and antagonistic effects. Weed Sci. 23: 4-6.

85. Sandermann, G., R. Lambert and P. Boger. 1981. Multifunctional mode of action of substitued nitrodiphenylethers in Scenedismus cells. Z. Naturforsch. Sect. C. Biosci. 36: 633.

86. Sterrett, J. P. and R. H. Hodgson. 1983. Enhanced response of bean (Phaseolus vulgaris) and Canada thistle (Cirsium arvense) to bentazon or glyphosate by gibberellin. Weed Sci. 31: 396-401.

87. Streibig, J.C. 1981. A method for determining the biological effect of herbicide mixtures. Weed Science 29: 469-473.

59. Morse, P. M. 1978. Some comments on the assessment of joint action in herbicide mixtures. Weed Sci 26: 58-71.

60. Nalewaja, J. D., J. Pudelko and D. A. Adamczewski. 1975. Influence of climate and additives on bentazon. Weed. Sci. 23: 504-507.

61. Nalewaja, J. D., S. D. Miller, A. G. Dexter. 1981. Interaction of herbicides for grass and broad-leaved weed control. Proc. NCWCC 36: 16-18.

62. Nash, R. G. 1976. Phytotoxic interactions - Techniques of evaluation and presentation. WSSA Abstracts. 105.

63. Nash, R. G. 1981. Phytotoxic interaction studies - Techniques for evaluation and presentation of results. Weed Sci. 29: 147-155.

64. Nash, R. G. and L. L. Jensen. 1973. Determining phytotoxic pesticide interactions in soil. J. Environ. Quality. 2: 503-510.

65. Olson, W. A. and J. D. Nalewaja. 1981. Antagonistic effects of MCPA on wild oat (Avena fatua) control with diclofop. Weed Sci. 29:566-571.

66. Orr, G. L., C. M. Elliott and M. E. Hogan. 1983. Activity in vivo and redox states in vitro of nitro- and chlorodiphenyl ether herbicide analogs. Plant Physiol. 73: 939-944.

67. Orr, G. L. and F. D. Hess. 1981. Charactorization of herbicidal injury by acifluorfen-methyl in excised cucumber (Cucumis sativus L.) cotyledons. Pestic. Biochem. and Physiol 16: 171-178.

68. Orr, G. L. and F. D. Hess. 1982. Mechanism of action of the diphenyl ether herbicides acifluorfen-methyl in exised cucumber (Cucumis sativus L.) cotyledons. Plant Physiol 69: 502-507.

69. Ostle B. and R. W. Mensing. 1975. Statistics in Research. Iowa State University Press. p. 272.

70. Paulo, E. M., M. A. Oliveira, N. M. P. Toledo, R. Forster. 1982. Control of grasses and broad-leaved weeds in soyabeans with mefluidide and bentazone tank-mix. Planta Daninha 5: 45-56.

71. Penner, D. 1974. Bentazon selectivity between soybean and Canada thistle. Weed Res. 15: 259-262.

72. Pfister, K. C. Buschman, and H. K. Lichtenthaler. 1974. Proceedings of the Third International Congress on Photosynthesis. Vol. 1: 675-681.

73. Potter, J. R. and W. P. Wergin. 1975. The role of light in bentazon toxicity to cocklebur: Physiology and ultrastructure. Pest. Biochem. Physio. 5: 458-470.

88. Suwanketnikom, R., K. K. Hatzios, D. Penner, D. Bell. 1982. The site of electron transport inhibition by bentazon (3-isopropyl-1H-2,1,3-benzothiadiazin-(4)3H-one 2,2-dioxide) in isolated chloroplasts. Canadian Journal of Botany 60: 409-412.

89. Tammes, P. M. L. 1964. Isoboles, a graphic representation of synergism in pesticides. Neth. J. Plant Pathol. 70: 73-80.

90. Vanstone, D. E. 1978. Physiological aspects of the mode of action of nitrofluorfen and oxyfluorfen. Diss. Abstr. Int. B. 38: 2974.

91. Vanstone, D. E. and E. H. Strobbe. 1967. Electrical conductivity - a rapid measure of herbicide injury. Weed Sci. 25: 352-354.

92. Vanstone, D. E. and E. H. Strobbe. 1979. Light requirement of the diphenylether herbicide oxyfluorfen. Weed Sci. 27: 88-91.

93. Veldstra, H. 1956. Synergism and potentiation; with special reference to the combination of structural analogues. Pharmacol. Rev. 8:339-387.

94. Wills, G. D. and G. G. McWhorter. 1981. Effect of environment on the translocation and toxicity of acifluorfen to showy crotularia. Weed Sci. 29: 397-401.

95. Waldrop, D. D. and P. A. Banks. 1983. Interaction of 2,4-DB, acifluorfen and toxaphene applied to foliage of sickle pod (Cassia obtusifolia). Weed Sci. 31: 351-354.

96. Webster's New International Dictionary of the English Language. 1981. G.C. Merriam Co., Springfield, Mass.