1974

Volatility, Drift and Phytotoxicity of Dicamba to Corn When Applied with Additives

Bart A. Brinkman

VOLATILITY, DRIFT AND PHYTOTOXICITY OF DICAMBA TO CORN WHEN APPLIED WITH ADDITIVES

By

BART A. BRINKMAN

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Agronomy, South Dakota
State University

1974

VOLATILITY, DRIFT AND PHYTOTOXICITY OF DICAMBA TO CORN WHEN APPLIED WITH ADDITIVES

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser　　　　Date

Head, Plant Science Department　　　　Date

TABLE OF CONTENTS

INTRODUCTION

Herbicides have become an important asset to the farmer since the discovery of 2,4-D as a useful weed killer. Although herbicides are a relatively new and useful tool, various hazards are associated with their use.

Drift and volatility are of primary concern. Air pollution is recognized as an environmental detriment to both plants and animals. The prevention of herbicide drift and volatility is necessary to maintain an environment suitable for many plant habitats.

Dicamba (3,6-dichloro-o-anisic acid) is used to control broadleaf weeds in corn, small grains, lawns, and rangelands. Sometimes nontarget areas adjacent to crops are affected seriously because of dicamba treatments. Particle drift and possibly vapor drift may be responsible for the injury to nontarget plants.

Compounds mixed with a herbicide to enhance phytotoxicity may also inhibit drift of minute herbicide particles and vapor. A compound mixed with a herbicide either to reduce drift or to enhance phytotoxicity is called an additive. Limited information exists about the drift and phytotoxicity of dicamba when applied in combination with additives. Therefore, the objectives of this thesis were to determine the influence of additives on phytotoxicity, particle drift, and vapor drift of dicamba.

LITERATURE REVIEW

Many herbicides are effective in trace amounts on sensitive plants. A chemical may move from a treated area to an untreated sensitive area by volatilization and drift particles (22).

Volatility is the result of vaporization of the chemical formulation. Factors which influence volatility are vapor pressure of the compound (11, 31, 45), wind velocity (4, 25, 39), air temperature (6, 8, 38, 39, 42), humidity (8, 30), surface properties of the target area (1, 20, 24, 32, 39, 42), and additives (1, 15, 17, 34).

Vapor pressure of a liquid is defined as the pressure of the vapor in equilibrium with the liquid at a given temperature. According to Klingman (31), the formulation of a herbicide has an important effect upon its vapor pressure. For example, the volatility of 2,4-D ester is reduced as the carbon chain of the alcohol used to formulate 2,4-D ester is increased. The term "volatile" describes the effect of vapors on sensitive plants rather than the actual magnitude of the vapor pressure of the herbicide.

Parochetti and Warren (39) determined the vapor loss of isopropyl N-phenyl-carbamate (IPC) and isopropyl N-(3-chlorophenyl) carbamate (CIPC) with various flow rates of air at 47C. Vapor losses from IPC and CIPC increased as the flow rate of air was increased from 56.6 l/hr to 169.8 l/hr. Grover and Kerr (25) measured the drift of 2,4-D during normal spraying conditions. They stated that 5 to 15% of the total material sprayed under normal spraying conditions may drift. Vapor

drift was greater than particle drift during the first half hour after spraying. The amount of evaporation from the sprayed surfaces was highly dependent on wind speed and temperature.

Baskin and Walker (6) reported that volatility of 2,4-D butyl-ester increased as temperature was increased from 21 to 49C. Parochetti et al. (38) reported that vapor losses of 2,6-dichlorobenzonitrile (dichlobenil) after three hours amounted to 10% at 30C and 18% at 40C. Burnside and Lavy (8) applied 14-C-dicamba to aluminum planchets and stored them at 15 and 36C. Eleven weeks after application the planchets stored at 15C had lost 15% of the 14-C-dicamba but those stored at 35C lost 48% of the dicamba. This loss was assumed to be due to volatility. Furthermore, Talbert et al. (42) found that injury to cotton (Gossypium hirsutum L.) plants exposed to 2,4-bis(isopropylamino)-6-methylmercapto-s-triazine (prometryne) generally increased as temperature was increased from 19 to 40C.

Burnside and Lavy (8) found that vapor loss of dicamba was less at 0% humidity than at 100%. Kearney et al. (30) found that less volatilization of seven s-triazines occurred at low humidities than at high humidities at 40C.

The surface to which herbicides are applied often influences the amount of volatility. Addink (1) found that aluminum planchets had considerable more vapor loss of dicamba than did steel planchets. After sixteen days at 32C only 1% 14-C-dicamba was lost from the steel planchets as compared to 20-35% lost from aluminum planchets. Talbert et al. (42), found that prometryne volatilized much greater from a

metal surface than from a soil surface. Parochetti and Warren (39) found that vapor losses of IPC decreased if the exchange capacity, percent clay, and organic matter of soil were increased. Gray (24) studied volatility of ethyl N, N-di-n-propylthiolcarbamate (EPTC) and reported that, "1" much more EPTC was lost after application to the surface of a moist soil than a dry soil, "2" a light sprinkling of water 0.01 - 0.1 inches to dry soil after application of EPTC increased vapor loss of EPTC, "3" immediate incorporation into the soil greatly reduced vapor loss, "4" vapor loss was less when EPTC was incorporated into dry soil than when EPTC was incorporated into moist soil.

Additives influence volatilization (1, 15, 17, 34). Marth and Mitchell (34) reported that 2,4-D butyl-ester was not volatile when dissolved in diesel oil, corn oil, or cottonseed oil, but was volatile when dissolved in varsol, kerosene, or castor oil. Danielson et al. (15) reported EPTC persistence in soil was influenced to a large extent by the solvent-carrier system used in application. The most persistent systems were commercial EPTC mixed in water, and technical EPTC mixed in either acetone, benzene, or xylene. Furthermore, technical EPTC mixed in kerosene was the least persistent. Addink (1) reported negligible losses of 14-C-dicamba vapors after 17 hours at 32C when 14-C-dicamba was mixed with additives. Ekins et al. (17) reported that Norbak and Dacagin reduced the injury to bush beans (<u>Phaseolus</u> <u>vulgaris</u> L.) from volatility of 2,4-D ethylester. He proposed two theories to explain the reduction in vapor loss: "1" plants

sprayed with Norbak were covered with fewer and larger spray droplets; therefore, less surface area was exposed which resulted in less vapor loss, "2" spray particles on the leaf of the plant dried rapidly when Dacagin was used; consequently, a film was formed which inhibited vapor loss. Furthermore Dacagin, Norbak and Vistik reduced drift of 1, 1'-dimethyl-4,4'-bipyridinuim ion (paraquat) but they were not effective substitutes for wetting agents which are used to increase the efficiency of paraquat. The reason was primarily because of insufficient spray coverage.

Spray drift is the movement of air borne spray particles. The amount of spray drift depends upon size of the droplets (35, 36, 37), amount of wind velocity (22, 33, 35), and height above the surface that the spray is released (22, 23, 41).

Droplet size is dependent upon size of nozzle orifice (35, 37), operating pressure (33, 35, 37), and fluid properties such as density, surface tension, and viscosity (1, 17, 19, 29, 37). Maybank and Yoshida (33) stated that the fraction of droplets that are subject to drift are those droplets that are less than 100µ (microns). They also indicated that the total spray volume potentially subject to some drifting may vary from 10 to 30% depending on orifice size and spray pressure. Page (37) studied the effect of the orifice size and spray angle on the amount of drift and reported that drift increased as orifice size decreased because smaller droplets were produced from the smaller orifices. Also, spray angle had a marked effect on drift. Nozzles with 80 degree spray angles had greater drift potential than

nozzles with 65 degree spray angles, at a discharge rate of 0.1 gallons per minute. It is assumed that more droplets are exposed to greater air volume at greater spray angles. Both nozzles were the same height which would not be applicable to field conditions because single coverage would occur at different heights with nozzles of different angles. If the nozzle height were adjusted to spray equal areas, then the 80 degree nozzle would be lower than the 65 degree nozzle. Consequently, less drift might result from using 80 degree nozzles rather than 65 degree nozzles.

Operating pressures affect spray drift (31, 33, 35). Morgan et al. (35) stated that high pressures produce more small droplets than low pressures. As stated before, small droplets are more of a hazard than large droplets.

The influence of increased viscosity and foaming agents on herbicide drift has been the subject of much recent research (29). Water-in-oil ("inverted emulsions"), particulate sprays, and gels reduce drift when compared to oil-in-water emulsions "conventional emulsions". However, good coverage is not obtained with these drift reducing methods and a large amount of time and special equipment is needed to use them (10, 29).

The concentration of surfactant may also influence drift. Page (37) determined the effect of Vatsol QT, X-77, and Triton 114 at 0.01 and 0.1% concentrations by weight with water. Triton 114 increased spray drift significantly at a concentration of 0.1%. The concentration of Vatsol QT and X-77 did not influence drift.

Additives that create foam droplets when sprayed through an air-aspirating nozzle have been used recently to reduce drift (19). The use of foam keeps the chemical droplets on plant surfaces wet for a longer period of time. The foaming action creates large "bubble like" droplets and reduce substantially the number of small droplets.

The wind velocity is an important factor when spraying herbicides. Plumb et al. (41) reported that wind speeds of three to four mph caused drift of more than 80 ft leeward to the flight line of an aerial application 25 ft above the ground with either whirljet or flat fan type nozzles. Maybank (33) studied the distance that droplets ranging in size from 20 - 100μ drifted when sprayed 1m above the soil surface in 3, 6, and 10 mph winds. The droplets drifted further as the wind velocity increased.

Height of spray application is important for reducing spray drift. Frost and Ware (23) reported a reduction in spray drift by as much as 80% by changing from an aerial application 30 ft above the ground to a high clearance application 1.5 ft above the ground. Furthermore, wind velocities of 5 mph and inversion temperatures had little influence on drift with the high clearance application.

Additives generally increase the phytotoxic activity of the herbicide when in contact with the plant surface (3, 14, 18, 26, 28, 43). Bandeen (3) stated that oils increase the rate and amount of atrazine uptake through the leaf cuticle because of increased wetting of the plant leaf and decreased evaporation of the droplet. Oil decreases the

surface tension of the spray droplet; thus, the wetting and spreading on the plant surface is increased. Also, oils evaporate slower than water; therefore, atrazine is maintained in a moist soluble condition longer which allows uptake for a longer period. Jansen (28) added that the effectiveness of additives depends upon their structure, concentration, and other physical-chemical characteristics. He stated that although additives can enhance herbicidal effectiveness they can also be suppressive in their action. For example, 2,4-D amine in oil resulted in greater phytotoxicity at .3% concentration (v/v) of oil than at 1% concentration.

Additives vary in their effect upon herbicide phytotoxicity (12, 13, 18, 21, 44). Ennis (18) reported that oil emulsion sprays of 2,4-D and 2,4,5-trichlorophonoxy acetic acid (2,3,5-T) were more inhibitory to soybeans than aqueous sprays containing surfactants. Frank (21) reported 5-amino-4-chloro-2-phenyl-3(2H)-pyridazinone (pyrazon) gave better broadleaf weed control when applied with oil additives than when applied with surface wetting additives. Peacock (40) and Thompson (44) reported that uptake by giant foxtail (Setaria faberii Herrm.) of atrazine plus oil was greater than that of atrazine with surface wetting agents. The uptake and translocation of 14-C-2,4-D ester was greater with petroleum oil than vegetable oils (13). Furthermore, soybean oil was a better penetrant than corn, peanut, or sunflower oils for uptake of 2,4-D by soybean. Coats and Foy (12) reported that naphthenic oils enabled greater penetration than the paraffinic oils.

Viscosity of the oils may influence the uptake and translocation

of herbicides by plants. Coats and Foy (12) indicated that 100 sec. viscosity oils had better penetrating ability than 70, 150, and 200 sec. viscosity oils. Temple and Hilton (43) reported the order of effectiveness of surfactants when applied in combination with atrazine was cationic, anionic, and nonionic types. However, Dexter et al. (16) reported that atrazine toxicity to large crabgrass (Digitaria sanquinalis L. Scap.) and sorghum (Sorghum vulgare Pers.) was not influenced by type of surfactant.

The concentration of surfactant has an effect on the phytotoxicity of herbicides (7, 12, 16). Dexter et al. (16) reported that 1.0% surfactant concentrations with atrazine increased the toxicity to large crabgrass more than the 0.1% concentration. Both the 1.0% and 0.1% concentrations increased the toxicity of atrazine to large crabgrass more than atrazine applied alone. Black (7) reported that the best herbicide surfactant ratio for 3-[p-(p-chlorophenoxy) phenyl]-1, 1-dimethylurea (chloroxuron) was three parts chloroxuron to one part surfactant. Coats and Foy (12) stated that translocation of atrazine increased as the concentration of petroleum oil increased from 1.25% to 20%.

Enhancement of phytotoxicity depends upon the plant species treated. Burr and Warren (9) reported that atrazine was 16 times more effective on ivyleaf morning glory (Ipomoea hederacea L. Jacq.) when applied in an isoparaffinic oil carrier at 140 l/ha but no enhancement on purple nutsedge (Cyperus rotundus L.) or quackgrass (Agropyron repens L. Beavr.) occurred.

It was reported (27) that 2,4-D when used in combination with a surfactant enhanced the herbicide's effectiveness on mustard but did not enhance activity on corn or other grasses.

Enhancement of phytotoxicity depends upon the herbicide used. Barrentine and Warren (5) reported that isoparaffinic oil increased giant foxtail control obtained with chloroxuron 8 times, with 3-tert-butyl-5-chloro-6-methyluracil (terbacil) 4 times, and with CIPC 3 times. Aya (2) reported that translocation of 3-amino-s-triazole (amitrole) and 3-amino-s-triazole plus ammonium thiocyonate (amitrol-T) was increased 12 times and 2 times, respectively, when applied with a paraffinic mineral oil.

MATERIALS AND METHODS

The Volatility of Dicamba in Combination with Additives

The volatility of dicamba was measured with radioisotope techniques. 10µl (lambda), containing 0.05uCi of 14-C-dicamba and 0.01 ml of water plus 0.05% X-77 or 2% Amoco Concentrate Crop Oil were applied to 3.0 x 0.3 cm aluminum planchets without soil and to 0.25 g of silty clay loam soil in another set of planchets. After treatment the planchets were placed in a closed system through which 1.0 x 10^4 ml of air/min was continuously circulated for a period of eight hours. The closed system consisted of a 19 x 4.5 x 5.5 cm plexiglass chamber containing a centrifugal fan attached to 12.7 mm plastic tubing. The plastic tubing was coiled in a water bath with controlled temperatures of 24, 30 and 35C. Humidities of 50, 75, and 95% were controlled $\pm$ 5% by pumping humid air from a humidity chamber into the closed system. The planchets without soil were washed with 3 ml of methanol and placed into scintillation vials. The scintillation solution contained 5.0 g/l of PPO plus 0.3 g/l of POPOP in toluene. The planchets with soil were washed with 3 ml of methanol but were left standing for 30 minutes after which the methanol was pipetted with a pasteur pipet into scintillation vials. Each set of scintillation vials were counted for radioactivity in a Packard liquid scintillation spectrometer for a period of ten minutes. The experiement was replicated four times.

The volatility of dicamba was measured also with bioassay techniques. The temperature was controlled by blowing air through plastic

tubing coiled in a water bath controlled at 24, 30, and 35C. Air was passed through test tubes containing either soil treated with dicamba or an aqueous solution of dicamba and onto soybean plants enclosed in plastic bags. An air escape was provided to keep the bags from bursting. A centrifugal fan blew the air through this system at 1500 ml/min. Ten day old Chippewa soybeans (Glycine max L.) in the early first trifoliate growth state were treated as a bioassay for dicamba vapor. The treatments are shown in Table 1. After exposure to the dicamba vapors

Table 1. Dicamba (0.06g) was applied in combination with these treatments to 15g of soil or to 5ml of water and the vapors emitted were measured with radioisotope and bioassay techniques.

Treatment	Surface applied to
Water + 0.5% X-77	Aqueous
Water + 2% Amoco Concentrate Crop Oil	Aqueous
Water	Aqueous
Water + 0.5% X-77	Soil
Water + 2% Amoco Concentrate Crop Oil	Soil
Water	Soil

for eight hours, the soybean plants were placed in a growth chamber with light intensity of 2,100 foot candles. Visual injury symptoms were recorded on the soybean plants 30 days after treatment using a scale of 0-4, where "0" equals no injury, "1" equals slight injury, "2" equals moderate injury, "3" equals moderate to severe injury, and "4" equals severe visual injury or death of the plant. After visual

injury notes were made the soybean plants were harvested by cutting the plants at the cotyledonary node. Fresh weights and dry weights (Metler scales) of the soybean plants were recorded. The experiment was repli- four times.

Drift of Dicamba when Applied with Additives and Spray Nozzles

Chippewa soybeans were seeded in 18x7 cm cartons. The plants were thinned after emergence to one plant per carton.

A polyethylene chamber was constructed to study particle and vapor drift. The chamber had longitudinal dimensions of 120 x 130 cm and a vertical dimension of 190 cm. Two sliding shelves were inserted on the wall of the chamber 60 cm and 120 cm from the top of the chamber. Between the two sliding shelves two 15 cm fans were inserted on the wall of the chamber 30 cm and 90 cm from the top. A 15 cm cylinder was attached to each fan and extended 85 cm from the wall of the chamber into a plastic bag containing soybean plants. Dimethylene salt of dicamba was sprayed at a rate of 1.12 kg/ha through 8001-E, 8002-E, 730039-E TeeJet nozzles and an air-asperating nozzle at a pressure of 258 cm of Hg. This procedure was to determine the effect of spray nozzles on particle drift under windy conditions. The two fans were used to pull air from the spray chamber and blow it onto the soybean plants which were used as a bioassay to measure drift. The wind velocity was 6.4 km/hr. Soybeans were treated in early trifoliate growth stage.

Temperature was regulated at 24, 30, and 35C by a spot heater.

Humidity was regulated at 50, 75, and 95% with a cool air humidifier. After spraying the plants were placed outdoors and grown for three weeks. All plant growth above the cotyledonary node was harvested. Plants were oven dried at 70C and dry weights were recorded. Air blowing from the chamber over the soybean plants constituted the check. The experiment was replicated four times.

Another experiment was conducted to determine the contribution of suspended particles of dicamba to drift. Dicamba was sprayed into the empty chamber and allowed to settle for 10 seconds. The 10 second settling period was to allow droplets larger than 80μ to reach the bottom of the chamber. Ten seconds after spraying the two sliding shelves were put in place; therefore, the sprayed air was isolated into the two separate compartments and then blown over the soybean plants. The plants were then placed outdoors. Visual injury observations were made on the soybean plants using a scale of 0 - 4, where "0" equals no injury, "1" equals slight injury, "2" equals moderate injury, "3" equals moderate to severe injury, and "4" equals severe visual injury or death of the plant. The plants were harvested and the dry weights recorded as previously described. Temperature and humidity were controlled also as previously described.

The effect of additives on particle drift and on suspended particles of dicamba was studied using a 8001-E TeeJet nozzle and an air-asperating nozzle. Dicamba was sprayed at a rate of 1.12 kg/ha in 187 l/ha water alone and with the additives shown in Table 2. Temperature and humidity were regulated as previously mentioned. The

Table 2. The additives and the rates (l/ha) which were applied in combination with dicamba and the nozzle used to spray the mixture to study particle drift.

Additives	Rate	Nozzle
	l/ha	
X-77 [Alkylarylpolyoxyethylene glycols, free fatty acids, isopropanol]	.74	8001-E
Texaco Oil + Tronic [Code 754 spraytex superior oil] + [alkylarylpolyoxyethylene glycols, mixed petroleum distillates, alkyl sulfates, alkylamine acetate]	9.3+.98	8001-E
Amoco Concentrate Crop Oil [Superior type horticulture oil]	3.5	8001-E
Accutrol [Alpha (p-alkylphenyl)-omega-hydroxypoly (oxyethylene), alpha (p-alkylphenyl)-omega-hydroxypoly (oxyethylene) sulfates, alkyl sulfate]	.94	air-asperating

treatment procedure was as previously described.

The Phytotoxicity of Dicamba to Corn Applied in Combination with Additives

This experiment was located near Redfield, South Dakota on a silty clay loam soil, which had an organic matter content of 3.3% and a pH of 7.4. To control annual grassy weeds 2-chloro-2',6'-diethyl-N-(methoxymethyl) acetanilide (alachlor) at a rate of 1.68 kg/ha was applied preemergence. The experimental design was a randomized complete block with four replications. The plot size was 3.04 m x 9.12 m.

Three rates of dicamba, 0.07 kg/ha, 0.14 kg/ha, and 0.280 kg/ha

were applied in combination with each of the additives shown in Table 3.

Table 3. The additives and the rates (l/ha or kg/ha) applied in combination with dicamba to study the phytotoxicity to corn and broadleaf weeds.

Additive	Rate
Accutrol [alpha (p-alkylphenyl)-omega-hydroxypoly (oxyethylene), alpha (p-alkylphenyl)-omega-hydroxypoly (oxyethylene) sulfates, alkyl sulfate]	0.9 l/ha
Agri-Oil Plus [Paraffin base petroleum oil]	3.5 l/ha
Amoco Concentrate Crop Oil [Superior type petroleum oil]	3.5 l/ha
Bio-Veg [Linseed oil + turgitol 15-s-5]	2.3 l/ha
Dacagin [Polysaccharide-gum mixture]	1.13 kg/ha
Surfol-Plus [Petroleum hydrocarbons]	4.8 l/ha
Texaco Oil + Tronic [Code 754 Spraytex superior spray oil] + [alkylarylpolyoxyethylene glycols, mixed petroleum distillates, alkyl sulfates, alkylamine acetate]	9.3 + .5% l/ha

The treatments were applied in 187 l/ha spray solution at 206 cm of Hg with the exception of treatments containing Dacagin and Accutrol. Dacagin was applied in 187 l/ha but at 300 cm of Hg. Accutrol was applied at 187 l/ha spray solution through an air-asperating nozzle at 300 cm of Hg. All treatments were applied with a tractor sprayer. Treatments were applied to corn (Pioneer 3812) June 22 when the corn was 15 to 20 cm tall. Redroot pigweed (*Amaranthus retroflexus* L.), prostrate pigweed (*Amaranthus graecizans* L.) and lambsquarters

(Chenopodium album L.) were 3 to 6 cm tall. Visual estimates of percent weed control were made June 27, July 6, July 18, and August 1, 1972. Corn injury ratings were made July 6 and July 18. Corn injury was based on a 0 - 100 scale in which "0" equals no injury and "100" equals complete kill. Corn height was measured June 27, July 6, July 18, and August 1. Corn roots were pulled September 9, and the amount of force in kilograms for extraction was recorded. The number of ears per plot and corn yields from 6.1 m of the two center rows were recorded.

A similar experiment to determine the phytotoxicity to corn of dicamba applied in combination with additives was carried out on the Southeast Experimental Farm near Centerville, South Dakota on a silty clay loam soil of 3.6% organic matter and a pH of 6.7. The experimental design was a randomized complete block with four replications. The plot size was 3.04 m by 6.08 m. Treatments were the same as above except that .23 l/ha of Wex was also applied in combination with the three different rates of dicamba. Treatments were applied to corn (Pioneer 3505) June 6, when the corn was 15 to 20 cm tall. No weeds were present because the area had been treated with 1.68 kg/ha of alachlor which controlled both broadleaf and grassy weeds. Corn height was measured June 19 and July 19. Visual symptoms of corn injury as described previously were made July 3 and July 10. Corn roots were pulled September 16 and extraction force (kg), basal node numbers and basal internode lengths were recorded. The number of ears per plot and corn yields from 6.1 m of the two center rows were recorded.

RESULTS AND DISCUSSION

The Volatility of Dicamba

The loss of 14-C-dicamba from bare aluminum planchets was measured by counting the radioactivity remaining on the planchets. The results are shown in Table 4. The loss of 14-C-dicamba applied alone in water was less than when dicamba was applied with Amoco Concentrate Crop Oil but more than when dicamba was applied with X-77. These results suggest that additives may increase or decrease volatility of dicamba depending on the type of additive.

Temperature and humidity had no significant effect on the volatility of 14-C-dicamba (Table 4). However, the amount of 14-C-dicamba remaining on the planchets tended to increase as the relative humidity increased from 50% to 95%.

The volatility of 14-C-dicamba from soil is shown in Table 5. The volatility of 14-C-dicamba applied with X-77 was less than when dicamba was applied with Amoco Concentrate Crop Oil or when applied alone. Temperature and humidity had no significant effect on volatility of dicamba from soil. These results are similar to those obtained with bare aluminum planchets.

The volatility of dicamba was measured by bioassay procedures using soybean plants. Visual injury observations, fresh weights, and dry weights were used as a measure of the injury of soybean plants after exposure to dicamba vapors. Vapor drift from dicamba significantly injured the soybean plants as shown in Table 6. There were no

Table 4. The effect of additives, temperature, and humidity on the volatility of 14-C-dicamba from aluminum planchets[a].

Additives Applied in Combination with 14-C-Dicamba	Counts[b]
X-77	48,571[a]
Water	89,305[b]
Amoco Concentrate Crop Oil	184,324[c]
Temperature (C)	
24	104,535[a]
30	108,218[a]
35	109,447[a]
Humidity (%)	
50	128,557[a]
75	97,795[a]
95	95,848[a]

[a]The counts represent the loss of 14-C-dicamba from aluminum planchets.

[b]Numbers within a column followed by the same letter are not significantly different at the 5% level according to the Orthogonal Comparison Test.

Table 5. The effect of additives, temperature, and humidity on the volatility of 14-C-dicamba from soil on aluminum planchets[a].

Additives Applied in Combination with 14-C-Dicamba	Counts[b]
X-77	281^{a}
Amoco Concentrate Crop Oil	$27,905^{b}$
Water	$28,084^{b}$
Temperature (C)	
24	$8,045^{a}$
30	$16,467^{a}$
35	$31,758^{b}$
Humidity (%)	
50	$15,538^{a}$
75	$20,821^{a}$
95	$19,910^{a}$

[a]The counts represent the loss of 14-C-dicamba from soil on aluminum planchets.

[b]Numbers within a column followed by the same letter are not significantly different at the 5% level according to the Orthogonal Comparison Test.

Table 6. The effects to soybeans of volatility from dicamba applied to soil and aqueous solutions as affected by additives and temperature[a].

Additives[b]	Visual Injury Observations[c]	Fresh Weight (g)	Dry Weight (g)
Water + Soil	3.258^{a}	4.749^{a*}	1.349^{a}
Water	2.992^{a}	4.932^{a*}	1.393^{a*}
X-77 + Soil	3.342^{a}	4.585^{a}	1.292^{a}
x-77	3.017^{a}	4.884^{a*}	1.372^{a}
Amoco Concentrate Crop Oil + Soil	3.097^{a}	4.414^{a}	1.230^{a}
Amoco Concentrate Crop Oil	3.283^{a}	4.418^{a}	1.252^{a}
Check	0^{*}	5.156^{*}	1.505^{*}
Temperature (C)			
24	2.773^{a}	5.117^{a*}	1.421^{a}
30	3.138^{b}	4.471^{b}	1.293^{b}
35	3.620^{c}	4.402^{b}	1.229^{b}
Check	0^{*}	5.156^{*}	1.505^{*}

[a]Numbers within a column followed by the same letter are not significantly different at the 5% level according to the Orthogonal Comparison Test.

[b]Dicamba was applied in combination with or without additives in soil or aqueous solution.

[c]Visual injury observations were based on a scale of 0 - 4 where "0" equals no injury, "1" equals slight injury, "2" equals moderate injury, "3" equals moderate to severe injury, "4" equals severe injury or death of the plant.

*Means without the asterisk are significantly different according to Dunnetts one sided t test at the 5% level.

significant differences in dicamba volatility among dicamba treatments as measured by visual observations. Furthermore, the surface to which dicamba was applied had no effect upon vapor drift of dicamba.

The effect of temperature on vapor drift of dicamba as measured by visual observations is shown in Table 6. Phytotoxicity due to vapor drift of dicamba was increased from 2.7 to 3.6 as the temperature was increased from 24 to 35C (Figure 1.). These results suggest that dicamba will volatilize more in high temperatures than in lower temperatures.

Measurements of fresh and dry weights of soybean plants were made to determine injury due to vapor drift of dicamba (Table 6). Vapor drift from dicamba applied with X-77 to soil, Amoco Concentrate Crop Oil to soil and Amoco Concentrate Crop Oil in aqueous solution significantly reduced soybean fresh weights. Furthermore, all treatments with the exception of dicamba applied in aqueous solution significantly reduced soybean dry weights. Dicamba vapors from aqueous solutions or soil did not significantly affect either the fresh or dry weights of soybeans.

Fresh and dry weights of plants exposed to vapor drift of dicamba at temperatures of 30 and 35C were significantly reduced when compared to the unexposed check. These results suggest as previously stated, that as the temperature increases volatility of dicamba will also increase, thus causing a greater degree of injury to soybean plants.

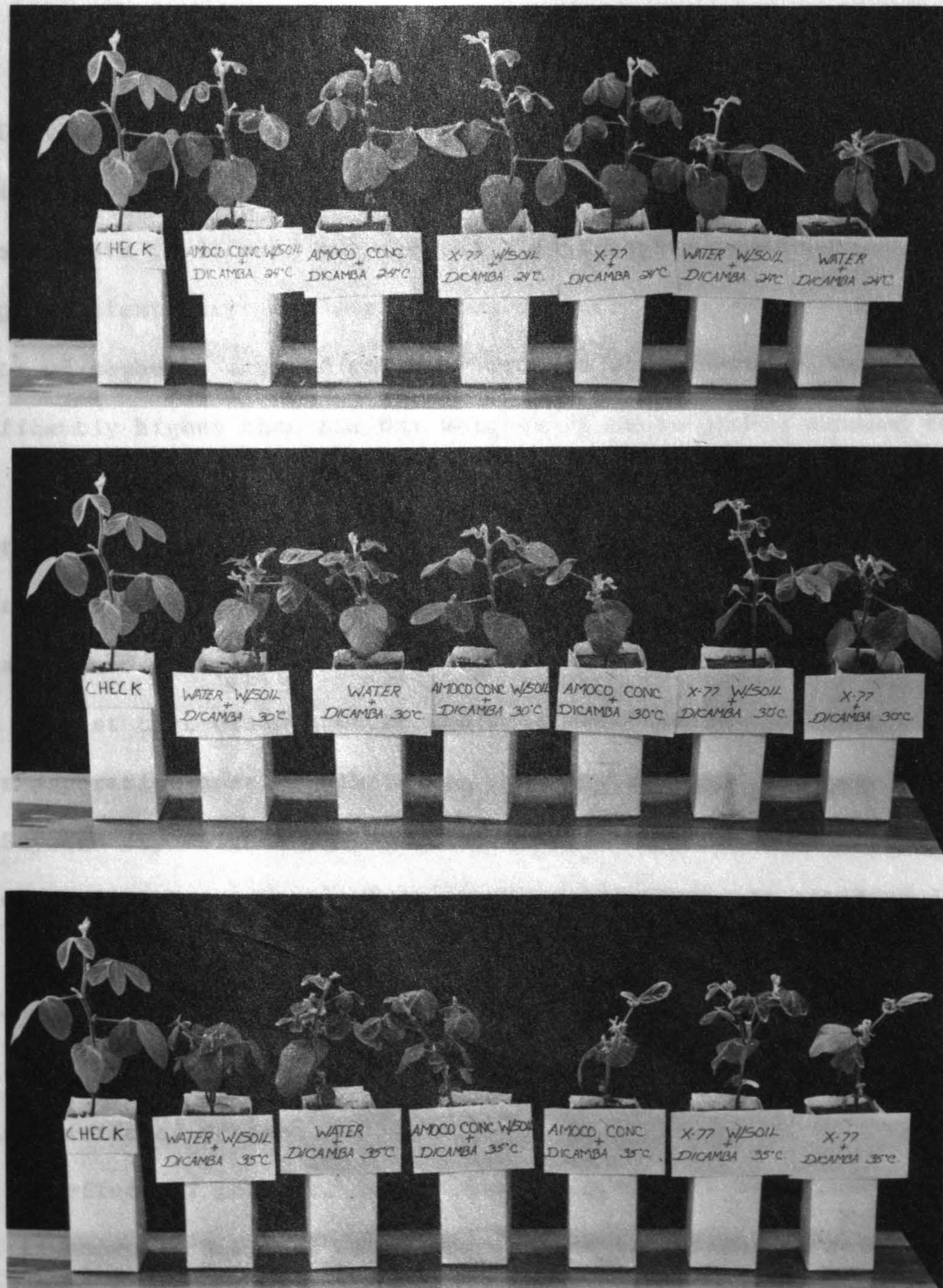

Figure 1. Soybean plants 21 days after exposure to volatility effected by applying dicamba mixed with various additives in soil and aqueous solutions at various temperatures

Dicamba Drift with Nozzles and Additives

Drift of dicamba was influenced by type of nozzle used when spraying in windy conditions (Table 7). The dry weight of soybean plants exposed to dicamba was reduced significantly compared to the nonexposed plants irregardless of nozzle type. However, the dry weights of soybeans exposed to spray from an air-asperating nozzle were significantly higher than the dry weights of those plants exposed to spray from the 8002-E, 8001-E and 730039-E TeeJet nozzles. Visual observations confirm these results. The soybean plants exposed to spray from the air-asperating nozzle had less visual injury symptoms than plants exposed to spray from the TeeJet nozzles (Table 7). These results suggest that dicamba drift could be decreased by spraying with an air-asperating nozzle rather than conventional type nozzles.

Soybean dry weights did not differ significantly for those plants exposed to dicamba drift 90 cm below the spray nozzle as compared to those plants exposed 30 cm below the spray nozzle. This was also confirmed with visual injury observations. These results suggest that the height of the nozzle above the plant had no significant effect on particle drift of dicamba.

The effect of relative humidity and temperature on dicamba drift is shown in Table 7. Soybeans exposed to dicamba at relative humidities of 75 and 95% tended to have higher dry weights than plants exposed to dicamba drift at a relative humidity of 50%. Furthermore, visual injury observation showed the same trend. These results suggest

Table 7. The effect of nozzles, height of spray nozzle above target, relative humidity, and temperature on drift of dicamba in windy conditions as measured by the dry weight and visual injury observations of soybean plants exposed to the drift[a,b].

Nozzle	Dry Weight (g)	Visual Injury Observations[c]
Air-asperating	.6994[a]	1.12[a]
8002-E	.5832[b]	2.10[b]
8001-E	.6083[b]	2.26[b]
730039-E	.6883[c]	1.97[b]
Check	.854*	0*
Height of Spray Nozzle (cm)[d]		
30	.6439[a]	1.79[a]
90	.6357[a]	1.93[a]
Check	.854*	0*
Relative Humidity (%)		
50	.6118[a]	1.97[a]
75	.6549[a]	1.81[a]
95	.6527[a]	1.80[a]
Check	.854*	0*
Temperature (C)		
24	.6260[a]	1.82[a]
30	.6523[a]	1.81[a]
35	.6412[a]	1.95[a]
Check	.854*	0*

[a]Dicamba was applied in aqueous solution at 1.12 kg/ha.

[b]Numbers within a column followed by the same letter are not significantly different at the 5% level according to the Orthogonal Comparison Test.

[c]Visual injury observations were based on a scale of 0 - 4 where "0" equals no injury, "1" equals slight injury, "2" equals moderate injury, "3" equals moderate to severe injury, and "4" equals severe injury or death of the plant.

[d]Height of spray nozzle over target when blown over soybean plants.

*Means without the asterisk are significantly different according to Dunnetts one sided t test at the 5% level.

that fewer particles are evaporated to small more drift hazardous sizes at high relative humidites than at low humidities.

The temperature at the time of spraying did not significantly influence dicamba drift as measured by soybean dry weight or by visual injury observations. However, visual injury measurements resulted in more injury at 35C than at 24 and 30C. This may indicate that higher temperatures at the time of spraying will cause more dicamba drift.

The dry weights and visual injury observation of soybean plants exposed to dicamba 10 seconds after spraying are shown in Table 8. The dry weight of soybean plants exposed to dicamba drift were significantly less than the dry weights not exposed to dicamba. These results suggest that dicamba sprayed with either the TeeJet or air-asperating nozzles was subject to drift. However, the air-asperating nozzle significantly reduced the amount of dicamba drift obtained with the TeeJet nozzles. These results are supported by visual injury ratings which show dicamba particles were suspended irregardless of nozzle type. However, fewer particles were suspended when the air-asperating nozzles were used than when the conventional TeeJet nozzles were used. This suggests that droplets sprayed from the air-asperating nozzle are less likely to be suspended and will reduce the amount of dicamba drift significantly.

Soybean dry weights tended to be greater for those plants exposed to dicamba drift at 30 cm below the spray nozzle than for those plants exposed 90 cm below the spray nozzle. Furthermore, visual measurements of soybean injury suggested that a greater amount of injury

Table 8. The effect of additives, height of spray nozzle above the target, relative humidity, and temperature on drift of dicamba after a 10 second lapse in time. The effect was measured by the dry weight and visual injury observations of soybean plants exposed to the drift[a,b].

Nozzle	Dry Weight (g)	Visual Injury Observations[c]
Air-asperating	.7031[a]	1.01[a]
8002-E	.5905[b]	1.85[b]
8001-E	.5947[b]	2.05[b]
730039-E	.6237[b]	1.81[b]
Check	.840*	0*
Height of Spray Nozzle (cm)[d]		
30	.6398[a]	1.56[a]
90	.6161[a]	1.80[b]
Check	.840*	0*
Relative Humidity (%)		
50	.5979[a]	1.77[a]
75	.6332[b]	1.71[a]
95	.6532[b]	1.56[b]
Check	.840*	0*
Temperature (C)		
24	.6326[a]	1.67[a]
30	.6250[a]	1.66[a]
35	.6265[a]	1.71[a]
Check	.840*	0*

[a]Dicamba was applied in aqueous solution at 1.12 kg/ha.

[b]Numbers within a column followed by the same letter are not significantly different at the 5% level according to the Orthogonal Comparison Test.

[c]Visual injury observations were based on a scale of 0 - 4 where "0" equals no injury, "1" equals slight injury, "2" equals moderate injury, "3" equals moderate to severe injury, and "4" equals severe injury or death of the plant.

[d]Height of spray nozzle over target when blown over soybean plants.

*Means without the asterisk are significantly different according to Dunnetts one sided t test at the 5% level.

resulted from droplets suspended 90 cm below the spray nozzle (Table 8).

The effect of relative humidity and temperature on suspension of droplets is also shown in Table 8. Suspended particles of dicamba sprayed at a relative humidity of 50% reduced the plant dry weight more than the suspended particles of dicamba sprayed at relative humidities of 75 and 95%. Visual injury measurements agree with the results obtained with the plant dry weights.

The temperature at the time of spraying did not influence the amount of suspended particles of dicamba as measured by dry weights (Table 8). However, visual injury ratings suggested greater injury at 35C than at 24 and 30C. These results show that high temperatures may increase the drift of dicamba.

Soybean plants were used in a bioassay test to determine the amount of dicamba drift with and without additives in the laboratory. Twenty-one days after exposure to dicamba drift, the soybean plants were harvested and dry weights were recorded. Soybean plants dry weights were less when dicamba was applied in combination with Texaco oil + Tronic, Amoco Concentrate Crop Oil or X-77 than when dicamba was applied alone or in combination with Accutrol (Table 9). The increase in spray drift caused by some additives agree with the results obtained by Page (37). Soybean dry weights tended to be greater for those plants exposed to dicamba drift 90 cm below the spray nozzle than for those plants exposed to dicamba drift at 30 cm below the spray nozzle (Table 9). This suggests that more particle drift is present at the upper level perhaps because of fine droplets that may have increased in

Table 9. The effect of additives, height of spray nozzle above target, relative humidity, and temperature on drift of dicamba in windy conditions. The effect was measured by dry weight of soybean plants exposed to the drift[a].

Additives Applied in Combination With Dicamba (1.12 kg/ha)	Dry Weight (g)
Texaco Oil + Tronic	.8329[a]
Amoco Concentrate Crop Oil	.8121[a]
X-77	.7781[a]
Water	.8646[b]
Accutrol	.8641[b]
Check	.9801*
Height of Spray Nozzle (cm)[b]	
30	.8234[a]
90	.8383[a]
Check	.9801*
Relative Humidity (%)	
50	.8070[a]
75	.8300[a]
95	.8550[b]
Check	.9801*
Temperature (C)	
24	.8370[a]
30	.8270[a]
35	.8290[a]
Check	.9801*

[a]Numbers within a column followed by the same letter are not significantly different at the 5% level according to the Orthogonal Comparison Test.

[b]Height of spray nozzle over target when blown over soybean plants.

*Means without the asterisk are significantly different according to Dunnetts one sided t test at the 5% level.

number because of the additives lowering the surface tension.

The effect of relative humidity and temperature on dicamba drift is shown in Table 9. Soybeans exposed to particle drift when the relative humidity was 95% had significantly higher dry weights than soybeans exposed at relative humidities of 50 and 75%. The temperature at the time of spraying did not significantly influence dicamba drift as measured by the dry weights of soybeans. However, soybean dry weights tended to decrease as the temperature increased. These results suggest that low relative humidities cause more drift than high humidities possibly because the drying power of the air would be greater at low humidities. This would cause large particles that are less likely to be a drift hazard to evaporate to small particles and thus become a greater drift hazard. Furthermore, high temperatures tended to cause more dicamba drift than lower temperatures. This supports the above statement that large droplets may be evaporated to smaller droplets soon after spraying.

The data in Table 10 show the results of an experiment to determine the contribution of suspended particles to dicamba drift. The air within the chamber was blown over the soybean plants ten seconds after spraying. The dry weight of soybean plants exposed to dicamba drift were significantly less than the dry weight of plants not exposed to dicamba except for plants treated with dicamba + Accutrol and sprayed with an air-asperating nozzle. These results suggest that dicamba drift in suspended conditions can be reduced substantially if

Table 10. The effect of additives, height of spray nozzle above target, relative humidity, and temperature on drift of dicamba after 10 second lapse in time. The effect was measured by the dry weights and visual injury observations of soybean plants exposed to the drift[a].

Additives Applied in Combination With Dicamba (1.12 kg/ha)	Effect on Soybeans	
	Dry Weight (g)	Visual Injury Observations[b]
Texaco Oil + Tronic	.7141[a]	2.22[a]
Amoco Concentrate Crop Oil	.6701[a]	2.20[a]
X-77	.7089[a]	2.01[a]
Water	.7218[a]	1.85[a]
Accutrol	.8125[b]*	1.15[b]
Check	.8540*	0*
Height of Spray Nozzle (cm)[c]		
30	.7385[a]	1.73[a]
90	.7124[a]	2.04[a]
Check	.8540*	0*
Relative Humidity (%)		
50	.6739[a]	2.08[a]
75	.7529[b]	1.80[b]
95	.7496[b]	1.79[b]
Check	.8540*	0*
Temperature (C)		
24	.7418[a]	1.76[a]
30	.7387[a]	1.81[a]
35	.6960[a]	2.09[b]
Check	.8540*	0*

[a]Numbers within a column followed by the same letter are not significantly different at the 5% level according to the Orthogonal Comparison Test.

[b]Visual injury observations were based on a scale of 0 - 4 where "0" equals no injury, "1" equals slight injury, "2" equals moderate injury, "3" equals moderate to severe injury, and "4" equals severe injury or death of the plant.

[c]Height of spray nozzle over target when blown over soybean plants.

*Means without the asterisk are significantly different according to Dunnetts one sided t test at the 5% level.

a foaming agent is used with an air-asperating nozzle (Table 10). The nontreated check had significantly less visual injury symptoms than plants exposed to dicamba drift. Again dicamba + Accutrol applied with an air-asperating nozzle had significantly less injury than the dicamba treatments applied with or without additives.

Soybean dry weight was less for those plants exposed to dicamba particles suspended 90 cm below the spray nozzle than for those plants exposed to suspended particles 30 cm below the spray nozzle. Also, greater visual injury was caused to plants exposed to dicamba drift at 90 cm below the spray nozzle than for those exposed at 30 cm below the spray nozzle. These results suggest that small droplet particles were suspended in the lower level. Therefore, soybean plants exposed to dicamba from the lower level tended to have lower dry weights and greater visual injury ratings than plants exposed to dicamba from the higher level (Table 10). Soybean dry weight indicated that less particles of dicamba were suspended at 95% than at 75 or 50% relative humidities.

The temperature at the time of spraying did not significantly affect dicamba drift as measured by dry weights (Table 10). Soybean dry weights did, however, tend to decrease as the temperatures increased from 24 to 35C. These results suggest that large droplets are evaporated to smaller, more drift hazardous droplets at higher temperatures. Further, visual injury measurements suggested a significantly higher amount of injury at 35C.

The Phytotoxicity of Dicamba to Corn and Broadleaf Weeds when Applied with Additives

The phytotoxicity of dicamba to corn was recorded as corn leaf rolling, corn height reduction, root and basal node inhibition, and corn yield reduction. These results are presented in Table 11 and Table 12.

Visual measurements of corn leaf rolling were taken on June 19 and July 19 at Centerville and on July 6 and July 18 at Redfield. The amount of leaf rolling on June 19 at Centerville and July 6 at Redfield ranged from 11.6 to 27.5% and 10.8 to 25.9%, respectively. On July 19 at Centerville and July 18 at Redfield corn leaf rolling had decreased substantially and ranged from 10.4 to 12.9% at Centerville and 10.0 to 15.5% at Redfield. The combined average of the percent leaf rolling at two dates ranged from 11.0 to 19.8% at Centerville and 10.4 to 20.7% at Redfield thus indicating similar phytotoxicity at both plot sites (Tables 11 and 12). With the exception of Dacagin, dicamba caused more leaf rolling when applied in combination with an additive than without an additive. Poor spray coverage may be the reason that Dacagin caused less leaf rolling than when other additives were applied in combination with dicamba. Texaco oil + Tronic and Amoco Concentrate Crop Oil tended to have a greater amount of leaf rolling at both locations. These results suggest that additives enhance the effect of dicamba and cause greater phytotoxicity.

Corn height measurements were recorded June 19 and July 19 at

Table 11. The phytotoxicity of dicamba to corn when applied with additives and measured by percent corn leaf rolling, height, ear number, basal node number, basal internode length, root extraction force and yield[a,b].

Treatment	Percent Corn Leaf Rolling at Two Dates[c] June 19	July 19	Mean
Dicamba + Amoco Concentrate Crop Oil	27.5	12.1	19.8[a]
Dicamba + Texaco Oil + Tronic	25.8	12.9	19.4[a]
Dicamba + Agri-Oil Plus	25.0	12.1	18.5[a]
Dicamba + Bio-Veg	22.9	12.9	17.9[a,b]
Dicamba + Surfol Plus	21.2	11.7	16.5[b,c]
Dicamba + X-77	20.8	12.1	16.5[b,c]
Dicamba + Accutrol[d]	18.3	11.7	15.0[c,d]
Dicamba + Accutrol	17.9	10.8	14.4[d]
Dicamba + Wex	15.8	11.7	13.8[d]
Dicamba + Dacagin	13.3	10.0	11.7[e]
Check	11.6	10.4	11.0[e]

[a]Experiment location was at Centerville, South Dakota.

[b]Numbers within a column followed by the same letter are not significantly different at the 5% level using Duncans multiple range test.

[c]Percent corn leaf rolling is based on 0 - 100 scale, where "0" equals no injury and "100" equals complete kill.

[d]Sprayed at double volume.

Corn Height (cm)	Corn Ear Number	Basal Node Number	Basal Node Length (cm)	Root extraction Force (kg)	Corn Yields (kg/ha)
128.6^{e}	33.3^{a}	7.4^{a}	4.0^{a}	197^{a}	8725^{a}
$130.1^{d,e}$	33.5^{a}	7.7^{a}	4.6^{a}	196^{a}	8995^{a}
$130.6^{c,d,e}$	34.0^{a}	7.5^{a}	4.3^{a}	189^{a}	9252^{a}
$130.4^{d,e}$	33.9^{a}	7.7^{a}	4.4^{a}	203^{a}	8963^{a}
$131.2^{a,b,c,d}$	34.6^{a}	7.4^{a}	4.7^{a}	202^{a}	9114^{a}
$132.8^{a,b,c}$	34.4^{a}	7.6^{a}	4.5^{a}	189^{a}	9108^{a}
$131.9^{a,b,c,d}$	34.1^{a}	7.8^{a}	4.2^{a}	212^{a}	9026^{a}
$131.0^{b,c,d}$	34.8^{a}	7.6^{a}	4.8^{a}	193^{a}	9070^{a}
133.5^{a}	34.4^{a}	7.7^{a}	4.0^{a}	197^{a}	8781^{a}
$133.3^{a,b}$	34.2^{a}	7.6^{a}	3.7^{a}	191^{a}	9308^{a}
$131.1^{a,b,c,d}$	33.6^{a}	7.5^{a}	4.2^{a}	215^{a}	9315^{a}

Table 12. The phytotoxicity of dicamba to corn when applied with additives and measured by percent corn leaf rolling, height, ear number, basal node number, root extraction force and corn yields[a,b].

Treatment	Percent Corn Leaf Rolling at Two Dates[c] June 19	July 19	Mean
Dicamba + Texaco Oil + Tronic	25.9	15.5	20.7[a]
Dicamba + Amoco Concentrate Crop Oil	23.5	14.2	18.9[a,b]
Dicamba + X-77	21.3	12.9	17.1[b,c]
Dicamba + Surfol Plus	21.7	12.1	16.9[b,c,d]
Dicamba + Agri-Oil Plus	20.0	13.8	16.9[b,c,d]
Dicamba + Bio-Veg	20.1	12.1	16.1[c,d]
Dicamba + Accutrol[d]	18.4	10.8	14.6[d,e]
Dicamba + Accutrol	16.3	10.4	13.4[e]
Dicamba + Dacagin	11.4	10.0	10.7[f]
Dicamba (Check)	10.8	10.0	10.4[f]

[a]Experiment location was at Redfield, South Dakota.

[b]Numbers within a column followed by the same letter are not significantly different at the 5% level using Duncans multiple range test.

[c]Percent corn leaf rolling is based on a 0 - 100 scale, where "0" equals no injury and "100" equals complete kill.

[d]Sprayed at double volume.

Corn Height (cm)	Corn Ear Number	Basal Node Number	Root extraction Force (kg)	Corn Yields (kg/ha)
102.1^{a,b}	28.3^{a}	7.40^{a}	198^{a}	6478^{a}
100.2^{a}	28.3^{a}	7.00^{a}	201^{a}	6176^{a}
101.1^{b}	27.8^{a}	7.75^{a}	176^{a}	6547^{a}
100.7^{b}	28.0^{a}	7.50^{a}	193^{a}	6471^{a}
102.2^{a,b}	28.0^{a}	7.50^{a}	203^{a}	6666^{a}
101.2^{b}	27.4^{a}	7.60^{a}	187^{a}	6283^{a}
101.4^{b}	28.8^{a}	7.50^{a}	190^{a}	6258^{a}
102.1^{a,b}	27.6^{a}	7.30^{a}	173^{a}	6565^{a}
101.7^{b}	27.8^{a}	7.40^{a}	206^{a}	6151^{a}
104.2^{a}	28.5^{a}	7.30^{a}	196^{a}	6371^{a}

Centerville and June 27, July 18, and August 1 at Redfield to determine if stunting occurred when dicamba was applied with additives. The data is shown in Tables 11 and 12. At Centerville corn height increased when dicamba was applied with Dacagin, Wex, X-77, and Accutrol (double volume), but tended to decrease when dicamba was applied with Texaco oil + Tronic, Amoco Concentrate Corp Oil, Agri-Oil Plus, and Bio-Veg. All treatments applied with additives at Redfield tended to reduce corn height over that of the corn treated with dicamba without additives. Amoco Concentrate Crop Oil was the only treatment that significantly decreased corn height at both locations (Tables 11 and 12).

The effect of dicamba applied with additives on basal node number, basal internode length (at Centerville only), and root extraction pull is shown in Tables 11 and 12. Basal node number, basal internode length, and the root extraction pull did not vary appreciably among treatments at either location.

Corn ear number and corn yields were taken October 4 at Redfield and September 28 at Centerville to further determine the phytotoxicity of dicamba when applied with additives. Results showed no difference among treatments. These results suggest that injury as indicated by leaf rolling and reduction of corn heights did not influence corn yields, basal node number, basal internode length, ear number, or root extraction force.

The effect of various rates of dicamba on corn injury as indicated by the amount of leaf rolling, corn height, corn ear number, basal

node number, basal internode length, root extraction force (Centerville only), and corn yields are shown in Tables 13 and 14. The amount of leaf rolling increased from 11.8 to 21.7% at Centerville and 11.8 to 21.6% at Redfield as the rate of dicamba was increased from 0.07 kg/ha to 0.28 kg/ha.

Injury to corn at all rates of dicamba decreased as the season progressed. At dicamba rates of 0.07 to 0.28 kg/ha, leaf rolling averages 13.4 and 27.4% , respectively, at Redfield and 13.1 and 29.1% at Centerville early in the season. These same plots averaged 10.1 and 15.8% at Redfield and 10.3 and 14.3% at Centerville later in the season.

Corn height decreased from 131.3 to 129.1 cm at Centerville and 103.5 to 99.7 cm at Redfield as the rate of dicamba was increased from 0.07 kg/ha and 0.28 kg/ha.

Basal node number, basal internode length, corn ear number and root extraction force did not vary significantly at any rate of di-camba (Tables 13 and 14). However, at Centerville root extraction force tended to decrease as the rate of dicamba was increased from 0.07 kg/ha to 0.28 kg/ha. These results suggest some phytotoxicity on root growth.

Corn yields were not altered significantly at either location. However, at Redfield yields of corn treated with 0.07 kg/ha were 6515 kg/ha while those treated with 0.28 kg/ha were 6377 kg/ha which suggests some phytotoxicity at the higher rates of dicamba.

The additives enhanced the phytotoxicity of dicamba more as the

Table 13. The phytotoxicity of dicamba to corn when applied at three rates as measured by percent corn leaf rolling, height, ear number, basal node number, basal internode length, root extraction force, and corn yields[a,b].

Treatment	Rate kg/ha	Percent Corn Leaf Rolling at Two Dates[c] June 19	July 19	Mean	Corn Height (cm)	Corn Ear Number	Basal Node Number	Basal Internode Length (cm)	Root Extraction Force (kg)	Corn Yield (kg/ha)
Dicamba	0.070	13.1	10.3	11.8[a]	131.3[a]	33.4[a]	7.6[a]	4.5[a]	203[a]	9001[a]
Dicamba	0.140	17.8	10.3	14.1[b]	132.7[a]	34.2[a]	7.6[a]	4.3[a]	198[a]	9138[a]
Dicamba	0.280	29.1	14.3	21.7[c]	129.1[b]	34.5[a]	7.6[a]	4.2[a]	194[a]	9032[a]

[a]Experiment location was at Centerville, South Dakota.

[b]Numbers within a column followed by the same letter are not significantly different at the 5% level according to Duncans multiple range test.

[c]Percent corn leaf rolling is based on a 0 - 100 scale, where "0" equals no injury and "100" equals complete kill.

Table 14. The phytotoxicity of dicamba to corn when applied at three rates as measured by percent corn leaf rolling, height, ear number, basal node number, root extraction force and corn yields[a,b].

Treatment	Rate (kg/ha)	Percent Corn Leaf Rolling at Two Dates[c] July 6	July 18	Mean	Corn Height (cm)	Corn Ear Number	Basal Node Number	Root Extraction Force (kg)	Corn Yields (kg/ha)
Dicamba	0.070	13.4	10.1	11.8[a]	103.5[a]	27.8[a]	7.5[a]	192[a]	6515[a]
Dicamba	0.140	16.0	10.6	13.3[a]	101.9[a,b]	28.2[a]	7.4[a]	189[a]	6308[a]
Dicamba	0.280	27.4	15.8	21.6[b]	99.7[b]	28.2[a]	7.5[a]	196[a]	6377[a]

[a]Experiment location was at Redfield, South Dakota.

[b]Numbers within a column followed by the same letter are not significantly different at the 5% level according to Duncans multiple range test.

[c]Percent corn leaf rolling is based on a 0 - 100 scale, where "0" equals no injury and "100" equals complete kill.

rate of dicamba increased (Tables 15 and 16). Little variation in the amount of leaf rolling was present when 0.07 kg/ha of dicamba was applied with the various additives. However, as the rate of dicamba was increased to 0.14 kg/ha the amount of leaf rolling ranged from 10.0 to 18.8% at Redfield and 10.6 to 18.1% at Centerville. The range in amount of leaf rolling was greater at 0.28 kg/ha of dicamba than at 0.14 kg/ha. The percent of leaf rolling at 0.28 kg/ha of dicamba ranged from 10.6 to 30.3% at Redfield and 11.9 to 28.1% at Centerville. At both locations, Amoco Concentrate Crop Oil and Texaco oil + Tronic caused more leaf rolling when applied in combination with dicamba than other additives applied in combination with dicamba.

Visual control estimates of redroot pigweed, prostrate pigweed, and lambsquarters made on June 27 are shown in Tables 17, 18, and 19. Some weed species were affected more by dicamba when applied in combination with additives than others. Amoco Concentrate Crop Oil, Surfol Plus, Agri-Oil Plus, and Texaco oil + Tronic significantly increased redroot pigweed control. Dacagin, Accutrol (single volume), and Accutrol (double volume) decreased redroot pigweed control. Poor spray coverage is probably the reason for the decreased control. No additives significantly increased prostrate pigweed control over the treated check (Table 18). Prostrate pigweed control obtained with Dacagin, Accutrol (single volume), Accutrol (double volume), X-77, Surfol Plus, Agri-Oil Plus, and Bio-Veg was substantially less than that obtained with the treated check. All additives applied with dicamba

Table 15. The phytotoxicity of dicamba to corn when applied at three rates and in combination with additives as measured by percent corn leaf rolling[a,b].

Treatment	Percent Corn Leaf Rolling at Three Rates of Dicamba (kg/ha)[c] 0.070	0.140	0.280	Mean
Dicamba + Amoco Concentrate Crop Oil	13.1	18.1	28.1	19.8[a]
Dicamba + Texaco Oil + Tronic	11.9	18.1	28.1	19.4[a]
Dicamba + Agri-Oil Plus	12.5	16.9	26.3	18.5[a]
Dicamba + Bio-Veg	10.6	16.3	26.9	17.9[a,b]
Dicamba + Surfol Plus	11.9	14.4	23.1	16.5[b,c]
Dicamba + X-77	10.6	13.8	25.0	16.5[b,c]
Dicamba + Accutrol[d]	11.3	13.1	20.6	15.0[c,d]
Dicamba + Accutrol	11.3	12.5	19.4	14.4[d]
Dicamba + Wex	13.8	11.3	16.3	13.8[d]
Dicamba + Dacagin	11.9	10.0	13.1	11.7[e]
Dicamba (Check)	10.6	10.6	11.9	11.0[e]
Mean	11.8[a]	14.1[b]	21.7[c]	

[a]Experiment location was at Centerville, South Dakota.

[b]Numbers within a column or row followed by the same letter are not significantly different at the 5% level using Duncans multiple range test.

[c]Percent corn leaf rolling based on a 0 - 100 scale where "0" equals no injury and "100" equals complete kill.

[d]Sprayed at double volume.

Table 16. The phytotoxicity of dicamba to corn when applied at three rates and in combination with additives as measured by percent corn leaf rolling[a,b].

Treatment	Percent Corn Leaf Rolling at Three Rates of Dicamba (kg/ha)[c]			
	0.070	0.140	0.280	Mean
Dicamba + Texaco Oil + Tronic	13.2	18.8	30.1	20.7[a]
Dicamba + Amoco Concentrate Crop Oil	11.3	15.0	30.3	18.9[a,b]
Dicamba + X-77	11.9	14.4	25.0	17.1[b,c]
Dicamba + Surfol Plus	11.3	13.8	25.6	16.9[b,c,d]
Dicamba + Agri-Oil Plus	10.6	12.5	27.5	16.9[b,c,d]
Dicamba + Bio-Veg	11.9	13.8	22.6	16.1[c,d]
Dicamba + Accutrol[d]	14.4	11.9	17.5	14.6[d,e]
Dicamba + Accutrol	11.3	13.2	15.6	13.4[e]
Dicamba + Dacagin	11.3	10.0	10.9	10.7[f]
Dicamba (Check)	10.6	10.0	10.6	10.4[f]
Mean	11.8[a]	13.3[a]	21.6[b]	

[a]Experiment location was at Redfield, South Dakota.

[b]Numbers within a column or row followed by the same letter are not significantly different at the 5% level using Duncans multiple range test.

[c]Percent corn leaf rolling based on a 0 - 100 scale where "0" equals no injury and "100" equals complete kill.

[d]Sprayed at double volume.

Table 17. The phytotoxicity of dicamba to redroot pigweed (Amaranthus retroflexus L.) applied at three rates and in combination with additives when measured by visual estimates of percent control[a,b].

Treatment	Percent Pigweed Control at Three Rates of Dicamba (kg/ha)[c]			
	0.070	0.140	0.280	Mean
Amoco Concentrate Crop Oil	45.0	66.3	86.7	66.0[a]
Surfol Plus	54.1	59.2	78.3	63.9[a,b]
Agri-Oil Plus	45.8	52.5	82.0	60.1[a,b]
Texaco Oil + Tronic	32.7	76.7	69.6	59.6[b]
X-77	35.0	53.3	65.0	51.1[c]
Bio-Veg	30.8	44.2	77.5	50.8[c]
Check	28.3	45.0	73.0	48.9[c,d]
Accutrol	28.3	50.0	60.4	46.3[c,d]
Accutrol[d]	28.3	48.3	54.1	43.6[d]
Dacagin	25.8	36.7	27.5	30.0[e]
Mean	35.4[a]	53.2[b]	67.5[c]	

[a]Experiment location at Redfield, South Dakota.

[b]Numbers within a column or row followed by the same letter are not significantly different at the 5% level using Duncans multiple range test.

[c]Percent rough pigweed control based on a 0 - 100 scale, where "0" equals no control and "100" equals complete control.

[d]Sprayed at double volume.

Table 18. The phytotoxicity of dicamba to prostrate pigweed (*Amaranthus graecizans* L.) applied at three rates and in combination with additives as measured by visual estimates of percent control[a,b].

Treatment	Percent Prostrate Pigweed Control at Three Rates of Dicamba (kg/ha)[c]			
	0.070	0.140	0.280	Mean
Amoco Concentrate Crop Oil	12.5	15.0	17.5	15.0[a]
Check	17.5	13.3	13.3	14.7[a]
Texaco Oil + Tronic	7.5	11.7	21.7	13.6[a,b]
Bio-Veg	5.0	9.2	20.0	11.3[b]
Agri-Oil Plus	5.8	7.5	19.2	10.8[b,c]
Surfol Plus	4.1	11.7	16.6	10.8[b,c]
Accutrol	5.0	10.0	9.2	8.0[c,d]
X-77	4.1	8.3	10.8	7.7[d]
Accutrol[d]	5.8	5.0	11.7	7.5[d]
Dacagin	1.7	4.2	10.0	5.2[d]
Mean	7.0[a]	10.0[b]	15.0[c]	

[a]Experiment location at Redfield, South Dakota.

[b]Numbers within a column or row followed by the same letter are not significantly different at the 5% level using Duncans multiple range test.

[c]Percent prostrate pigweed control is based on a 0 - 100 scale, where "0" equals no control and "100" equals complete control.

[d]Sprayed at double volume.

Table 19. The phytotoxicity of dicamba to lambsquarters (Chenopodium album L.) applied at three rates and in combination with additives as measured by visual estimates of percent control[a,b].

Treatment	Percent Lambsquarters Control at Three Rates of Dicamba (kg/ha)[c]			
	0.070	0.140	0.280	Mean
Agri-Oil Plus	79.2	84.6	89.6	84.0[a]
Amoco Concentrate Crop Oil	77.5	86.7	84.2	83.0[a,]
Bio-Veg	65.0	80.8	90.0	79.0[b,]
Surfol Plus	78.3	74.6	83.3	79.0[b,]
X-77	75.0	82.9	80.0	79.0[b,]
Texaco Oil + Tronic	65.4	78.8	83.3	76.0[c]
Accutrol	61.7	80.0	80.4	74.0[c]
Accutrol[d]	43.3	72.5	74.1	63.0[d]
Check	34.1	71.3	71.7	59.0[d]
Dacagin	37.5	37.5	45.0	40.0[e]
Mean	61.7[a]	75.0[b]	78.2[c]	

[a]Experiment location at Redfield, South Dakota.

[b]Numbers within a column or row followed by the same letter are not significantly different at the 5% level using Duncans multiple range test.

[c]Percent lambsquarters control is based on a scale of 0 - 100, where "0" equals no control and "100" equals complete control.

[d]Sprayed at double volume.

increased lambsquarters control with the exception of Dacagin and Accutrol (double volume). Poor spray coverage is probably the explanation for poor control of lambsquarters when treated with Dacagin and Accutrol (double volume).

The control of redroot pigweed, prostrate pigweed, and lambsquarters generally increased as the rate of dicamba was increased. Redroot pigweed control was 35.4, 53.2, and 67.5% at 0.07, 0.14, and 0.28 kg/ha, respectively. Prostrate pigweed control was 7, 10, and 15% and 0.07, 0.14, and 0.28 kg/ha, respectively, which indicates that prostrate pigweed control was not satisfactory at any rate.

Lambsquarters control was 61.7, 75.0, and 78.2% at 0.07, 0.14, and 0.28 kg/ha, respectively. These results suggest that the control of redroot pigweed is rate dependent, prostrate pigweed is not easily controlled, but lambsquarters is controlled with dicamba.

The difference between weed control obtained with a specific rate of dicamba with and without additives varied with redroot pigweed, prostrate pigweed, and lambsquarters (Tables 17, 18, and 19). Surfol Plus, Agri-Oil Plus, and Amoco Concentrate Crop Oil increased redroot pigweed control from 17.5 to 25.8% over that obtained with 0.07 kg/ha of dicamba without additives. Texaco oil + Tronic, Amoco Concentrate Crop Oil, and Surfol Plus increased redroot pigweed control 8.3 to 31.7% over that obtained with 0.14 kg/ha of dicamba applied without additives. Amoco Concentrate Crop Oil increased redroot pigweed control 13.7% over that obtained with 0.28 kg/ha of dicamba without additives. Dacagin and Accutrol (double volume) tended to

decrease redroot pigweed control obtained with dicamba applied alone. These results suggest that dicamba when applied with additives increase redroot pigweed control when compared to dicamba applied alone.

Dicamba applied without additives at a rate of 0.07 and 0.14 kg/ha gave better prostrate pigweed control when compared to dicamba applied with additives (Table 18). However, when dicamba was applied at a rate of 0.28 kg/ha prostrate pigweed control was increased when dicamba was applied with additives when compared to dicamba applied alone. Surfol Plus, Amoco Concentrate Crop Oil, Agri-Oil Plus, Bio-Veg, and Texaco oil + Tronic all increased prostrate pigweed control applied in combination with 0.28 kg/ha of dicamba over that obtained with dicamba alone. These results suggest that additives increase the effectiveness of high rates of dicamba for controlling prostrate pigweed but not low rates.

Dacagin was the only additive that did not significantly increase lambsquarters control over that obtained with 0.07 kg/ha of dicamba without an additive presumably because of poor spray coverage caused by Dacagin. Accutrol (single volume), Bio-Veg, X-77, Agri-Oil Plus, Amoco Concentrate Crop Oil, Texaco Oil + Tronic, and Surfol Plus increased lambsquarters control substantially when applied at 0.14 kg/ha of dicamba than when dicamba was applied alone. Dicamba plus additives substantially increased lambsquarters control over that obtained with 0.28 kg/ha of dicamba applied without additives. Accutrol (double volume) and Dacagin were the exceptions to this statement. These results suggest that dicamba applied with most additives will increase lambsquarters control.

SUMMARY

Experiments were conducted to determine the influence of additives on vapor drift, particle drift and phytotoxicity of dicamba.

The loss of 14-C-dicamba from bare aluminum planchets was less when dicamba was applied without additives than when dicamba was applied with Amoco Concentrate Crop Oil but more than when dicamba was applied with X-77. Loss of 14-C-dicamba tended to increase as the temperature increased and humidity decreased. The volatility of 14-C-dicamba from soil could be decreased by mixing dicamba with either X-77 or Amoco Concentrate Crop Oil. Loss of 14-C-dicamba increased as the temperature was increased from 24 to 35C; however, humidity did not influence the loss of 14-C-dicamba in this experiment.

The soybean plants used to measure the amount of dicamba volatility by bioassy procedures were injured by all treatments. The loss of dicamba from an aqueous solution was not significantly different than the loss of dicamba from soil. Vapor loss from dicamba applied with additives was not different from the vapor loss of dicamba applied without additives. Greater vapor loss occurred when the temperature was increased from 24 to 35C.

Particle drift of dicamba was reduced when dicamba was sprayed from an air-asperating nozzle. There was no significant difference in the amount of particle drift of dicamba coming from either the 30 cm level or the 90 cm level. Less drift of dicamba occurred at high humidities than at low humidities which suggests fewer particles are

evaporated to small more drift hazardous sizes at high humidities than at low humidities. An increase in temperature from 24 to 35C tended to increase drift.

Results indicated that droplets sprayed from the air-asperating nozzle are less likely to be suspended because the amount of dicamba drift was reduced. Injury due to dicamba drift occurred with the air-asperating nozzle but less than with the 8002-E, 8001-E and 730039-E TeeJet nozzles. More drift was apparent at 90 cm below the spray nozzle than 30 cm below the spray nozzle, which may indicate that droplets were suspended at the lower level after the 10 second lapse in time. Less injury resulted when dicamba was sprayed in high humidities than low humidities. Greater drift of dicamba occurred at high temperatures than at low temperatures.

Under windy conditions more drift of dicamba occurred with Texaco oil + Tronic, Amoco Concentrate Crop Oil, and X-77 than when dicamba was sprayed alone or with Accutrol. More drift of dicamba was evident at 30 cm below the spray nozzle than 90 cm below the nozzle. This may suggest more sheering of the spray is a result of lowering the surface tension with the addition of additives. Again less injury resulted when dicamba was sprayed in high humidity. Greater drift of dicamba occurred at high temperatures than at low temperatures.

Soybean plants exposed to suspended particles of dicamba 10 seconds after spraying were reduced in dry weight and exhibited visual injury symptoms. Dicamba applied alone and in combination with all additives except Accutrol injured the soybeans. More drift was apparent

to plants exposed to suspended particles 90 cm below the spray nozzle than those suspended 30 cm below the spray nozzle. Furthermore, more drift of dicamba occurred at low humidities than at high humidities and more drift occurred at high temperatures than at low temperatures.

Phytotoxicity to corn as measured by percent leaf roll increased when dicamba was applied in combination with additives with the exception of Dacagin. Dacagin did not increase the phytotoxicity of dicamba to corn presumably because of poor spray coverage. Amoco Concentrate Crop Oil was the only additive which significantly altered corn height. Corn ear number, basal node number, basal internode length, root extraction force, and corn yields were not significantly altered when additives were applied with dicamba.

The control of redroot pigweed was increased by the addition of additives to dicamba. Amoco Concentrate Crop Oil, Surfol Plus, Agri-Oil Plus, and Texaco oil + Tronic significantly increased redroot pigweed control when compared to dicamba applied without additives. Prostrate pigweed control with dicamba was not increased with additives. Common lambsquarter control was increased by all additives except Dacagin. The addition of additives to dicamba increased redroot pigweed and common lambsquarter control more at 0.28 kg/ha than at 0.07 kg/ha.

In conclusion, these results suggest that dicamba drift can be reduced by spraying in cool weather with high humidity. As a guideline, the expected high temperature for the day should not exceed 30C. Wind speed influences the amount of drift. Therefore, the wind speed should not exceed 5 mph when spraying dicamba. Particle drift could be reduced

by spraying dicamba in combination with a foaming agent through an air-asperating nozzle. However, dicamba injured corn more when sprayed through the air-emulsion system than when sprayed with TeeJet nozzles without the foaming agent. To overcome the increased injury, drop nozzles should be used when dicamba is sprayed through an air-emulsion system; therefore, less spray would contact the corn plant and less injury should result.

BIBLIOGRAPHY

1. Addink, Sylvan. 1972. Effect of additives on decamba. Masters thesis, North Dakota State University. 53 pp.

2. Aya, F. O., and S. K. Ries. 1968. Influence of oils on the toxicity of amitrol to quackgrass. Weed Sci. 16: 288-290.

3. Bandeen, J. D. 1969. Wetting agents, oils are they a plus for atrazine? Crops and Soils. 21(7): 14-15.

4. Bardsley, C. E., K. E. Savage, and J. C. Walker. 1968. Trifluralin behavior in soil. II. Volatilization as influenced by concentration, time, soil moisture content and placement. Agr. Journal. 60: 89-92.

5. Barrentine, J. L., and G. F. Warren. 1969. The influence of an isoparaffinic oil as a carrier for several herbicides. Proc. Weed Sci. Soc. Amer. Abstract No. 206.

6. Baskin, A. D., and E. A. Walker. 1953. The responses of tomato plants to vapors of 2,4-D and/or 2,4,5-T formulations at normal and higher temperature. Weed Sci. 2: 280-287.

7. Black, F. S., and H. P. Wilson. 1969. Performance of herbicide adjuvant sprays as effected by the time of day, by the ratio of herbicide to adjuvant, and by the chemical type of the adjuvant. Proc. Weed Sci. Soc. Amer. Abstract No. 1.

8. Burnside, O. C., and T. L. Lavy. 1966. Dissipation of dicamba. Weed Sci. 14:211-214.

9. Burr, R. J., and G. F. Warren. 1971. Enhancement of herbicide activity with an isoparaffinic oil carrier. Weed Sci. 19(6): 701-705.

10. Butler, B. J., N. B. Akesson, and W. E. Yates. 1969. Use of a spray adjuvants to reduce drift. Amer. Soc. Agr. Eng. Trans. 12: 182-186.

11. Carter, E. P. 1957. Report on volatility of ester forms of hormone type herbicides. Assoc. Off. Agri. Chem. 40(3): 750-753.

12. Coats, G. E., and C. L. Foy. 1971. Phytobland petroleum and vegetable oils as penetrant aids for atrazine. Proc. Weed Sci. Soc. Amer. Abstract No. 43.

13. Coats, G. E., and C. L. Foy. 1971. Four vegetable oils as atrazine and 2,4-D penetrant aids for the species of their origin. Weed Sci. Soc. Amer. Abstract No. 44.

14. Crafts, A. S., and H. G. Reiber. 1952. Herbicidal uses of oils. Advances in Chemistry Series. No. 7 page 70-75.

15. Danielson, L. L., W. A. Genter, and L. L. Jansen. 1961. Persistence of soil incorporated EPTC and other carbamates. Weed Sci. 9: 363-376.

16. Dexter, A. G., O. C. Burnside, and T. L. Lavy. 1966. Factors influencing the phytotoxicity of foliar applications of atrazine. Weed Sci. 14: 222-228.

17. Ekins, W. L., A. P. Appleby, and W. R. Furtick. 1970. Influence of three drift control adjuvants on volatility, adherence, and efficiency of herbicides. Weed Sci. 18: 505-508.

18. Ennis, W. B., Jr. 1951. Influence of different carriers upon the inhibitory properties of growth-regulatory sprays. Weed Sci. 1: 43-47.

19. Eron, R. E. 1969. Drift-free positive application of herbicides using foams as carriers. Proc. Weed Sci. Soc. Amer. Abstract No. 99.

20. Foy, C. L. 1964. Volatility and tracer studies with alkylamino-s-triazines. Weed Sci. 12: 103-108.

21. Frank, R. 1967. Pyrazon, a selective herbicide for sugarbeets. Weed Sci. 15: 197-200.

22. Freed, V. H. 1966. Drift and volatility of herbicides. Plants and Gard. 22: 76.

23. Frost, K. R., and G. W. Ware. 1970. Pesticide drift from aerial and ground applications. Ag. Eng. 51(8): 460-464.

24. Gray, R. A. 1965. A vapor trapping apparatus for determining the loss of EPTC and other herbicides from soils. Weed Sci. 13: 138-141.

25. Grover, R., and L. A. Kerr. 1971. Field trial investigations of droplet and vapor drift hazards from 2,4-D spraying. Proc. Weed Sci. Soc. America. Abstract No. 195.

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

27. How surfactants effect herbicides. 1961. Ag. Res. 9: 3-4.

28. Jansen, L. L. 1964. Surfactant enhancement of herbicide entry. Weed Sci. 12: 251-255.

29. Kaupke, C. R., and W. E. Yates. 1966. Physical properties and drift characteristics of viscosity modified agricultural sprays. Proc. Amer. Soc. Agr. Eng. Trans. 9(6): 797-799.

30. Kearney, P. C., T. J. Sheets, and J. W. Smith. 1964. Volatility of seven s-triazines. Weed Sci. 12: 83-87.

31. Klingman, G. C. 1961. Weed Control: as a science. John Wiley and Sons, Inc., New York, New York. pp. 96-98.

32. Koren, E., C. L. Foy, and F. M. Ashton. 1969. Adsorption, volatility, and migration of thiocarbamate herbicides in soil. Weed Sci. 17(2): 148-153.

33. Maybank, J., and K. Yoshida. 1969. Determinations of herbicide spread factors. Can. Agr. Eng. 11(2): 66-70.

34. Marth, P. C., and Mitchell, J. W. 1949. Comparative volatility of various forms of 2,4-D. Bot. Gaz. 110: 632-636.

35. Morgan, M. J., L. W. Rasmussen, and L. W. Ortor. 1957. The effects of wind on delivery patterns of nozzles used for weed spraying. Weed Sci. 5: 350-361.

36. Mullison, W. R. 1953. The effect of droplet size upon herbicidal effectiveness of plant growth regulators. Down to Earth. 9(2): 11-13.

37. Page, G. E. 1961. Influence of nozzle size and type of hardness of water, and wetting agents on spray drift. Weed Sci. 9: 258-263.

38. Parochetti, J. V., E. R. Hein, and S. R. Colby. 1971. Volatility of dichlobenil. Weed Sci. 19: 28-31.

39. Parochetti, J. V., and G. F. Warren. 1966. Vapor losses of IPC and CIPC. Weed Sci. 14: 281-285.

40. Peacock, J. F. 1970. Enhancement of foliar penetration and herbicide activity by oil. Ph.D. thesis. South Dakota State University (Libr. Congr. card No. Mic. 71-0899). 121 pp. Ann Arbor, Mich. (Diss. Abstr. 31, No. 8B: 4431).

41. Plumb, T. R., L. R. Green, and V. E. White. 1966. Spray pattern and drift from two types of nozzles used for helicopter sprayings. Weed Sci. 14: 114-116.

42. Talbert, R. E., D. R. Smith, and R. E. Frans. 1971. Volatilization, leaching and absorption of promethryne in relation to selectivity in cotton. Weed Sci. 19: 6-10.

43. Temple, R. E. and H. W. Hilton. 1963. The effect of surfactants on the water solubility of herbicides, and the foliar phytotoxicity of surfactants. Weed Sci. 11: 297-300.

44. Thompson, L., Jr., and F. W. Slife. 1969. Foliar and root absorption of atrazine applied post-emergence to giant foxtail. Weed Sci. 17: 215-256.

45. Weed killers and volatility. 1953. Ag. Res. 2: 6-7.