Response of Soybean Cultivars to Bentazon, Bromoxynil, Chloroxuron, and 2,4-DB

L. M. WAX, R. L. BERNARD, and R. M. HAYES

Abstract. The response of several hundred soybean [Glycine max (L.) Merr.] cultivars to postemergence application of four herbicides was evaluated in the field, greenhouse, and growth chamber in 1970, 1971, and 1972. Postemergence application of 3.4 kg/ha of bentazon [3-isopropyl-1H,2,1,3-benzothiadiazin-(4)3H-one 2,2-dioxide] did not significantly reduce yields of the seven commercially important soybean cultivars evaluated. All entries in the regional breeding trials, Uniform Test I to IV, were relatively tolerant of postemergence applications of the herbicides at rates about double those required for weed control. The observed order of phytotoxicity was 3.4 kg/ha of bentazon < 3.4 kg/ha of chloroxuron [3-(p-chlorophenoxy)phenyl]-1,1-dimethyleurea] < 0.3 kg/ha of bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) = 0.4 kg/ha of 2,4-DB [4-(2,4-dichlorophenoxy)butyric acid]. Of the 338 named U.S. and Canadian cultivars in the U.S. Department of Agriculture soybean germplasm collection, all but one were tolerant to a postemergence application of 3.4 kg/ha bentazon. One U.S. cultivar, “Hurrelbrink,” and ten plant introductions from Japan were highly sensitive to bentazon. These 11 cultivars were also highly sensitive to bromoxynil and 2,4-DB and somewhat sensitive to chloroxuron.

INTRODUCTION

A broad spectrum of troublesome weeds infests soybean fields throughout the major soybean-producing areas of the United States. Annual grass and broadleaf weeds are most prevalent. However, perennial grasses, perennial broadleaf weeds, and perennial sedges are especially troublesome in many areas. Presently available herbicides, which can be applied preplanting or preemergence in soybeans, selectively control most annual grass weeds and some of the annual broadleaf weeds. However, certain annual broadleaf weeds are not controlled adequately with the available preplanting or preemergence treatments. These resistant weed species often become the dominant weed problem and reduce soybean yields by competition, increase harvesting losses, and reduce the quality of the harvested crop.

Several candidate herbicides have been evaluated as postemergence treatments in recent years. Some of these treatments control certain broadleaf weeds in soybeans. In field experiments, 2,4-DB applied postemergence selectively controlled common cocklebur (Xanthium pensylvanicum Wallr.) in soybeans (17, 26). Over-the-top applications of 2,4-DB on soybeans and cocklebur frequently cause soybean injury and reduce yields; however, the yield reduction is much less than that caused by cocklebur when not controlled. Directed applications of 2,4-DB on soybeans control young cocklebur and are less injurious to soybeans than are over-the-top applications (40). Although primarily effective on common cocklebur at the rates used, 2,4-DB also partially controls annual morning glory (Ipomoea spp.).

Chloroxuron, as a postemergence spray, controls a broad spectrum of annual broadleaf weeds in soybeans (3, 8, 17, 24, 33). Although chloroxuron often causes initial soybean injury, significant yield reduction seldom occurs. Chloroxuron is most effective on very young annual broadleaf weeds and, in practice, is applied either over-the-top on young soybeans and weeds or as a directed spray on larger soybeans.

Andersen and Behrens (5) first demonstrated selective control of common cocklebur in soybeans with over-the-top postemergence applications of bromoxynil. Other researchers (25, 41) confirmed these results on common cocklebur and reported potential for the control of other broadleaf weeds as well. Later, Andersen et al. (6) reported that bromoxynil caused early injury to soybeans but seldom reduced yield at rates required for control of young cocklebur.

Recently, bentazon has shown considerable potential for selective control of many annual broadleaf weed species in soybeans (7, 9, 42, 44, 45). Bentazon is ineffective as a preemergence application and is only slightly effective as a postemergence application on annual grasses. However, bentazon has been extremely effective as an early postemergence application for control of several young annual broadleaf weeds; and in addition, soybeans are quite tolerant of bentazon at rates required for control of the broadleaf weeds.

The effectiveness of modern herbicide treatments in crops is based on interspecific selectivity or differential response to herbicides among species. There are also many instances of intraspecific selectivity or differential response to herbicides within species. These differential responses within a species may result in poor weed control or in injury to the crop.

Differential response within species to herbicides has been reported in Canada thistle [Cirsium arvense (L.) Scop.] (19, 22), wild oat (Avena fatua L.) (23), foxtail (Setaria spp.) (31, 38), hoary cress [Cardaria draba (L.) Desv.] (39), field bindweed (Convolvulus arvensis L.) (43), Kochia [Kochia scoparia (L.) Schrad.] (10), barnyardgrass [Echinochloa crus-galli (L.) Beauv.] (35), and common groundsel (Senecio vulgaris L.) (36, 37). In some instances, a 10-fold increase in rate of herbicide was required to achieve control of all plants within the species.

There are also numerous reports of differential response to herbicides by crop cultivars. The identification and characterization of these differences may be helpful in preventing substantial crop injury and in developing more tolerant lines for the future. Differential response to herbicides has been re-

ported among cultivars in corn (Zea mays L.) (1, 15, 18), sorghum [Sorghum bicolor (L.) Moench] (12, 28), flax (Linum usitatissimum L.) (4, 30), barley (Hordeum vulgare L.) (13), sugarcane (Saccharum officinarum L.) (29, 32, 34), cabbage [Brassica oleracea var. Capitata (L.)] (20), and bentgrass (Agrostis palustris Huds.) (21).

Soybean cultivars vary considerably in many agronomic characteristics and might vary in response to weed competition and to herbicides. Differential response of soybean cultivars to weed competition has been demonstrated by McWhorter and Hartwig (27) and Burnside (11). Burnside (11) also reported differential response of these cultivars to some of the herbicides currently in use for weed control in soybeans. Highly significant differences in response to 2,4-D [(2,4-dichlorophenoxy)acetic acid] and 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid] have been found among selected soybean strains from the U.S. Department of Agriculture germplasm collection (16). Andersen (2) found that soybean plants from small-seeded lines were more sensitive to atrazine [2-chloro-4-ethylamino]-6-(isopropylamino)-s-triazine than were plants from large-seeded lines.

Postemergence herbicide treatments are not used widely for weed control in soybeans in the midwestern United States. However, the increasing infestation of annual broadleaf weeds in midwestern soybean fields is likely to necessitate use of herbicides such as 2,4-DB and chloroxuron. Bentazon and bromoxynil have potential for solving some of the present broadleaf weed problems. Because of this potential use of postemergence herbicide applications on soybeans, we initiated studies to determine the differential response of commercially grown soybean cultivars and selected experimental breeding strains to postemergence applications of bentazon, bromoxynil, chloroxuron, and 2,4-DB.

MATERIALS and METHODS

Field experiments. We conducted several field experiments in 1971 and 1972 to evaluate the response of several species of weeds and several commercially important soybean cultivars to bentazon and bromoxynil, in comparison with standard postemergence treatments such as chloroxuron. These experiments were conducted on the Agronomy South Farm at Urbana, Illinois, on silt loams of 4 to 5% organic matter. Treatments were usually replicated three times in a randomized complete block design. Plot sizes ranged from two rows (76 cm apart) by 10 m to four rows (76 cm apart) by 16 m. Where yield was measured, the smaller plots were harvested by hand, and the larger plots were harvested with a combine. All postemergence treatments were applied broadcast in a volume of 240 L/ha aqueous spray over the tops of soybeans and weeds.

An experiment to evaluate application rates of bentazon and bromoxynil on soybeans at different stages of growth was conducted in 1971 and 1972. All plots (including the weedy check) were treated before planting 'Beeson' soybeans with a preplanting incorporated application of trifluralin (α,αα-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine) at 1.1 kg/ha to control the annual grass weeds. The plots were evaluated 2 weeks after the postemergence application for soybean injury and for control of individual weed species. All plots were cultivated twice during the season. The weed-free checks were weeded by hand as needed during the season. At maturation, soybeans were harvested and yields were expressed as kilograms per hectare at 13% moisture. The experimental data were analyzed statistically. Differences among treatment means were tested with Bayes LSD (14) at the 5% level.

In other experiments we evaluated the response of the cultivars and experimental strains of the regional breeding trials, Uniform Test I to IV, to postemergence applications of bentazon, bromoxynil, chloroxuron, and 2,4-DB in 1970, 1971, and 1972. In addition to the material in the Uniform Test I to IV, we included several selections from the U.S. Department of Agriculture soybean germplasm collection that were selected by researchers. We have reported that there is an increase in sensitivity to 2,4-D and 2,4-DB. Individual entries were planted in single rows (1 m apart) 13 m long, and were replicated two or three times. These experiments were located on areas of low natural weed infestation and were treated with trifluralin before planting. In addition, the area was cultivated as needed during the season for weed control. The various postemergence treatments were applied in 1-m-wide strips across the soybean rows, over the tops of soybeans in either the first or second trifoliate stage of growth. All treatments were applied in a volume of 240 L/ha on the same day under similar environmental conditions. Strips across the soybean rows were left untreated for comparison. The plots were evaluated for soybean injury at 1, 2, 4, and 8 weeks after application, using a rating scale where 0 = no injury and 100 = death of all plants. Later, the plants were rated for maturity and lodging (1 = erect, 5 = prostrate), and height at maturity was measured to the nearest centimeter.

In another experiment, conducted in 1972, 338 named U.S. and Canadian cultivars from the U.S. Department of Agriculture soybean germplasm collection and several other selections from the germplasm collection were grown at Urbana, Illinois, in duplicated hill plantings (12 seeds per hill). All plants were treated over-the-top at the first trifoliate stage of growth, with 3.4 kg/ha of bentazon in a volume of 240 L/ha of aqueous spray. Plants were evaluated for soybean injury 1, 2, 4, and 8 weeks after application of the treatments, using the rating system described above.

Greenhouse experiments. Numerous experiments were conducted in 1971 and 1972 to confirm the field results and further evaluate herbicide sensitivity of certain soybean cultivars at different stages of growth. Five soybean seeds were planted 2.5 cm deep in a silty clay loam soil in 0.5-L plastic containers. After emergence, the stand was thinned to two uniform plants per container. Water was added as needed. Natural illumination was supplemented by a 14-hr photoperiod of fluorescent and incandescent lighting. Air temperature was maintained between 20 and 30°C. Treatments were replicated three or four times in a randomized complete block design, and experiments were repeated at least once. Herbicide sprays were applied over-the-top to the soybeans in a volume of 240 L/ha, using a small hand-carried plot sprayer. Soybeans were treated at the first trifoliate stage of growth, except when the experimental variables included stage of growth. One
Table 1. Response of 'Beeson' soybeans to postemergence applications of bentazon, bromoxynil, and chloroxuron at Urbana, Illinois in field experiments during 1971 and 1972.a.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate (kg/ha)</th>
<th>Soybean injuryb</th>
<th>Soybean yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unifoliolatec</td>
<td>(kg/ha)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bentazon</td>
<td>0.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bentazon</td>
<td>1.7</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Bentazon</td>
<td>0.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bromoxynil</td>
<td>0.1</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Bromoxynil</td>
<td>0.2</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>First trifoliolatec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bentazon</td>
<td>0.8</td>
<td>0</td>
<td>0</td>
</tr>
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<td>Bentazon</td>
<td>1.7</td>
<td>5</td>
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<td>Bentazon</td>
<td>0.8</td>
<td>5</td>
<td>0</td>
</tr>
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<td>Bromoxynil</td>
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</tr>
<tr>
<td>Chloroxuron</td>
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<td>20</td>
<td>20</td>
</tr>
<tr>
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<td>20</td>
<td></td>
</tr>
<tr>
<td>Chloroxuron</td>
<td>0.4</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Second trifoliolatec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bentazon</td>
<td>0.8</td>
<td>0</td>
<td>0</td>
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<td>Bentazon</td>
<td>1.7</td>
<td>5</td>
<td>0</td>
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<td>7</td>
</tr>
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<td>Bromoxynil</td>
<td>0.1</td>
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<td>Bromoxynil</td>
<td>0.2</td>
<td>30</td>
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<td>Chloroxuron</td>
<td>0.3</td>
<td>30</td>
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<td>1.7</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Check (weedy)</td>
<td></td>
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<td>Check (hand weeded)</td>
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<td>3010</td>
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<tr>
<td>Bayes LSD 0.05</td>
<td>6</td>
<td>4</td>
<td>320</td>
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aAll plots were treated with 1.1 kg/ha of trifluralin incorporated before planting.
bInjury ratings 2 weeks after treatment: 0 = no injury, 100 = death of all plants.cIndicates stage of growth of soybeans at time of treatment application.
dSpray included 0.5% v/v surfactant (alkylaryl polyglycol ether).eSpray included 0.5% v/v surfactant (trimethylnonanol-ethyleneoxide complex).

RESULTS

Field experiments. ‘Beeson’ soybeans were rather tolerant at rates required to control many broadleaf weeds when bentazon was applied at soybean stages ranging from the unifoliolate to the second trifoliolate leaf stage (Table 1). Except at the lowest rate in some circumstances, bentazon application increased yields to as much as those of the hand-weeded check and much more than those of the weedy check (which had also been treated with trifluralin and received two cultivations). Bentazon provided adequate control of several troublesome broadleaf weed species at 0.8 kg/ha, especially when a surfactant was included in the spray (41, 42). The best weed control was achieved with bentazon applied at 3.4 kg/ha during the second trifoliolate stage of soybeans. However, the increased control with 3.4 kg/ha over 1.7 kg/ha was slight; and, therefore, the higher rate of bentazon probably would not be justified (or economically feasible).

Postemergence applications of bromoxynil caused greater visible soybean injury than was caused by bentazon (Table 1). However, this injury was considered acceptable, and the soybeans appeared to recover by mid season. We think the reduced yields on some bromoxynil plots were caused in part by weed competition. The soybeans tolerated bromoxynil at rates required to control certain broadleaf weeds. About 0.2 kg/ha of bromoxynil achieved the desired control (41, 42).

In several similar field experiments, where bentazon was applied at rates up to 3.4 kg/ha over the tops of soybeans in the first trifoliolate stage, ‘Amsoy,’ ‘Amsoy 71,’ ‘Calland,’ ‘Clark 63,’ ‘Corsoy,’ and ‘Wayne’ showed only slight injury symptoms and produced yields equivalent to those from the hand-weeded checks.

In the experiment involving the cultivars and experimental strains of regional breeding trials, Uniform Test I to IV, considerable differences existed among the entries in response to the postemergence treatments (Table 2). The ratings, which were made 4 weeks after treatment application, are presented in Table 2. Ratings made 1, 2, and 8 weeks after treatment; and data on height, maturity, and lodging are not shown because they indicated the same responses as the 4-week data. The commercially important cultivars differed only slightly with respect to a particular herbicide treatment. However, as a group, the cultivars were most sensitive to bromoxynil and 2,4-DB, considerably less sensitive to chloroxuron, and least sensitive to bentazon.
Table 2. Response of several soybean cultivars and experimental strains to postemergence applications of bentazon, bromoxynil, chloroxuron, and 2,4-DB in field experiments at Urbana, Illinois in 1970, 1971, and 1972.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Maturity</th>
<th>Bentazon 3.4 kg/ha</th>
<th>Bromoxynil 0.3 kg/ha</th>
<th>Chloroxuron 3.4 kg/ha</th>
<th>2,4-DB 0.2 kg/ha</th>
<th>2,4-DB 0.4 kg/ha</th>
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<tr>
<td>'Chippewa 64'</td>
<td>I</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>35</td>
<td>10</td>
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<tr>
<td>'Hark'</td>
<td>I</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>'Steelie'</td>
<td>I</td>
<td>0</td>
<td>0</td>
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<td>25</td>
<td>10</td>
</tr>
<tr>
<td>'Adams'</td>
<td>II</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>'Amsoy'</td>
<td>II</td>
<td></td>
<td></td>
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<td></td>
<td>23</td>
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<tr>
<td>'Amsoy 71'</td>
<td>II</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>35</td>
<td>10</td>
</tr>
<tr>
<td>'Beeson'</td>
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<td>0</td>
<td>0</td>
<td>10</td>
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<td>5</td>
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<td>'Harosoy'</td>
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<td>'Calland'</td>
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<td>'Wayne'</td>
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<td>'Williams'</td>
<td>III</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>10</td>
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<td>'Bonus'</td>
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<td>0</td>
<td>15</td>
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<td>'Clark 63'</td>
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</tr>
<tr>
<td>'Cutler 71'</td>
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<td>0</td>
<td>10</td>
<td>25</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>'Kent'</td>
<td>IV</td>
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<td>5</td>
<td>30</td>
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<tr>
<td>'Wye'</td>
<td>IV</td>
<td>0</td>
<td>5</td>
<td>20</td>
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<td>15</td>
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</table>

\*Treatments were applied as broadcast applications at a volume of 240 L/ha over the tops of soybeans in either the first or second trifoliate stage of growth. Bentazon sprays included 0.5% w/v surfactant (alkylaryl polyglycol ether). Chloroxuron sprays included 0.5% v/v surfactant (trimethylnonanol-ethylene oxide complex).

\*Injury ratings 4 weeks after treatment: 0 = no injury, 100 = death of all plants.

About 50 experimental breeding strains, also in the Uniform Test I to IV, responded similarly to the herbicide treatments as did the named cultivars discussed above (data not presented). There were only small differences in response to a particular herbicide; but as a group they were most tolerant of bentazon, somewhat less tolerant of chloroxuron, and least tolerant of bromoxynil and 2,4-DB.

Several of the lines selected from the soybean germplasm collection were highly sensitive to postemergence applications of bentazon (Table 2). As a group, the order of sensitivity was bentazon > bromoxynil > 2,4-DB > chloroxuron. All 11 of these entries that were sensitive to bentazon were also much more sensitive to the other three herbicides than were the cultivars and experimental breeding strains in the Uniform Test I to IV. Again, only the data taken 4 weeks after treatment are presented because the other data collected indicated similar results.

Three hundred and thirty-seven of the named U.S. and Canadian cultivars from the U.S. Department of Agriculture soybean germplasm collection sustained less than 30% injury from postemergence application of bentazon at 3.4 kg/ha. One named cultivar, 'Hurrelbrink,' was killed by this application.
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Figure 1. Response of 'Clark 63' and 'Hurrelbrink' soybeans to post-emergence application of bentazon at the first trifoliolate stage, with and without surfactant, in the growth chamber. Injury ratings were made 2 weeks after treatment. Data shown are averages of duplicate experiments, each treatment replicated four times.

All other plant introduction selections (listed by number in Table 2) were also killed by 3.4 kg/ha bentazon.

Greenhouse experiments. Preliminary experiments on the effect of stage of growth on response of soybeans to the four herbicides showed little effect of stage of growth when applications were made at the unifoliolate, first, or second trifoliolate stage. In all later greenhouse experiments, soybeans were routinely treated when they were in the first trifoliolate stage.

Data from several experiments indicated similar responses as found in the field. The order of phytotoxicity of the four herbicides to 'Beeson' and 'Clark 63' was 2,4-DB > bromoxynil = chloroxuron > bentazon (Table 3). 'Hurrelbrink,' PI 86.504, PI 229.342, and PI 243.532 varied somewhat in response to the various herbicide treatments, but in general the order of sensitivity was bentazon > 2,4-DB > bromoxynil > chloroxuron. The ratings in Table 3 were made 1 week after treatment. Ratings made 2 weeks after treatment (not presented) indicated similar results.

Growth chamber experiments. There was a remarkable difference in response to bentazon between 'Hurrelbrink' and 'Clark 63' (Figure 1). Also, greater phytotoxicity to both sensitive and tolerant cultivars occurred with the addition of a surfactant to the spray. Similar responses were found when 'Clark 63' was compared with PI 229.342 ('Nookishirohana'), which indicated that the sensitivity to bentazon at low rates was not limited to 'Hurrelbrink' (Figure 2).

In the experiment designed to compare various formulations of bentazon on sensitive [PI 86.504 ('Chinko')] and tolerant ('Clark 63') soybeans over a range of rates from 0.4 kg/ha to 3.4 kg/ha, 'Chinko' was highly and equally sensitive to the following formulations of bentazon: (a) 80% wettable powder, (b) 80% wettable powder, with 0.5% surfactant (alkylaryl polyglycol ether), (c) dimethylamine salt, and (d) sodium salt. 'Clark 63' was tolerant of all bentazon applications in this study.

DISCUSSION

Several major soybean cultivars had tolerance to postemergence applications of bentazon. In less extensive studies, bromoxynil also controlled certain broadleaf weeds at rates that did not reduce soybean yields, thus confirming the work of Andersen et al. (6).

The cultivars and experimental breeding strains in the regional breeding trial, Uniform Test I to IV, in 1970, 1971, and 1972, were relatively tolerant of bentazon, bromoxynil, chlo-

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Table 3. Response of selected soybean cultivars to postemergence applications of bentazon, bromoxynil, chloroxuron, and 2,4-DB in greenhouse experimentsa.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>0.8 kg/ha</th>
<th>3.4 kg/ha</th>
<th>0.07 kg/ha</th>
<th>0.3 kg/ha</th>
<th>0.8 kg/ha</th>
<th>3.4 kg/ha</th>
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<td>'Hurrelbrink'</td>
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<td>PI 229.342 'Nookishirohana'</td>
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<td>96</td>
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<td>Bayes LSD 0.05</td>
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aTreatments were applied at a volume of 240 L/ha over the tops of soybeans in the first trifoliolate stage. Bentazon and chloroxuron sprays included 0.5% v/v surfactant (alkylaryl polyglycol ether) and 0.5% v/v surfactant (trimethylnonanolethyleneoxide complex), respectively.

bInjury ratings 1 week after treatment: 0 = noninjury, 100 = death of all plants. Values shown are averages over two experiments, each with four replications.
2,4-D seems to hold. None of their lines, however, appear to be as sensitive to 2,4-DB as does 'Hurrelbrink.' In contrast, however, all of those lines tolerated an application of 1.7 kg/ha of bentazon with only slight injury.

Additional work seems warranted to determine the extent of this correlation and to discover if there are additional examples of extreme sensitivity to bentazon in the soybean germplasm. Further, we cannot explain why these cultivars differ so greatly in response to these herbicide treatments. More work seems needed to explain this differential response.

We believe our data indicate that all commercially important soybean cultivars in the U.S. and Canada are tolerant of bentazon. Eleven soybean cultivars have been found to be highly sensitive to bentazon. They also appear sensitive to 2,4-DB and bromoxynil and are somewhat sensitive to chloroxuron. These findings may help in preventing this sensitivity trait from being incorporated into a commercial cultivar inadvertently in a breeding program. These sensitive cultivars would seem useful in experiments on the basis-selectivity of bentazon, bromoxynil, and 2,4-DB, as well as in studies on the genetic inheritance of this sensitivity.

LITERATURE CITED

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