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DICAMBA USE IN RELATIONSHIP TO DRIFT INJURY

ON SOYBEANS IN SOUTHEASTERN

SOUTH DAKOTA

BY

DUANE E. AUCH

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

1977

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ON SOYBEANS IN SOUTHEASTERN

SOUTH DAKOTA

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

Head, Plant Science Department Date

ACKNOWLEDGMENTS

The author wishes to express appreciation to his major adviser, Dr. W. E. Arnold, for his guidance and encouragement. The author also wishes to thank faculty, co-workers, family, and others involved for their concern and aid. The author acknowledges God's grace and help in all situations.

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INTRODUCTION

The benefits of using herbicides have been demonstrated repeatedly, but less is known about the risks involved in the use of herbicides. Any herbicide movement out of its field of application increases the potential damage to sensitive plants and animals.

Herbicides move through the air by herbicide drift. Spraying equipment, application methods, and spray additives have been developed to reduce the amount of drift. Unfortunately, none have been shown to eliminate drift without reducing herbicide effectiveness.

Dicamba (3,6-dichloro-o-anisic acid) has the potential to cause drift injury. Dicamba controls certain broadleaf weeds in corn (*Zea mays* L.), small grain, and pasture, but soybeans (*Glycine max* L.) are extremely sensitive. Since soybeans are often grown near corn, drift injury to soybeans can occur from dicamba application to corn. The growth stage and variety influence the sensitivity of soybeans to many herbicides and, therefore, may influence the sensitivity of soybeans to dicamba.

The extent of dicamba drift is not known. In cases of drift injury, the causative agent is difficult to identify and the effect of the drifting agent on production is difficult to determine because of inadequate comparisons. The objectives of this research were to determine: (1) tolerant growth stages for soybeans challenged with dicamba, (2) varietal tolerance to dicamba, (3) dicamba residue by analysis of soybean foliage, and (4) the extent of dicamba use and drift occurrence in southeastern South Dakota.

LITERATURE REVIEW

Herbicide drift is the movement of a herbicide in droplet or vapor form to a nontarget area (7,27,37,42,61). Possible adverse effects of drift are: (1) damage and/or contamination to nearby crops, (2) detrimental effects on the general environment, and (3) reduction in treatment effectiveness (33,37,51).

The factors which influence drift are: (1) spray formulation, (2) wind conditions, (3) nozzle height, and (4) droplet size. Vapor drift of systemic herbicides is also affected by the rate of chemical penetration and translocation (42).

The first factor, spray formulation, affects mainly vapor drift. According to Brinkman (11), volatility of dicamba may be affected by different additives. Gentner (23) found that dicamba (dimethylamine salt) vapors were more phytotoxic to pinto beans than 2,4-D [(2,4-dichlorophenoxy) acetic acid propylene glycol butyl ether esters], but not as phytotoxic as picloram (4-amino-3,5,6-trichloropicolinic acid potassium salt).

The second factor affecting drift is wind conditions. Wind direction determines the risk of injuring a particular nearby field, while wind velocity determines the amount of spray drift (61). Nordby and Skuterud (37) reported that 1.5 percent of a spray with 305 μ mass median diameter (MMD) droplets drifted in a 1.5 m/s wind, but 7.0 percent of the spray drifted in a 4 m/s wind. With very stable conditions, an inversion condition can exist where ground level air is cooler than higher level air. Under these conditions, fine droplets do not rise but form a cloud which may eventually move and settle on a sensitive crop (10). Yates and Akesson (62) reported that under very stable conditions, spray residue in plants one-fourth mile downwind was 1.18 ppm. Under conditions with wind from 8 to 16 mph, the amount of residue collected was 0.40 ppm.

The third factor affecting spray drift is nozzle height. Nordby and Skuterud (37) reported that drift increased from 7 percent of the spray with 40 cm high nozzles to 14 percent with 80 cm high nozzles. Low nozzle height results in less drift because wind velocities are less close to the ground, and the amount of time that the falling droplets are subject to the wind is less (7,29,61).

The fourth factor affecting spray drift is spray droplet size. Droplets less than 100 μ in diameter are the most prone to drift (8,9). Courshee (16) reported nearly 100 percent of a spray consisting of droplets less than 100 μ drifted in an 8 mph wind with a 15 in. high nozzle.

Droplet size is influenced by nozzle characteristics and spraying pressure (8). Most nozzles produce a wide range of droplet sizes (7,30). Maybank (29) estimated that 20 percent of the total spray volume of typical herbicide nozzles is potentially subject to drift. Butler (7) found that with a flooding flat fan nozzle an increase in pressure from 10 to 50 psi decreased the volume median diameter (VMD) of droplets from 600 μ to 300 μ. Bode, _et al_. (3) found that 8002 flat fan nozzles averaged 100 percent more drift than 8002 low pressure nozzles.

Although large droplets reduce drift, they also reduce herbicide effectiveness. Behrens (2) reported that droplet spacing was of major importance in 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid] effectiveness on cotton (Gossypium hirsutum L.) and mesquite (Prosopis juliflora L.). He found that at least 72 droplets per square inch were necessary for maximum effectiveness. Unfortunately, eight times as much liquid is required to apply a given number of 200 μ droplets as an equal number of 100 μ droplets (1,31). McKinlay, et al. (32) reported that three to six times as much active ingredient of 2,4-D was necessary with 200 to 400 μ droplets to produce the inhibition caused by 100 μ droplets. Buehring, et al. (12) found that in almost all tests a flat fan nozzle with 375 μ MMD droplets produced better weed control than homogeneous sprays of 200 μ, 400 μ, and 600 μ droplets.

Nozzles and spray additives which reduce drift continue to be developed. The objective is to eliminate fine droplets without increasing large droplet size and number (29).

Bode (3) compared raindrop, TK-2 flooding, 8002 LP, and 8002 flat fan nozzles for spray drift. With an average wind velocity of 5.3 m/s, 4.4 percent of the spray drifted using raindrop nozzles. Flooding flat fan nozzles with an average wind of 3.0 m/s produced 2.6 percent drift. With an average wind of 3.3 m/s using 8002 LP low pressure nozzles, 4.0 percent of the spray drifted. Flat fan 8002 nozzles with average wind velocity of 4.2 m/s had 16.5 percent drift.

Water-in-oil inverted emulsions have been shown to reduce drift. Drawbacks in their use include instability, increased phytoxicity, and increased number of large droplets (8).

Butler, Akesson, and Yates (8) studied droplet size distributions of sprays containing commercially available drift reducing adjuvants Dacagin, Vistik, and Norbak. All the adjuvants shifted the droplet spectrum upward. The spray solution without adjuvant had a droplet size spectrum ranging from 80 to 600 μ. Norbak produced the most uniform droplet spectrum with a droplet size range of 300 to 1,800 μ. The use of these adjuvants has been limited by their sensitivity to salts, longer mixing time requirements, and high cost (33).

Bode, Butler, and Goering (3) made drift comparisons with Nalco-Trol concentrations ranging from 0.031 to 0.125 percent. In general, low concentrations decreased total drift deposits 15 to 20 percent, and high concentrations decreased total drift deposits 70 to 80 percent.

Bouse (4) studied the use of foam adjuvants with air inducting nozzles and concluded that they had no advantage for drift control over sprays produced by air inducting nozzles without the adjuvant. In some comparisons the drift deposits between 1.83 and 6.1 m downwind were significantly increased with the additions of foam adjuvants.

Drift control measures and methods of drift prediction have not eliminated drift. The emphasis has been to establish realistic levels that will prevent significant crop damage (29). Growth stage and variety of the crop may influence the amount of damage which occurs. Studies have been conducted to evaluate soybean tolerance to various herbicides applied at various growth stages (45,46,54,59).

Slife (45) applied 2,4-D to Hawkeye soybeans to control broadleaf weeds. Five rates ranging from 0 to ½ lb/A were applied at four growth stages ranging from 3 to 32 in. With later applications yield and plant height reductions were more severe. Seed yields were not affected by 1/16 or 1/8 lb/A of 2,4-D applied before soybeans were 9 in. tall. The high rates affected yield at all stages. Germination was reduced by the 1/2 lb/A rate at all stages and by the 1/4 lb/A rate at the last two stages.

Smith (46) applied silvex [2-(2,4,5-trichlorophenoxy) propionic acid], 2,4,5-T, and 2,4-DB [4-(2,4-dichlorophenoxy) butyric acid] to Lee soybeans. Rates of 0.01 to 0.25 lb/A applied at the 5-trifoliate growth stage were more injurious than applications made at the early bloom stage. Although vegetative stage applications did not delay maturity, bloom stage applications did. Silvex application at the bloom stage reduced germination.

Dicamba was applied by Wax (59) at rates ranging from 1/8 to 4 oz/A to Harosoy 63 soybeans in the 3-trifoliate (prebloom) and 8-trifoliate (bloom) growth stages. At both stages dicamba caused petiole and stem curvature followed by cupping and crinkling of leaves. Yield was reduced about 20 percent by the 1/8 oz/A dicamba rate applied at the bloom stage, but at the prebloom stage, a 1 oz/A dicamba rate was required to produce the same yield reduction. Height was reduced an average of 9 in. by prebloom applications and 12 in. by bloom applications. Dicamba caused the greatest maturity delay when applied at the bloom stage. One hundred seed weight was reduced by prebloom stage applications and increased by bloom stage applications. Dicamba had little effect on germination when applied before bloom stage, but at the bloom stage 1/2 and 1 oz/A rates reduced germination. Seedlings from these treatments had leaf malformations.

Thompson and Egli (54) also noted that progeny from dicamba treated plants lacked vigor and had malformations of first trifoliate leaves ranging from slight crinkling to complete restriction of expansion. Dicamba applications at podfill of 0.56 kg/ha prevented seed production and applications of 0.03 and 0.22 kg/ha prevented normal seed germination. Only 36 to 50 percent of the seed from plants treated with 0.03 kg/ha dicamba at the flowering stage germinated normally. Seeds from plants treated at flowering or pod fill with 0.03 kg/ha dicamba were planted in a greenhouse and approximately 50 percent of the seeds emerged.

Differences in crop tolerance to dicamba application at various growth stages have been noted with other crops (22,36,41,42). Generally early and very late growth stages are most tolerant (41,43). Quimby, _et al_. (43) reported germination reduction from dicamba application to wheat (_Triticum aestivum_ L.) in one of two years tested. Nalewaja (36) reported germination reduction in flax (_Linum usitatissimum_ L.).

Use of tolerant soybean varieties could reduce losses caused by drift (47). Fribourg and Johnson (21) treated 185 soybean varieties with 2,4,5-T during the bloom stage. Yields were reduced by 40 to 50 percent in 10 percent of the varieties, and by 85 to 95 percent in another 10 percent of the varieties.

Fribourg and Johnson (21) also tested 185 soybean varieties in the greenhouse for tolerance to 2,4-D. A single microdroplet was applied to the first trifoliate leaf while the seedlings were in the 1-trifoliate stage. The second trifoliate leaf was measured and reduction in leaf size varied from 25 to 90 percent.

Walters and Caviness (57) reported that _Phytophthora_ root rot resistant varieties were also more resistant to 2,4-DB. Applications of 0.2 lb/A of 2,4-DB caused drastic yield reductions in suspectible varieties 'Jackson' and 'Lee', but yields of resistant varieties 'Semmes' and 'Lee 68' were not reduced. In growing areas not infested by _Phytophthora_ root rot there was no difference in variety response to 2,4-DB.

Smith and Caviness (47) studied the response of 10 soybean varieties to propanil (3',4'-dichloropropionanilide). Propanil was applied at the 3-trifoliate stage at rates of 0.56 and 3.36 kg/ha. 'Davis', 'Hood', and 'York' varieties exhibited the most chlorosis, necrosis, and yield reduction from treatments. Slight to moderate damage occurred to 'Hill', 'Lee', 'Lee 68', 'Pickett', 'Semmes', 'Bragg', and 'Dare' varieties.

Differential varietal responses to recommended soybean herbicides have been noted. Stanton and Frans (52) found that 'Hale 7', 'Clark 63', and 'York' varieties were sensitive to dinoseb (2-*sec*-butyl-4, 6-dinitrophenol), but 'Bragg', 'Lee 68', and 'Pickett' varieties were tolerant. Burnside (5) reported that 4.5 kg/ha linuron [3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea] reduced yield of 'Harosoy 63' by 5 percent and of 'Ford' by 31 percent. Hardcastle, Wilkinson, and Young (26) reported height, stand, and yield reductions from metribuzin [4-amino-6-*tert*-butyl-3-(methylthio)-*as*-triazine-5(4H)one] application to 'Coker 102'. No reductions were noted with 'Bragg', 'Hampton', 'Bienville', 'Coker 318', and 'Hardee' varieties. Wax, Bernard, and Haynes (58) tested the 338 varieties in the U. S. Department of Agriculture soybean germplasm collection for tolerance to bentazon (3-isopropyl-1H-2,1,3-benzothiadiazin-(4)-3H-one 2,2-dioxide), bromoxynil (3,5-dibromo-4-hydroxybenzonitrile), chloroxuron (3-[p-(p-chlorophenoxy) phenyl]-1, 1-dimethylurea), and 2,4-DB. One U. S. cultivar 'Hurrelbrink' and 10 introductions from Japan were highly sensitive to the four herbicides.

Dicamba metabolism and residue analysis in soybeans has not been studied, but metabolism of dicamba in sensitive weeds occurs slowly (13,14,15,28). Chang (14) found that in tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn) 10 percent of the dicamba was detoxified 20 days after treatment. Magalhaes (28) reported that dicamba was not degraded by purple nutsedge (*Cyperus rotundus* L.) during the first 10 days after treatment. Chang (13) found that 54 days after treating Canada thistle

(Cirsium arvense (L.) Scop.) with 14 C dicamba, 63.1 percent of the recovered radioactivity in the treated leaf was still in the form of unaltered dicamba.

Morton, Robison, and Meyer (35) studied the persistence of dicamba in range grasses and found the half life of dicamba to be approximately two weeks in silver beardgrass (Andropogon saccharoides Swartz.), little bluestem (A. scoparius Michx.), and dallisgrass (Paspalum dilatatum Poir.). Marked reductions of dicamba concentrations in green tissue occurred after rainfall, but without rainfall the reductions were gradual. Important reductions were not found in dead tissue; therefore, dilution of dicamba by increased plant growth after rainfall may have occurred.

Evidence that a pesticide use may cause unreasonable risk to man or the environment triggers a Rebuttable Presumption Against Registration (RPAR) by the Environmental Protection Agency (EPA). A preliminary plan of the U. S. Department of Agriculture in cooperation with the State Universities and the EPA includes assessment teams to study the biologic, economic, environmental, and health risk implications of the RPAR (55).

The effect of dicamba use on the environment has not been fully determined. The extent of dicamba drift occurrence is difficult to determine. Only one case of dicamba drift injury was reported to the South Dakota Department of Agriculture in 1975.[1] Results of a survey

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1 Personal correspondence with C. Ray Peery, Pesticide Section Director, South Dakota Department of Agriculture.

of county agents in five midwestern states indicated that in 1971, between 124 and 136 herbicide drift cases were reported in Minnesota and between 256 and 278 cases were reported in Iowa. The county agents suggested that farmers were reluctant to report pesticide incidents because they felt that incidents were distorted out of proportion (19).

Dicamba contamination of water appears to be minor except when applied to or drifted over the surface. Tests with aerial spraying of forests indicated that the highest concentrations of dicamba in streams occurred immediately after spraying (38,48). No residue was found in water after 11 days in one study and after 30 days in another study, even after intense rainfall or in the late spring when the stream flow consisted mainly of ground water.

Health risks have been determined by toxicity tests. Results of these tests indicate that dicamba is slightly toxic with an acute oral toxicity of 1,040 mg/kg. Toxicity is low for honey bees (Anthophora mellifera), fish, birds, and larger animals (17,31,34). Dicamba fed to dairy cows was excreted in the urine, and none was found in the milk (53).

Although dicamba ia only slightly toxic, it is considered to be a potential mutagen. Fishbein (20) classified dicamba, along with several other herbicides, as a possible mutagen because of its structural and biological similarities to known mutagens. The list of potential mutagenic herbicides included linuron, simazine [2-chloro-4,6-bis(ethylamino)-s-triazine], atrazine (2-chloro-4-(ethylamino)-6-

(isopropylamino)-s-triazine), monuron [3-(p-chlorophenyl)-1, 1-dimethylurea], 2,4-DB, and dicamba in decreasing order of relative mutagenic efficiency. Studies have not been conducted to determine the true mutagenicity of these herbicides.

Information concerning usage patterns is necessary in order to determine the benefits and economic importance of dicamba use. In 1975, commercial applicators in South Dakota treated 161,973 A with dicamba alone or in combination with other herbicides. Of this total, 121,646 A were sprayed with ground equipment and 40,327 A with aerial equipment (50,51). Dicamba was sprayed on 112,647 A of corn, 46,931 A of small grain, and 2,395 A of other crops or uses.

Custom application does not necessarily give a true picture of herbicide use. Results of a survey in five midwestern states indicate that the following proportion of farmers applied their own herbicides: Illinois, 90 percent; Iowa, 78 percent; Kansas, 67 percent; Minnesota, 89 percent; and Missouri, 80 percent (19). The results of a survey conducted in Utah in 1969 indicate that commercial applicators applied only 12 lb of the 2,904 lb (active ingredient) of dicamba used (56).

This research was conducted to determine differences in soybean growth stage and variety sensitivity to dicamba which could be utilized to reduce soybean drift injury. These results and those obtained by the residue analysis study should also aid in interpreting the cause and effects of injury in drift incidents. In anticipation of possible EPA action against dicamba use, a survey of dicamba use in southeastern South Dakota was conducted.

As a note, in February, 1977, dicamba was listed by the Office of Special Pesticide Reviews (OSPR) of the EPA as a possible candidate for RPAR. The group sending the RPAR to the OSPR was the Office of Pesticide Program's (OPP) Pesticide Episode Reporting System (39). No reason for the action was given, but it may be due to dicamba drift reports or possible dicamba mutagenicity.

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MATERIALS AND METHODS

Soybean Growth Stage Experiment

Field Procedure

This experiment was conducted at the James Valley Research and Extension Center at Redfield in 1974, and at the South East South Dakota Research and Extension Center at Centerville in 1975 and 1976. Planting information and experiment plot size are noted in Table 1. A randomized complete block design with four replications was used. Dicamba (dimethylamine salt) was applied at different rates (Table 1) and soybean growth stages (Table 2).

In 1974, application was made with a compressed air sprayer mounted on an IH Cub tractor. The sprayer was equipped with TeeJet 8002 flat fan nozzles which applied 187 liters of spray solution per hectare with a 2.8 kg/cm^2 pressure and a 4.8 km/hr ground speed. The nozzles were 46 cm above the tops of the plants. Climatic conditions at each application date are noted in Table 2.

In 1975 and 1976, applications were made with a bicycle wheel-type compressed air sprayer equipped with TeeJet 80015 flat fan nozzles. The nozzles were spaced 51 cm apart and adjusted at 46 cm above the tops of the plants. A spray volume of 187 l/ha was sprayed at 2.2 kg/cm^2 pressure. The sprayer was pushed approximately 3.2 km/hr.

Table 1. Planting, plot, and application rate information for soybean growth stage experiments.

		Planting Information[a]				
Year	Variety	Date	Rate (kg/ha)	Depth (cm)	Plot Size (m)	Dicamba Rates (kg/ha)
1974	Jacques 109	5-25	68	5.0	3.0 by 7.6	0.001, 0.011, 0.056
1975	Corsoy	5-29	67	2.5	3.0 by 15.2	0.001, 0.011, 0.056
1976	Corsoy	5-25	62	4.0	2.3 by 15.2	0.011, 0.028, 0.056

[a]76 cm row spacing in all three years.

Table 2. Climatic conditions at time of dicamba application to soybeans in the growth stage experiments.

Application Date	Growth Stage	Time of Day	Air Temperature (^{o}C)	Relative Humidity (%)
1974				
6-27	1 to 2-trifoliate	not recorded	19	80
7-4	3 to 4-trifoliate	not recorded	18	73
7-12	6 to 7-trifoliate	not recorded	23	82
7-19	7-trifoliate	not recorded	22	84
1975				
7-18	early bloom	8:30 p.m.	31	52
8-5	early pod	7:00 a.m.	26	82
1976				
7-7	early bloom	3:00 p.m.	38	45
7-14	mid-bloom	1:30 p.m.	35	50
7-26	early pod	11:30 a.m.	27	76
8-12	late pod	3:30 p.m.	29	32

Weeds were controlled by machine cultivation and rogueing. In 1975, summer fallow the previous year reduced the weed problem. A 35 cm band of alachlor [2-chloro-2',6'-diethyl-N-(methoxymethyl) acetanilide] was applied at 3.4 kg/ha in 1976.

In 1974 and 1975, 3.0 m of the two center rows of each plot were cut and threshed with a small plot thresher. In 1976, the two center rows of each plot were combined with a Massey Harris 35 combine.

Measurements

Plant heights were taken before harvest each year. In 1975, an average of three random measurements was recorded, and in 1976, an average of six random measurements was recorded.

In 1976, maturity ratings were made visually on September 23. Plants with 50 percent yellow pods were rated as being seven days from harvest. If 50 percent of the pods were green, maturity was estimated to occur in 14 days. Plants with all green pods were estimated to mature in 21 days.

Harvested samples were cleaned, and plot weights were recorded. In 1976, test weights and 1,000-seed weights were taken.

Germination tests were conducted on seed from treated plants. One hundred seeds from each plot were germinated for six to eight days at 20°C. The tests were begun on January 30, 1975; June 24, 1976; and November 1, 1976.

An analysis of variance was conducted on all data and the treatment means for the first two years were compared by Dunnett's procedure and by orthogonal comparisons in 1976.

Seeds from plants treated in 1975 were planted under field conditions at Centerville on May 26, 1976. The soil was loam containing 33.6 percent sand, 46.7 percent silt, and 19.9 percent clay. Organic matter content was 4.2 percent, and the pH was 6.6. At planting time the soil was 18°C and moist at 5 cm. One hundred seeds were planted per plot at a depth of 4 cm with a hand planter. A randomized complete block design with four replications was used.

Plots were 0.8 by 6.1 m. The number of plants per plot was recorded 9, 15, 21, and 41 days after planting. Dry weight measurements were made from samples collected 41 days after planting. Twenty randomly chosen plants were harvested per plot. An analysis of variance was conducted and treatment means were compared using Duncan's multiple range test.

Variety Experiment

Field Procedure

Thirteen standard and commercial soybean varieties adapted for southern South Dakota were planted at Centerville on May 27, 1976. These varieties varied in maturity group classification and in leaf shape. 'SRF' varieties are narrow-leaved commercial varieties. 'SRF-100' is the only variety classified as maturity group zero. Varieties classified as group one are: 'Chippewa', 'Hodgson', 'SRF-150', and 'Steele'. Varieties classified as group two are: 'Corsoy', 'Harcor', 'Wells', 'SRF-200', 'Amsoy 71', and 'Beeson'. Varieties classified as group three are 'Woodworth' and 'Wayne'. These varieties were planted in nine-row strips. Planting depth was 4 cm and the planting rate varied due to differences in seed size among varieties. The treatments were randomized within varieties and replicated four times. Plot size was 2.3 by 15.2 m. Weeds were controlled by broadcasting 1.12 kg/ha trifluralin (*a*,*a*,*a*,-trifluoro-2,6-dinitro-N,N-dipropyl-*p*-toluidine), machine cultivation, and rogueing. Dicamba was applied at 0.028 kg/ha on July 7, July 24, and

August 2 with the bicycle-type sprayer. The climatic conditions at application are noted in Table 3. The plots were harvested with a Massey Harris 35 combine.

Table 3. Climatic conditions at time of dicamba application to soybeans in the variety experiment.

Application Date	Time of Day	Air Temperature (°C)	Relative Humidity (%)
7-7-1976	12:30 p.m.	37	48
7-24-1976	7:00 a.m.	27	80
8-2-1976	3:30 p.m.	29	36

Measurements

Visual injury estimates were made on August 3, and maturity estimates were made visually on September 14 and gravimetrically on September 21. Criteria for estimating maturity have been outlined previously. Gravimetric measurement of maturity was made by randomly selecting six plants per plot, placing them in plastic bags, and refrigerating them at 2.2°C. The foliage and pods were weighed separately, dried, and weighed again to determine moisture content.

An average of six random height measurements was recorded per plot. Plot samples were cleaned and plot weights, test weights, and

1,000-seed weights were taken. Analysis of variance of the data was computed and orthogonal comparisons or Dunnett's procedure were used to compare treatment means.

Residue Analysis Experiment

Corsoy soybeans were planted at Centerville on May 26, 1976. The seed was planted in 76 cm rows at a depth of 4 cm and a seedling rate of 62 kg/ha. Plots were 3.0 by 7.6 m and randomized in a complete block design with four replications. Weeds were controlled by a broadcast application of trifluralin at 1.12 kg/ha and rogueing.

Dicamba was applied at rates of 0.0, 0.011, 0.028, and 0.056 kg/ha on July 16 when the soybeans were in the mid-bloom stage. Application was made with a bicycle-type sprayer at 7:30 a.m. when the air temperature was 15°C. Immediately after application approximately 2 kg of foliage were randomly collected from each plot. The plants were cut approximately 2 cm above the ground surface and placed in plastic bags. Control plots were sampled first to reduce contamination. The samples were stored at -18°C. Foliage samples were taken 7 and 18 days after application. After harvest, foliage and seed samples were shipped to the EPA Organic Chemicals Laboratory in Denver, Colorado for analysis. The residue was extracted, esterified, and then analyzed by gas chromatography. An analysis of variance was conducted on the data and treatments were compared by orthogonal comparisons.

Dicamba Use Survey

A farmer survey was conducted in Turner, Lincoln, Union, and Clay counties of southeastern South Dakota. In 1975, these counties contained 55 percent of the state's total soybean acreage (49). Also, 4,236 ha of corn were treated with dicamba by commercial applicators in 1975 (51).

A list of farmers was obtained from the property tax listings in each county. All persons with a taxable agricultural property value over $2,500 were included in the population. The value was lowered to $1,000 if a person had over 1,000 bu of grain on hand. The random sample consisting of 5 percent of the population in each township was selected using a random number table. Information was obtained by telephone contact. Another selection was made from the population if: (1) telephone contact could not be made after three attempts, (2) the farmer's telephone number could not be obtained, (3) the farmer had moved to a different area, (4) the farmer was no longer living, or (5) the farmer refused to participate in the survey. The responses were tabulated for each county and expressed as percentages of the sample.

RESULTS AND DISCUSSION

Growth Stage Experiment

The risk of drift injury may be reduced by applying dicamba to corn when soybeans are most tolerant to dicamba. To determine the most tolerant growth stage of soybeans, several rates of dicamba were applied to soybeans in various stages of growth.

Visual effects of dicamba on soybeans included cupped leaves, bent stems, grayish leaf margins, abnormal pods, maturity delay, and plant height reduction. Leaf and stem injury appeared 1 to 14 days after application and persisted through the season. Higher dicamba rates caused more severe visual injury. Wax, *et al.* (59) described similar morphological effects from dicamba.

Soybean maturity was delayed more by the higher rates of dicamba than by lower rates (Table 4). The 0.028 kg/ha rate applied at the mid-bloom stage produced the same amount of maturity delay as the 0.056 kg/ha rate applied at the early bloom stage. Maturity delay of soybeans treated at early pod stage was similar to the maturity delay of soybeans treated at the late pod stage. These results indicate that soybeans may be delayed in maturity when challenged at any stage of growth; however, the most sensitive stages of growth occur at mid-bloom stage or thereafter. This agrees with Wax, *et al.* (59) who reported that dicamba when applied to soybeans in the mid-bloom stage delayed maturity most.

At rates above 0.001 kg/ha dicamba application inhibited plant growth, thereby reducing plant height (Tables 5, 6, and 7). The

Table 4. Maturity delay of Corsoy soybeans caused by dicamba treatment at various rates and application date (1976).

Dicamba Rate (kg/ha)	Rate Mean	Soybean Maturity Delay: Growth Stage at Time of Treatment — Early Bloom (days)	Mid-Bloom (days)	Early Pod (days)	Late Pod (days)
0	0	0	0	0	0
0.011	3.5	3	4	4	3
0.028	12.0	7	12	14	15
0.056	14.8	12	13	19	15
Growth stage mean		5.5	7.2	9.2	8.2

ANALYSIS OF VARIANCE[a]

Source	DF	MS
Dicamba Rate	3	765.31**
(0.0,0.011) vs (0.028,0.056)	1	2,127.52**
0.0 vs 0.011	1	105.12**
0.028 vs 0.056	1	63.28**
Growth Stage	3	43.26**
(EB,MB) vs (EP,LP)	1	92.64**
EB vs MB	1	28.12**
EP vs LP	1	9.03
Rate x stage interaction	9	17.07**

*,**Significant F-test at the 0.05 and 0.01 levels, respectively.

[a]Used orthogonal comparisons.

Table 5. Yield, plant height, and germination of Jacques 109 soybeans treated with dicamba at various rates and growth stages (1974).

Soybean Growth Stage at Time of Treatment	Dicamba Rate (kg/ha)	Yield (kg/ha)	Plant Height (cm)	Germination (%)
1-2 trifoliate				
	0.001	833	93	90
	0.011	905	88	92
	0.056	833	77	92
3-4 trifoliate				
	0.001	920	80	92
	0.011	855	69**	92
	0.056	669	59**	92
6-7 trifoliate				
	0.001	989	93	89
	0.011	862	56**	90
	0.056	665	45**	93
7 trifoliate				
	0.001	954	80	90
	0.011	763	46**	93
	0.056	388*	36**	88
No herbicide	--	837	92	90

*,**Significant at the 0.05 and 0.01 levels, respectively, using Dunnett's procedure.

Table 6. Yield, plant height, and germination of Corsoy soybeans treated with dicamba at various rates and growth stages (1975).

Soybean Growth Stage at Time of Treatment	Dicamba Rate (kg/ha)	Yield (kg/ha)	Height (cm)	Germination (%)
Early bloom				
	0.001	548	47	86
	0.011	381*	40	79
	0.056	368*	40	76
Early pod				
	0.001	561	54	85
	0.011	589	47	74
	0.056	114*	50	59**
No herbicide	--	579	49	89

*,**Significant at the 0.05 and 0.01 levels, respectively, using Dunnett's procedure.

Table 7. Height of Corsoy soybeans treated with dicamba at various rates and dates of application (1976).

Dicamba Rate (kg/ha)	Rate Mean	Soybean Height — Growth Stage at Time of Treatment: Early Bloom (cm)	Mid-Bloom (cm)	Early Pod (cm)	Late Pod (cm)
0	60	56	61	58	64
0.011	54	46	46	56	66
0.028	48	38	43	51	61
0.056	46	36	38	53	58
Growth stage mean		44	47	54	62

ANALYSIS OF VARIANCE

Source	DF	MS
Dicamba Rate	3	98.22**
Growth Stage	3	164.85**
Rate x stage interaction	9	12.02**

COMPARISONS[a]

	DF	MS
Early Bloom Stage		
0.0 vs (0.011,0.028,0.056	1	139.06**
0.011 vs (0.028,0.056)	1	22.43**
0.028 vs 0.056	1	0.60
Mid-Bloom Stage		
0.0 vs (0.011,0.028,0.056)	1	161.33**
0.011 vs (0.028,0.056)	1	12.33*
0.028 vs 0.056	1	6.12
Early Pod Stage		
0.0 vs (0.011,0.028,0.056)	1	23.80**
0.011 vs (0.028,0.056)	1	7.82
0.028 vs 0.056	1	2.76
Late Pod Stage		
0.0 vs (0.011,0.028,0.056)	1	0.99
0.011 vs (0.028,0.056)	1	19.98**
0.028 vs 0.056	1	5.61

*,**Significant F-test at the 0.05 and 0.01 levels, respectively.

[a]Orthogonal comparisons of rates within each growth stage by partitioning the effects of rate and the rate x stage interaction.

0.056 kg/ha rate did not inhibit plant growth more than the 0.028 kg/ha rate (Table 7). In 1974, height tended to be reduced more as plants neared the 7-trifoliate stage (Table 5). Plants treated at the early bloom stage tended to be shorter than those treated at later stages (Tables 6 and 7). Height was not reduced by applications at the 1 to 2-trifoliate stage or the pod stages (Tables 5, 6, and 7). Results obtained by Wax, et al. (59) indicate that applications at mid-bloom tend to cause greater height reduction than applications at prebloom stage.

These results indicate that dicamba application during rapid vegetative growth causes the greatest height reduction. Dry weight accumulates slowly in young plants since they have few meristematic regions. As the number of meristematic regions increases, the rate of dry matter accumulation in leaves, petioles, and stems increases. Maximum growth rate occurs from the beginning of flowering to the beginning of podfill (25). Consequently, at this stage growth inhibition caused by dicamba has the greatest effect on total dry weight and plant height. Plants treated before this stage may partially recover and produce some vegetative growth during the bloom stage. After the bloom stage, little vegetative growth occurs so plant height is not reduced by pod stage applications.

As with height, dicamba application at the early bloom stage caused the greatest yield reduction (Tables 6 and 8). In 1975, the 0.011 kg/ha rate reduced yield at the early bloom stage but not at the early pod indicating greater soybean sensitivity at the early bloom

Table 8. Yield of Corsoy soybeans treated with dicamba at various rates and growth stages (1976).

		Soybean Yield Growth Stage at Time of Treatment			
Dicamba Rate (kg/ha)	Rate Mean	Early Bloom (kg/ha)	Mid-Bloom (kg/ha)	Early Pod (kg/ha)	Late Pod (kg/ha)
0	819	720	912	806	837
0.011	727	476	674	769	989
0.028	537	327	589	450	782
0.056	362	272	301	341	532
Growth stage mean		449	619	592	785

ANALYSIS OF VARIANCE[a]

Source	DF	MS
Dicamba Rate	3	146.96**
(0.0,0.011) vs (0.028,0.056)	1	371.00**
0.0 vs 0.011	1	14.89
0.028 vs 0.056	1	54.71**
Growth Stage	3	67.10**
(EB,MB) vs (EP,LP)	1	84.11**
EB vs MB	1	51.26**
EP vs LP	1	65.92**
Rate x stage interaction	9	8.12

*,**Significant F-test at the 0.05 and 0.01 levels, respectively.

[a]Used orthogonal comparisons.

stage (Table 6). The low yield from the 0.05 lb/A application rate at the early pod stage may have been caused partially by harvesting loss rather than by reduced seed production. Since this treatment caused a delay in maturity, some pods were immature at harvest and the seed could not be threshed. Dicamba applications before the 7-trifoliate stage (Table 5) or after the early pod stage (Table 8) did not reduce yield.

Furthermore, Wax, et al. (59) reported yield reduction from dicamba applied at the bloom stage but not from dicamba applied at the 3 to 4-trifoliate stage. These results suggest the yield reduction can be minimized if dicamba is applied before soybeans in the area are blooming. This recommendation is included in the precautions given for the dicamba treatment for weed control in corn (60). In South Dakota, satisfactory weed control can be obtained usually by applications before this stage.

The growth stage when drift occurred is the most important factor to consider when estimating the affect of dicamba drift on yield. Visual symptoms do not necessarily indicate yield reduction but may be an indication of the amount of drift that occurred. The correlation between height and yield was significant when dicamba was applied at the early bloom stage or later ($r = 0.81$), but no correlation existed between height and yield with applications before early bloom. The correlation between yield and maturity delay was negative ($r = -0.56$).

Test weights and 1,000-seed weights were taken to determine the effects of dicamba on soybean seed quality, and to aid in the interpretation of yield differences.

Dicamba increased test weight at all rates of application regardless of soybean stage (Table 9). Apparently, dicamba caused a change in the seed which resulted in increased test weight. The 0.011 and 0.056 kg/ha rates increased test weight more than the 0.028 kg/ha rate. These results are difficult to explain.

One thousand seed weight was increased by dicamba application at the mid-bloom and late pod stages (Table 10). All three rates of application at the mid-bloom stage caused similar increases in seed weight. The 0.028 and 0.056 kg/ha rates applied at the late pod stage caused greater increases in seed weight than the 0.011 kg/ha rate.

Wax, _et al_. (59) attributed increase in seed weight from dicamba application to a reduction in the pod number and a reduction in the number of seeds per pod. With fewer seeds per plant the seed attained greater weight. Also, fewer pods on the upper portion of the plant produced seed since more dicamba was deposited on the upper portion of the plant than on the lower portion. Pods on the upper nodes normally produce smaller seeds, which reduce 1,000-seed weight.

Dicamba application before pod fill did not affect germination (Tables 5, 6, and 11). Only the 0.056 kg/ha rate applied at the early pod stage reduced germination in 1975 (Table 6). In 1976, all rates applied at the early pod stage caused similar reductions in germination (Table 11). However, when applied at the late pod-stage the 0.028 and

Table 9. Test weight of Corsoy soybeans treated with dicamba at various rates and growth stages (1976).

		Soybean Test Weight Growth Stage at Time of Treatment			
Dicamba Rate (kg/ha)	Rate Mean	Early Bloom (kg/hl)	Mid-Bloom (kg/hl)	Early Pod (kg/hl)	Late Pod (kg/hl)
0.0	74.2	74.4	74.0	74.0	74.3
0.011	74.9	74.7	74.7	75.2	74.9
0.028	74.7	74.7	74.8	74.9	74.5
0.056	75.1	75.0	75.2	75.2	74.8
Growth stage mean		74.7	74.7	74.8	74.6

ANALYSIS OF VARIANCE[a]

Source	DF	MS
Dicamba Rate	3	1.31**
(0.0,0.011) vs (0.028,0.056)	1	1.50**
0.0 vs 0.011	1	1.95**
0.028 vs 0.056	1	0.48*
Growth Stage	3	0.09
Rate x stage interaction	9	0.12

*,**Significant F-test at the 0.05 and 0.01 levels, respectively.

[a]Used orthogonal comparisons.

Table 10. One thousand seed weight of Corsoy soybeans treated with dicamba at various rates and growth stages (1976).

		Soybean 1,000 Seed Weight Growth Stage at Time of Treatment			
Dicamba Rate (kg/ha)	Rate Mean	Early Bloom (gm)	Mid-Bloom (gm)	Early Pod (gm)	Late Pod (gm)
0.0	135.0	132.9	139.0	133.4	134.5
0.011	143.0	134.9	154.3	135.5	147.1
0.028	145.8	129.3	157.2	140.3	156.3
0.056	146.1	129.9	157.5	139.7	157.4
Growth stage mean		131.8	152.0	137.2	148.8

ANALYSIS OF VARIANCE

Source	DF	MS
Dicamba Rate	3	434.75**
Growth Stage	3	145.81**
Rate x stage interaction	9	132.97**

COMPARISONS[a]

	DF	MS
Early Bloom Stage		
0.0 vs (0.011,0.028,0.056)	1	6.68
0.011 vs (0.028,0.056)	1	75.26
0.028 vs 0.056	1	0.78
Mid-Bloom Stage		
0.0 vs (0.011,0.028,0.056)	1	903.94**
0.011 vs (0.028,0.056)	1	24.81
0.028 vs 0.056	1	0.10
Early Pod Stage		
0.0 vs (0.011,0.028,0.056)	1	23.80**
0.011 vs (0.028,0.056)	1	7.82
0.028 vs 0.056	1	2.76
Late Pod Stage		
0.0 vs (0.011,0.028,0.056)	1	0.99
0.011 vs (0.028,0.056)	1	19.98**
0.028 vs 0.056	1	5.61

*,**Significant F-test at the 0.05 and 0.01 levels, respectively.

[a]Orthogonal comparisons of rates within each growth stage by partitioning the effects of rate and the rate x stage interaction.

Table 11. Germination of seed from Corsoy soybeans which had been treated with dicamba at various rates and growth stages (1976).

Dicamba Rate (kg/ha)	Rate Mean	Soybean Seed Germination Growth Stage at Time of Treatment Early Bloom (%)	Mid-Bloom (%)	Early Pod (%)	Late Pod (%)
0	68.8	67.9	66.0	70.0	71.2
0.011	62.8	72.2	72.5	56.2	50.2
0.028	51.5	68.5	61.1	53.1	23.2
0.056	54.1	70.9	66.0	52.5	27.1
Growth stage mean		69.9	66.4	58.0	42.9

ANALYSIS OF VARIANCE

Source	DF	MS
Dicamba Rate	3	1,080.60**
Growth Stage	3	2,349.09**
Rate x stage interaction	9	428.55**

COMPARISONS[a]

	DF	MS
Early Bloom		
0.0 vs (0.011,0.028,0.056)	1	21.33
0.011 vs (0.028,0.056)	1	17.51
0.028 vs 0.056	1	11.28
Mid-Bloom		
0.0 vs (0.011,0.028,0.056)	1	13.02
0.011 vs (0.028,0.056)	1	213.01*
0.028 vs 0.056	1	47.53
Early Pod		
0.0 vs (0.011,0.028,0.056)	1	772.00**
0.011 vs (0.028,0.056)	1	31.51
0.028 vs 0.056	1	0.78
Late Pod		
0.0 vs (0.011,0.028,0.056)	1	4,265.76**
0.011 vs (0.028,0.056)	1	1,675.10**
0.028 vs 0.056	1	30.03

*,**Significant F-test at 0.05 and 0.01 levels, respectively.

[a]Orthogonal comparisons of rates within each growth stage by partitioning the effects of rate and the rate x stage interaction.

0.056 kg/ha rates of dicamba caused greater germination reductions than the 0.011 kg/ha rate. Soybean emergence was reduced by the same treatment of 1975, which caused a reduction in germination (Table 12). The 0.011 kg/ha rate of dicamba applied at early pod may have delayed emergence. This is indicated by the difference between emergence 9 and 15 days after planting.

Germination tests in this study do not agree entirely with those of Wax, et al. (59). They reported no germination reduction from applications made at prebloom stage, but they reported a reduction in germination caused by dicamba applied at the bloom stage. Thompson and Egli (54) reported that under greenhouse conditions, 50 percent emergence was obtained from seed of plants treated with 0.03 kg/ha of dicamba at bloom and podfill stages. Seedlings in the 2 to 3-trifoliate stage had leaf abnormalities and less dry weight than normal seedlings. In my study, leaf abnormalities and dry weight reductions were not apparent (Table 13). Since dry weights were taken at later growth stages, the progeny may have overcome effects of dicamba treatment. Unusual swellings approximately 1 cm from the root cap of the radical were noted in seedlings in the germination tests. Dicamba accumulation in the seed may have caused the reduction in germination when dicamba was applied at the reproductive growth stage. Dicamba moves with the photosynthate to the metabolic sinks, which at seed formation is the pod (13,14,15,59). Abnormalities observed on seedlings may be an indication of dicamba presence in the seed.

Table 12. Emergence of progeny from Corsoy soybeans which were treated with dicamba at various rates and growth stages in 1975.[a]

Soybean Growth Stage of Time of Treatment	Dicamba Rate (kg/ha)	Soybean Seed Emergence Days After Planting			
		9 (%)	15 (%)	21 (%)	41 (%)
Early bloom					
	0.00	63.5a-c	71.2a-b	71.2a-c	72.0a-d
	0.001	62.8a-c	64.8a-c	62.5a-f	66.8a-e
	0.011	54.8c-e	64.5a-c	64.5a-e	64.8a-e
	0.056	53.8c-e	65.2a-c	64.2a-e	63.5a-e
Early pod					
	0.00	66.2a-c	74.0a-b	72.2a-c	74.3a-b
	0.001	63.2a-c	74.2a	74.0a-b	70.0a-e
	0.011	44.8e-f	59.8b-d	59.5b-f	56.8c-f
	0.056	37.2f	47.2e-f	49.0f	47.8f

[a]Means followed by different letters indicate significant difference at the 0.05 level using Duncan's multiple range test.

Table 13. Vigor of progeny from Corsoy soybeans which had been treated with dicamba at various rates and growth stages in 1975.[a]

Soybean Growth Stage at Time of Treatment	Dicamba Rate (kg/ha)	Dry Weight per Plant[b] (gm)
Early bloom		
	0.00	3.1a
	0.001	3.2a
	0.011	3.4a
	0.056	3.2a
Early pod		
	0.00	3.3a
	0.001	2.6a
	0.011	2.4a
	0.056	2.8a

[a]Means followed by different letters indicate significant difference at the 0.05 level using Duncan's multiple range test.

[b]Dry weights taken 41 days after planting.

Applications before the pod stages probably caused flowers to abort or prevented seed formation. Seeds were already being formed when pod stage applications were made, and dicamba was translocated into the seed. Maturity delay caused by dicamba application may also influence germination. Seed germination increases as the seed matures (6); therefore, a killing frost before the proper seed maturity may reduce germination. Analysis of dicamba residue in seed with reduced germination might aid in determining the cause of germination reduction.

Variety Experiment

Dicamba was applied at three dates to 13 soybean varieties to determine varieties tolerant to dicamba. Significant interactions between variety, dicamba treatment, and treatment date were observed; therefore, data was analyzed using orthogonal comparisons of treated to untreated plots for each date.

Leaf and stem abnormalities were rated. This rating disregarded height reduction. A zero rating indicates no injury and a 100 percent rating indicates death. A slight amount of drift injury occurred on some of the controls; but, apparently yield was not affected.

Dicamba application resulted in significant leaf injury to all varieties except 'SRF-100' (Table 14). Furthermore, all varieties

Table 14. Visual injury on 13 soybean varieties treated with dicamba at various dates (1976).[a]

Soybean Variety	Maturity Group	Dicamba Rate (kg/ha)	Soybean Visual Injury Application Date 7-7 (%)	7-24 (%)	8-2 (%)
SRF-100	0	0	0	3	2
		0.028	7	5	8
Chippewa	I	0	0	3	0
		0.028	5	20**	27**
Hodgson	I	0	0	5	0
		0.028	12**	8	22**
SRF-150	I	0	0	0	0
		0.028	0	12*	12*
Steele	I	0	0	0	0
		0.028	23**	15**	22**
Corsoy	II	0	0	5	3
		0.028	20**	22**	18**
Harcor	II	0	0	0	3
		0.028	23**	22**	27**
SRF-200	II	0	0	2	0
		0.028	0	20**	28**
Wells	II	0	3	3	0
		0.028	8	18**	28**
Amsoy 71	II	0	2	0	3
		0.028	18**	17**	23**
Beeson	II	0	2	0	3
		0.028	18**	12*	25**
Woodworth	III	0	0	0	3
		0.028	12*	20**	20**
Wayne	III	0	0	0	0
		0.028	17**	15**	30**

*,**Significant F-test at the 0.05 and 0.01 levels, respectively.

[a]Used orthogonal comparisons of treated and untreated plots for each date and variety by partitioning the effects of rate and the rate x date, rate x variety, and rate x date x variety interactions.

were reduced in height by application of dicamba (Table 15). Dicamba reduced height more for later maturing varieties than for earlier maturing varieties. A possible explanation for this might be that vegetative growth rate at the last application was less for the earlier varieties than for the later maturing varieties. Therefore, plant height was not reduced.

Due to the wide maturity differences among the varieties, maturity delay was difficult to detect. One could visually detect delays in maturity of the early maturity varieties but could not detect delays in maturity of the later maturing varieties (Table 16). One week after visual estimates of maturity were made, pod moisture samples were taken. At this date, delays in maturity could be recognized in later maturing varieties but not in earlier maturing varieties (Table 17).

Dicamba delayed maturity for all varieties, but varietal differences in response to dicamba appear to exist. 'SRF-150' was the only variety of group one maturity that was not delayed by the first two dicamba applications (Table 16).

Assuming that pod moisture content correlates with maturity, 'Chippewa' and 'Steele' varieties were delayed more than 'Hodgson' and 'SRF-150' (Table 17). However, considering visual ratings, 'Hodgson' was delayed more by the first two dicamba applications than 'SRF-150' (Table 16).

Table 15. Plant height of 13 soybean varieties treated with dicamba at various dates (1976).[a]

Variety	Maturity Group	Dicamba Rate (kg/ha)	Soybean Height Application Date 7-7 (cm)	7-24 (cm)	8-2 (cm)
SRF-100	0	0	44	53	54
		0.028	27**	44*	46
Chippewa	I	0	70	72	76
		0.028	36**	63*	69
Hodgson	I	0	66	69	76
		0.028	42**	59*	71
SRF-150	I	0	45	48	55
		0.028	24**	42	53
Steele	I	0	84	83	82
		0.028	40**	61**	75
Corsoy	II	0	72	70	71
		0.028	37**	56**	71
Harcor	II	0	90	90	89
		0.028	52**	67**	88
SRF-200	II	0	82	80	86
		0.028	45**	64**	69**
Wells	II	0	83	82	81
		0.028	49**	66**	70**
Amsoy 71	II	0	89	83	82
		0.028	46**	70**	73*
Beeson	II	0	78	79	76
		0.028	48**	55**	68*
Woodworth	III	0	74	73	69
		0.028	40**	51**	58
Wayne	III	0	84	85	88
		0.028	50**	51**	60**

*,**Significant F-test at the 0.05 and 0.01 levels, respectively.

[a]Used orthogonal comparisons of treated and untreated plots for each date and variety by partitioning the effects of rate and the rate x date, rate x variety, and rate x date x variety interactions.

Table 16. Maturity of 13 soybean varieties treated with dicamba at various dates (1976).[a]

Soybean Variety	Maturity Group	Dicamba Rate (kg/ha)	Days to Maturity Application Date 7-7	7-24	8-2
SRF-100	0	0	-1	-1	-1
		0.028	5**	8**	8**
Chippewa	I	0	1	1	1
		0.028	10**	10**	15**
Hodgson	I	0	2	2	2
		0.028	9**	11**	12**
SRF-150	I	0	3	2	2
		0.028	6	6	9**
Steele	I	0	3	3	3
		0.028	12**	10**	16**
Corsoy	II	0	5	5	5
		0.028	12**	12*	16**
Harcor	II	0	9	9	8
		0.028	12	17**	20**
SRF-200	II	0	12	12	12
		0.028	15**	11	18**
Wells	II	0	9	9	9
		0.028	14**	17**	23**
Amsoy 71	II	0	13	13	13
		0.028	13	14	22**
Beeson	II	0	15	14	14
		0.028	17	19*	25**
Woodworth	III	0	16	16	16
		0.028	16	22*	22**
Wayne	III	0	19	19	19
		0.028	22	26**	23*

*,**Significant F-test at the 0.05 and 0.01 levels, respectively.

[a]Used orthogonal comparisons of treated and untreated plots for each date and variety by partitioning the effects of rate and the rate x date, rate x variety, and rate x date x variety interactions.

Table 17. Pod moisture content of 13 soybean varieties treated with dicamba at various dates (1976).

			Soybean Pod Moisture Content		
			Application Date		
Soybean Variety	Maturity Group	Control (%)	7-7 (%)	7-24 (%)	8-2 (%)
SRF-100	0	10	16	13	14
Chippewa	I	11	20**	17	20**
Hodgson	I	10	12	14	15
SRF-150	I	10	14	13	17*
Steele	I	9	35**	17*	26**
Corsoy	II	11	13	15	20**
Harcor	II	11	13	35**	21**
SRF-200	II	10	14	13	35**
Wells	II	14	16	40**	45**
Amsoy 71	II	13	17	18	47**
Beeson	II	21	36**	46**	65**
Woodworth	III	20	29	49**	61**
Wayne	III	28	54**	62**	62**

*,**Significance at the 0.05 and 0.01 levels, respectively, using Dunnett's procedure.

There was no correlation between yield and maturity or yield and visual injury, but the correlation between height and yield was highly significant ($r = 0.67$). This may indicate that dicamba applications causing visual injury or maturity delay do not necessarily reduce yield.

Dicamba application reduced the yield of all varieties except 'Wells', 'SRF-200', and 'Woodworth' (Table 18). Tolerance is probably due to factors other than maturity since these varieties differ in maturity and since yield was reduced in varieties with similar maturity.

The 1,000-seed weight increased in most varieties as a result of dicamba application at the last two dates (Table 19). The variety 'Steele' had increased 1,000-seed weights for all dates of application. The first application reduced the seed weight of 'SRF-200' and 'Amsoy 71'.

Dicamba application increased the test weights of early maturing varieties, but decreased the test weights of late maturing varieties (Table 20).

<u>Residue Analysis Experiment</u>

Dicamba in soybean foliage can be detected by residue analysis. The amount detected was significantly influenced by the amount applied and the sampling date.

Table 18. Yield of 13 soybean varieties treated with dicamba at various dates (1976).[a]

Soybean Variety	Maturity Group	Dicamba Rate (kg/ha)	Soybean Yield Application Date 7-7 (kg/ha)	7-24 (kg/ha)	8-2 (kg/ha)
SRF-100	0	0	476	830	908
		0.028	105*	564	531
Chippewa	I	0	1,569	1,538	1,623
		0.028	640**	1,488	1,433
Hodgson	I	0	1,153	1,156	1,353
		0.028	714**	1,215	1,163
SRF-150	I	0	564	608	611
		0.028	185*	556	900
Steele	I	0	1,330	1,332	1,460
		0.028	499**	1,324	1,212
Corsoy	II	0	1,166	1,262	1,250
		0.028	799*	1,113	1,007
Harcor	II	0	1,377	1,361	1,478
		0.028	1,256	1,239	1,036**
SRF-200	II	0	1,543	1,810	1,666
		0.028	1,306	1,521	1,402
Wells	II	0	1,555	1,660	1,526
		0.028	1,319	1,578	1,251
Amsoy 71	II	0	1,568	1,621	1,704
		0.028	1,107**	1,463	1,459
Beeson	II	0	1,599	1,554	1,644
		0.028	1,069**	1,435	1,207**
Woodworth	III	0	764	892	660
		0.028	511	712	647
Wayne	III	0	1,191	1,109	1,341
		0.028	1,252	997	992*

*,**Significant F-test at the 0.05 and 0.01 levels, respectively.

[a]Used orthogonal comparisons of treated and untreated plots for each date and variety by partitioning the effects of rate and the rate x date, rate x variety, and rate x date x variety interactions.

Table 19. One thousand seed weight of 13 soybean varieties treated with dicamba at various dates (1976).[a]

Soybean Variety	Maturity Group	Dicamba Rate (kg/ha)	Soybean 1,000 Seed Weight Application Date 7-7 (gm)	7-24 (gm)	8-2 (gm)
SRF-100	0	0	124	125	124
		0.028	128	136*	147**
Chippewa	I	0	134	133	135
		0.028	128	141	169**
Hodgson	I	0	134	141	136
		0.028	143*	141	174**
SRF-150	I	0	122	125	122
		0.028	122	133*	147**
Steele	I	0	141	136	147
		0.028	154**	162**	178**
Corsoy	II	0	127	136	131
		0.028	119	145*	150**
Harcor	II	0	118	119	125
		0.028	113	144**	145**
SRF-200	II	0	127	129	128
		0.028	119*	136	146**
Wells	II	0	135	140	138
		0.028	121	164**	160**
Amsoy 71	II	0	140	137	138
		0.028	123**	155**	160**
Beeson	II	0	150	159	148
		0.028	144	188**	165**
Woodworth	III	0	122	120	120
		0.028	116	141**	137**
Wayne	III	0	139	141	146
		0.028	146	169**	172**

*,**Significant F-test at the 0.05 and 0.01 levels, respectively.

[a]Used orthogonal comparisons of treated and untreated plots for each date and variety by partitioning the effects of rate and the rate x date, rate x variety, and rate x date x variety interactions.

Table 20. Test weight of 13 soybean varieties treated with dicamba at various dates (1976).[a]

Soybean Variety	Maturity Group	Dicamba Rate (kg/ha)	Soybean Test Weight Application Date 7-7 (kg/hl)	7-24 (kg/hl)	8-2 (kg/hl)
SRF-100	0	0	69.1	70.7	70.9
		0.028	69.6	71.7*	71.3
Chippewa	I	0	70.7	70.8	70.3
		0.028	72.0**	72.9**	73.0**
Hodgson	I	0	70.8	72.2	71.9
		0.028	73.6**	72.8	73.7**
SRF-150	I	0	72.8	73.2	73.2
		0.028	72.5	73.5	74.9**
Steele	I	0	72.6	73.4	73.0
		0.028	72.9	73.8	73.6
Corsoy	II	0	74.2	74.1	74.4
		0.028	74.4	74.6	75.0
Harcor	II	0	75.8	74.5	75.1
		0.028	75.6	75.1	76.0
SRF-200	II	0	75.3	75.0	75.0
		0.028	74.9	75.0	76.1*
Wells	II	0	72.9	72.8	73.2
		0.028	73.2	72.4	73.9
Amsoy 71	II	0	74.6	74.5	74.6
		0.028	74.4	74.4	75.2
Beeson	II	0	74.1	74.3	74.6
		0.028	73.8	73.3*	74.4
Woodworth	III	0	73.5	73.7	74.0
		0.028	73.3	73.2	73.1*
Wayne	III	0	73.5	74.0	73.4
		0.028	73.7	72.9*	73.8

*,**Significant F-test at the 0.05 and 0.01 levels, respectively.

[a]Used orthogonal comparisons of treated and untreated plots for each date and variety by partitioning the effects of rate and the rate x date, rate x variety, and rate x date x variety interactions.

A significant interaction was observed between application rate and sampling date. Soybean foliage from treated plots sampled immediately after dicamba application had higher dicamba residue levels than foliage from untreated plots (Figure 1). However, very little difference was observed between the rates of application. This is difficult to explain since residue levels would be expected to correspond closely with the rate applied.

One week after dicamba application the residue levels were less than levels immediately after application for all application rates, but the reduction was greater with the two lower rates (Figure 1). Chang and Vander Born (13) reported similar reductions in dicamba recovered from Canada thistle. Nine days after dicamba application they were able to recover only 60 percent of the dicamba applied. Six percent of the dicamba recovered was on the leaf surface. After nine days the recovery percentage remained fairly constant. Chang and Vander Born (13) indicated that the dicamba loss during the first nine days was due mainly to evaporation. Dicamba residue on the leaves could also be reduced by rainfall, but in our study only 0.18 cm of rain fell during the week after application.

Dicamba residue levels became indetectable between 7 and 18 days after application since 18 days after application there was no difference between control and treatment residue levels. These results do not necessarily indicate dicamba breakdown because dicamba metabolism is slow in sensitive plants (13,14,15,28). Rather, dicamba

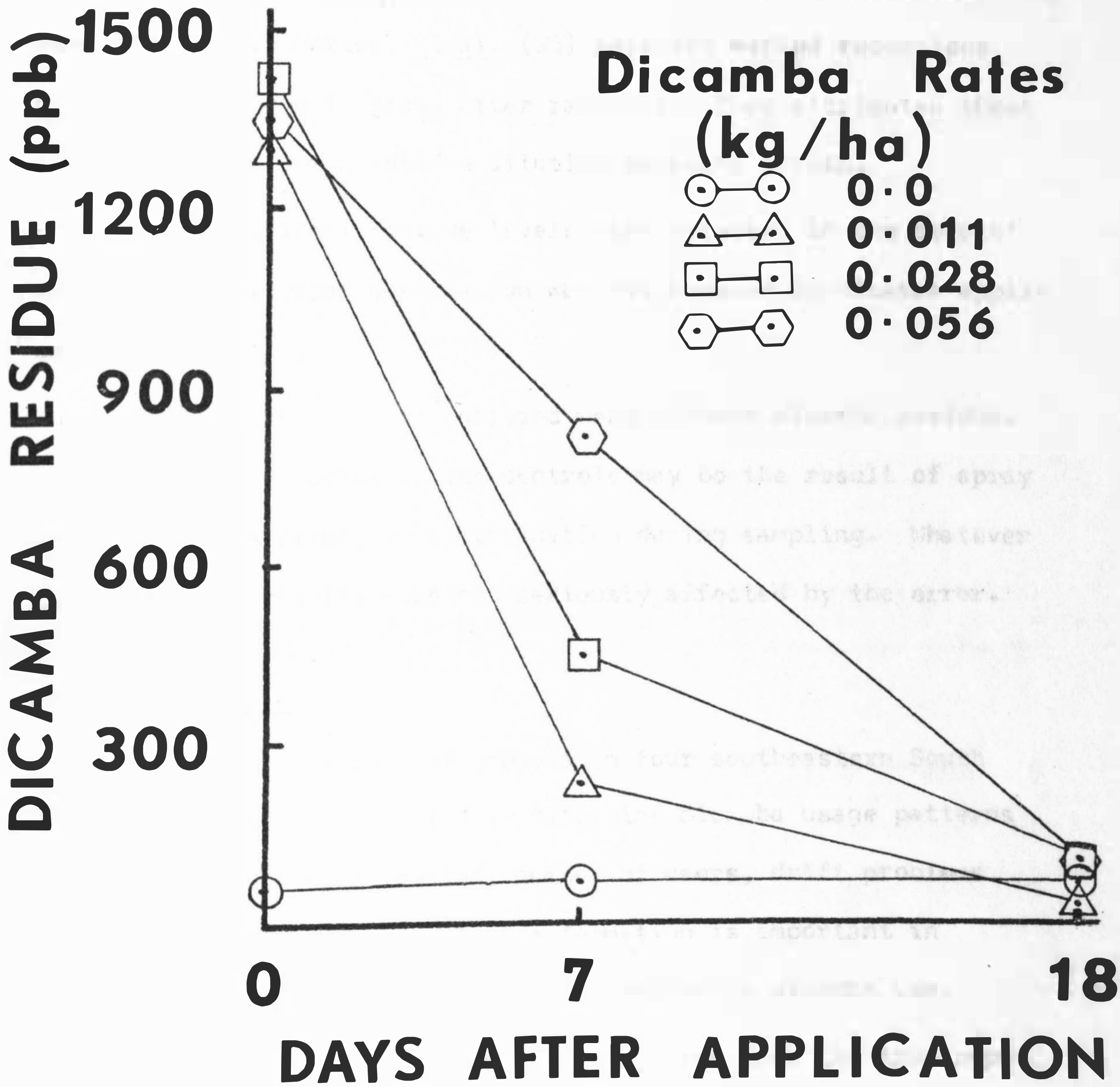

Figure 1. Dicamba residue in soybean foliage 0, 7, and 18 days after application.

residue may have been diluted by plant growth. Plant growth was stimulated by 3.28 cm of rainfall between the second and third sampling dates. Morton, et al. (35) reported marked reductions of dicamba residue in grass after rainfall. They attributed these reductions to dicamba residue dilution by plant growth.

No significant residue levels were detected in the seed of treated plants. Seed germination was not reduced by dicamba application.

None of the samples analyzed were without dicamba residue. The presence of dicamba in the controls may be the result of spray drift, analysis error, or contamination during sampling. Whatever the cause, the results were not seriously affected by the error.

Dicamba Use Survey

A telephone survey of growers in four southeastern South Dakota counties was conducted to determine dicamba usage patterns relating to: hectares treated, number of users, drift problems encounted, and future use. This information is important in evaluation of the benefits and risks involved in dicamba use.

Due to sampling error, results may vary from the true population. According to Sabrosky (44), with a sample size of 160, if the true percentage is 50, the percentage obtained from the sample might range from 40 to 60. If the true percentage is 10, the results might range from 6 to 14 percent. The results in this study should be more accurate since random samples were taken from each township in the survey area, thereby giving better representativeness.

Dicamba users surveyed treated 2,431 ha in 1976 (Table 21). Users in Lincoln County treated the most hectares, followed by Clay, Turner, and Union Counties. In southeastern South Dakota, dicamba is used mainly to control Canada thistle; therefore, dicamba use patterns followed patterns of Canada thistle distribution. County weed board estimates of Canada thistle infestation in each county in 1975 were as follows: Lincoln, 3,600 ha; Clay, 2,000 ha; and Union, 650 ha (18). No estimate of Canada thistle infestation was given for Turner County.

Eighty-three percent of the hectares treated with dicamba were corn. Approximately 20 percent of the corn grown in the survey area was treated with dicamba. Dicamba was applied to approximately one-third of the corn raised in Lincoln County. Greater tolerance of corn to dicamba than 2,4-D encourages the use of dicamba on corn.

Thirty-one percent of 159 farmers used dicamba in 1976 (Table 22). A greater percentage of Lincoln and Union County farmers used dicamba than in Turner and Clay County farmers. In Lincoln County, 41 percent of the farmers used dicamba compared to 20 percent in Turner County.

Table 21. Dicamba users, hectares per user, and hectares of corn, small grain, and pasture treated with dicamba in 1976 by farmers surveyed in Clay, Lincoln, Turner, and Union Counties of South Dakota.

Crop	Counties				Total per Crop
	Clay,	Lincoln,	Turner,	Union	
Corn:					
Hectares treated	391	1,056	308	270	2,025
Number of users	7	17	10	12	46
Hectares per user	56	62	31	23	44
Small Grain:					
Hectares treated	263	0	28	22	313
Number of users	2	0	1	1	4
Hectares per user	132	0	28	22	78
Pasture:					
Hectares treated	28	36	10	19	93
Number of users	2	3	1	3	9
Hectares per user	14	12	10	6	10
Total hectares treated	682	1,092	346	311	2,431
Total hectares per user[a]					49

[a]Average of 50 users surveyed. Some farmers used dicamba on more than one crop.

Table 22. Farmers surveyed in southeastern South Dakota who have had experience using dicamba.

	Counties				
	Clay,	Lincoln,	Turner,	Union	Total
Farmers surveyed	26	46	54	33	159
Farmers who have used dicamba	11	27	20	16	74
Percent of total surveyed	42	59	37	48	47
Farmers who used dicamba in 1976	7	19	11	13	50
Percent of total surveyed	27	41	20	39	31

The hectares treated per user ranged from 4 ha or less to 280 ha (Table 23); the average per farmer was 47 ha. Approximately one-third of the dicamba users treated between 21 and 40 ha.

Most of the dicamba users did their own application. Only three of the 50 dicamba users hired commercial applicators and two of these also applied some dicamba themselves. Six of the 50 dicamba users in 1976 were first time users; indicating that most treatments were applied by farmers with experience in using dicamba.

Seven of the 50 dicamba users reported drift injury on soybeans (Table 24, cases 1 to 7). One drift incident resulted from commercial application (Table 24, case 7). This was the only drift incident reported by dicamba users that caused injury to a neighbor's soybeans; it involved 8 to 12 ha. Five of the seven drift occurrences injured less than 4 ha. In the other case, dicamba drift injured 4 to 8 ha.

All but two of the dicamba drift incidents occurred before soybeans were in the bloom stage. Only one farmer thought that yield was reduced, and he estimated the yield reduction at less than 10 percent. Either the dicamba concentration was not high enough to reduce yield--the soybeans were in tolerant growth stages--or the farmers did not notice yield reductions that occurred.

The dicamba users having problems with drift treated an average of 89 ha, which is nearly twice as many hectares as the average per

Table 23. Distribution of dicamba use among users surveyed in 1976 in Clay, Lincoln, Turner, and Union Counties of South Dakota.

Hectares Treated	Number of Dicamba Users — Counties: Clay	Lincoln	Turner	Union	Total
Less than 4	--	3	--	3	6
4 - 10	1	--	1	1	3
11 - 20	1	3	5	--	9
21 - 40	2	3	4	8	17
41 - 60	--	2	--	--	2
61 - 80	--	3	--	1	4
81 - 100	--	1	--	--	1
101 - 120	1	3	--	--	4
121 - 140	--	--	1	1	2
141 - 160	--	--	--	--	0
161 - 180	1	--	--	--	1
More than 180	1	--	--	--	1
					50

Table 24. Cases of drift injury on soybeans reported in 1976 when 159 farmers were surveyed in Clay, Lincoln, Turner, and Union Counties of South Dakota.

Case Number	Individual Responsible	Chemical Involved	Hectares Injured[a]	Growth Stage Injured	Yield Reduction
1	owner	dicamba	4-8	bloom	none
2	owner	dicamba	less than 4.0	25 cm to before bloom	none
3	owner	dicamba	less than 4.0	25 cm to before bloom	none
4	owner	dicamba	less than 4.0	25 cm to before bloom	none
5	owner	dicamba	less than 4.0	25 cm to before bloom	none
6	owner	dicamba	less than 4.0	emergence to 24 cm	none
7	commercial applicator	dicamba	8-12	bloom	less than 10 %
8	neighbor	dicamba	less than 4.0	emergence to 24 cm	none
9	neighbor	dicamba	less than 4.0	emergence to 24 cm	none
10	neighbor	dicamba	less than 4.0	25 cm to before bloom	uncertain
11	owner	2,4-D	less than 4.0	25 cm to before bloom	none
12	owner	2,4-D	less than 0.5	emergence to 24 cm	uncertain
13	owner	picloram	less than 0.5	bloom	10 - 19 %
14	county applicator	uncertain	less than 0.5	emergence to 24 cm	uncertain
15	county applicator	uncertain	less than 4.0	25 cm to before bloom	10 - 19 %
16	uncertain	uncertain	less than 1.0	25 cm to before bloom	none
17	neighbor	uncertain	less than 1.5	emergence to 24 cm	80 %
18	uncertain	uncertain	less than 4.0	25 cm to before bloom	none

[a]The farmers were not asked to specify the hectares injured if less than 4.0 ha. If they did, the response is indicated.

user. Six of the cases involving drift occurred when farmers were treating corn, and the other incident occurred when a farmer sprayed a fence line with a high rate of dicamba. Earlier, he had treated 80 ha of corn without problems. No drift incidents occurred from dicamba application to small grain because these applications are made before soybeans are susceptible to drift injury.

All of the dicamba users who experienced drift injury had used dicamba at least once before 1976. Three of these users did not know the cause of drift. Three others blamed windy conditions. One applicator said that vapor drift caused the injury.

Three soybean growers reported dicamba drift injury from applications made by neighbors (Table 24, cases 8 to 10). In each case, less than 4 ha of soybeans showed injury symptoms. Although one farmer was uncertain, none of the farmers indicated that the yield was reduced.

Besides the drift cases known to be caused by dicamba, eight soybean growers reported other drift injury cases (Table 24, cases 11-18). None of these cases involved more than 4 ha of soybeans and the estimates of yield reduction ranged from none to 80 percent.

The herbicides causing injury were 2,4-D in two cases and picloram in one case. In the other five cases the growers did not know what chemical caused the injury, but they were sure that the injury was caused by herbicide drift.

Dicamba can probably be ruled out as the cause of injury in two of the cases involving an unknown herbicide. Drift injury was caused by county roadside sprayers in these cases (Table 24, cases 14 and 15). Dicamba probably would not have been used because of the danger of drift and the higher cost of chemical as compared to 2,4-D.

In 1976, dicamba drift injury did not appear to be a major problem. Although drift injury did occur on soybeans, the number of hectares affected was small, and the effects on yield were slight to none. Most of the dicamba drift occurred on the users' own soybeans. In 70 percent of the dicamba drift cases, injury occurred after soybeans had reached the height of 25 cm.

About the same amount of dicamba will be used in 1977 as was used in 1976. Of all the farmers surveyed, 41 indicated they will use dicamba in 1977 (Table 25). Another 35 farmers were undecided. Three of the farmers planning to use dicamba will be first time users. One of the farmers who used dicamba in 1976 plans not to use dicamba in 1977, but 13 users were undecided about using dicamba in 1977.

The 41 farmers who will be using dicamba in 1977 indicated that they will treat 2,183 ha (Table 26). This is an average of 53 ha per farmer--slightly higher than the 1976 average of 49 ha.

The main factors influencing dicamba use in the survey area are the need for Canada thistle control and the risk of dicamba drift. Apparently, the farmer with an extensive Canada thistle problem was more willing to risk drift injury than one with a lesser problem. The

Table 25. Farmers surveyed in 1976 in Clay, Lincoln, Turner, and Union Counties of South Dakota who plan to use dicamba, do not plan to use dicamba, or are undecided about dicamba use in 1977.

	Counties				Total	
	Clay,	Lincoln,	Turner,	Union	(Number)	(%)
Will use dicamba	6	17	9	9	41	26
Will not use dicamba	17	20	30	16	83	52
Undecided	3	9	15	8	35	22

Table 26. Hectares of corn, small grain, and pasture to be treated with dicamba in 1977 by the farmers surveyed in Clay, Lincoln, Turner, and Union Counties who plan to use dicamba.

	Counties				Total
Crop	Clay,	Lincoln,	Turner,	Union	(ha)
Corn	245	1,002	238	292	1,777
Small grain	263	0	28	22	313
Pasture	28	36	10	19	93
					2,183

farmers using dicamba in past years who did not have severe thistle problems may have quit using it. This is indicated by the difference between the number of farmers who have used dicamba in the past and those who used it in 1976 (Table 22).

The small difference between 1976 use and the use planned for 1977 is an indication that farmers presently using dicamba feel that the benefits of use outweigh the risks of drift. This was true even among the dicamba users who had drift injury. None of them said that they will not use dicamba in 1977, although two were undecided.

Since most of the dicamba users are experienced, the drift incidents should continue to be minor. Although they were not asked directly, it was apparent by their comments that many users were practicing precautions recommended for dicamba use.

SUMMARY AND CONCLUSIONS

Growth Stage Experiment

Soybeans are most sensitive to dicamba at the early bloom growth stage. The greatest yield and height reductions occurred from treatments at this stage. Height was reduced by dicamba injury at all stages, with the exception of very early and very late growth stages. However, yield was reduced by dicamba injury occurring at the bloom and early pod stages.

Seed test weight was increased by high rates of dicamba. The 1,000-seed weight was increased by dicamba injury occurring at mid-bloom and late pod. Dicamba injury at podfill reduced germination and emergence.

Variety Experiment

All dicamba treatments to the 13 soybean varieties caused visual injury symptoms. Yield was reduced by dicamba application to all varieties except 'SRF-200', 'Wells', and 'Woodworth'.

Residue Analysis Experiment

Dicamba residue could be detected in soybean foliage 7 days but not 18 days after application. The amount of dicamba detected after application depended on the amount applied and on the sampling date.

Dicamba Use Survey

Thirty-one percent of the farmers surveyed used dicamba in 1976. They treated a total of 2,431 ha. Most users had used dicamba in previous years. Dicamba was applied mainly by farmers. Drift incidents appeared to be minor. In most cases there was no estimate of yield reduction. About the same amount of dicamba is expected to be used in 1977.

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