Factors Affecting the Use of Herbicides in Conservation Tillage

Pamela J. Hutchinson
FACTORS AFFECTING THE USE OF HERBICIDES
IN CONSERVATION TILLAGE

BY

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IN CONSERVATION TILLAGE

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

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Date
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INTRODUCTION

Efficacy of Bentazon and Haloxyfop When Tank mixed

Farm operators use conservation tillage to reduce time, labor and equipment costs, moisture loss, and soil erosion. The USDA reported in a recent survey that 21% of the farmers in the United States use conservation tillage. In the northern plains states of North Dakota, South Dakota, Nebraska, and Kansas, 30% of the farmers use conservation tillage.

Conservation tillage is usually defined as any planting and harvesting system which retains at least 30% residue cover on the soil surface after planting. The maintenance of this residue cover limits the use of preplant-incorporated herbicides and cultivation for weed control. The effectiveness of many preemergence herbicides is also reduced.

Postemergence herbicides enable operators to leave crop residue on the soil surface while obtaining effective weed control.

Foxtail spp. [Setaria spp.], velvetleaf [Abutilon theophrasti], and common cocklebur [Xanthium strumarium] are problem weeds in the corn/soybean rotation of the northern corn belt and often cause severe yield reductions
and harvesting difficulties.

Bentazon [3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4-(3H)-one 2,2-dioxide] is a postemergence herbicide labelled for use in soybeans to control several broadleaf species.

Haloxyfop \{2-[4-[[3-chloro-5-((trifluoromethyl)-2-pyridinyl)oxy]phenoxy]propanoic acid} is being developed as a postemergence herbicide in soybeans to control various grass species.

Production costs can be reduced when herbicides are tank mixed because the number of applications is reduced. In a tank mix, the efficacy of the combination depends upon the interactions between the herbicides in the mix. Antagonism is defined as occurring when the control obtained from two herbicides used in a tank mix is less than the sum control of each herbicide applied alone. Bentazon has been demonstrated to antagonize some postemergence grass herbicides used in a tank mix with bentazon. The effect of the graminicide on broadleaf weed control with bentazon has not been reported.

The objective of this study was to determine the interaction between haloxyfop and bentazon when used in a tank mix to control foxtail, velvetleaf, and common cocklebur.
The Effect of Human Capital Variables on the Use of Conservation Tillage and Postemergence Herbicides

A factor often cited for the use of conservation tillage is the prevention of soil erosion. The control of a specific weed problem often is cited as a reason for the use of postemergence herbicides. However, other factors affect adoption of new farming practices. The effect of human capital factors on the adoption of conservation tillage and postemergence herbicides is of interest and would be beneficial to governmental agencies when planning educational and regulatory programs and to industry when planning marketing programs.

New farming practices are readily adopted when the innovations are simple, have a distinct competitive advantage, can be used on a small scale initially, have positive visible results, are inexpensive, and are compatible with the existing farm practices (34). The adoption of new farming practices may also depend on economic benefit, initial adjustment costs, and availability of new technology.

Some aspects of conservation tillage, including weed control, can be complex. The immediate visible results are not positive for growers who perceive plant residue on the soil surface as contributing to production
problems such as stand establishment, pest control, and fertilizer placement. Similarly, the use of postemergence herbicides allows the weeds to emerge, contributing to a weedy appearance.

Distinct comparative advantages have been shown for conservation tillage as reductions in time, labor, fuel, and equipment costs, and moisture loss (1, 28). However, a producer may be hesitant to adopt a new tillage system due to initial adjustment costs. Initial adjustment costs occur during the learning-to-use phase when adopting a new method. Yields may be reduced or production costs may be increased initially until the method is perfected. Also, a change in tillage practices may require the purchase of new equipment.

Weed control is an important part of a conservation tillage system. Until recently, soybean postemergence herbicides were used primarily to control weeds uncontrolled by preemergence herbicides. However, the number of herbicides registered by the EPA for use in conservation-tillage systems has increased during the past 10 years. The fear of more intense chemical management may inhibit adoption of conservation tillage practices (1).

The objective of this study was to determine how human capital variables—such as education, experience, age, health, sources of information, and future plans—
affect adoption of conservation tillage and the use of soybean postemergence herbicides.
LITERATURE REVIEW

There are soil erosion problems on approximately one-half of the 180 million hectares of available cropland in the United States (36). Pimental (98) reports an estimated two billion tons of top soil lost annually from erosion by wind and water.

Soil erosion is effectively controlled by the use of reduced-tillage systems (25, 51, 56, 64, 73, 108).

Phillips et al (97) report that other advantages of reduced tillage are: 1) increased efficiency of water use due to lowered water runoff amounts and greater infiltration; 2) sloping land not suitable to farming with conventional tillage can be farmed with reduced-tillage methods; 3) improved timing of planting and harvesting operations; 4) reduced machinery investments and energy requirements. Other researchers have reported similar advantages to using reduced-tillage methods.

Energy use for tillage and planting can be reduced by 40 to 50% with reduced tillage. Herbicides are more energy efficient than cultivation (27, 45, 127, 141). Two mechanical cultivations require 140,000 BTU's per acre for fuel alone while one pound a.i. per acre of herbicide requires 115,000 BTU's (including energy required in basic
production, formulation, and distribution) (9). Herbicide weed control has been shown to have 35% greater net energy return for each unit of energy invested when compared to mechanical cultivation (27).

Machinery requirements for reduced tillage are similar to conventional-tillage requirements, but with less yearly usage, the usable life of the machinery should increase (2, 28).

Up to 50% of the time needed for conventional-tillage systems can be saved by using reduced-tillage methods (28). This time saved allows for more timely planting and harvesting.

Sloping land with high soil erosion potential can be farmed with reduced tillage (67, 72). Studies at Madison, SD show that water born soil erosion on a 5.8% slope decreased significantly when reduced-tillage methods were used (128). Meyer and Mannering (75) found that soil loss after high intensity storms from land with a 6% slope was reduced from 22.3 tons per acre with conventional tillage to 6.7 tons per acre when reduced-tillage systems were used.

An increased efficiency of water use occurs when reduced tillage is used. Nelson et al (87) reported that soybeans (Glycine max) yielded more in fields that were
non-compacted because of fewer machinery passages through the fields while using reduced-tillage methods. The soybeans produced more extensive root systems and used the moisture better in the non-compacted fields. There are other examples of no-till and reduced-tillage soybean yields being equal to or better than conventional yields (49, 58, 118, 96, 111, 122, 124)

The rate of evaporation usually decreases as the amount of residue increases (112). Seasonal and annual runoff has been reported as consistently less from reduced-tillage systems than from conventional-tillage systems (90). Moody et al (77) found that during a ten-year study, the average annual runoff and erosion from a plowed check plot was more than six times greater than that from reduced-tillage plots. Greb (44) reported a 16-33% decrease in soil-water loss from wet soil during a 20 day period when using reduced-tillage methods that left 30-60% of the soil surface covered.

Crop residues are most beneficial when they are left on the soil surface rather than being incorporated into the top soil (140), but herbicide effectiveness may be affected detrimentally. The residues left on the soil surface intercept herbicides and prevent the herbicides from contacting the soil where they are activated or prevent a uniform distribution of the herbicides on the
soil surface (61). Rain is needed to wash the herbicides from the residue to the soil (7, 41, 65, 117, 139). Herbicides may volatilize or decompose more readily from crop residues than from the soil (71).

Organic matter levels increase at the soil surface in reduced-tillage systems due to residue build up (12, 78, 120). This may negate weed control by some herbicides when they are used with reduced tillage because more of the herbicide is adsorbed and bound by the increased organic matter (50, 119, 129, 133).

Reduced-tillage methods that leave crop residues on the soil surface do not always allow for the use of herbicides that need to be incorporated or for cultivation to be used to control weeds. The development of selective postemergence herbicides has been said to allow flexibility in weed management strategies (81). Staniforth et al (115) reported that even with normal cultivation practices, weed competition may reduce soybean yields up to 10%. Weeds that are not controlled by early season treatments or that emerge later in the season in soybeans may produce enough seeds to make control a problem in later years (13). If the use of preplant- incorporated and preemergence herbicides and cultivation is limited when using reduced-tillage methods, then postemergence herbicides must be relied on for weed control.
Weeds reduce yields by competing with soybeans for light, nutrients, and moisture. Weeds can also reduce the quantity and the quality of harvested seed by delaying harvest and decreasing the efficiency of harvest equipment (114, 126). Light penetration within the soybean canopy influences soybean yield. If there is decreased light penetration because of a severe weed growth making a canopy over the crop, then the number of pods per plant and the seed yields are decreased (48, 55, 63). Weeds increase lodging of soybean plants (116), and limited rainfall increases the weed competition effect on soybeans (113).

Murphy and Gosset (80) reported a 27% soybean yield reduction from a population in which annual grasses predominated. Soybean yields were reduced from 37 bushels per acre to 25.4 bushels per acre by competition from foxtail averaging 3200 pounds per acre in a three-year study done in Ames, IA (114). The predominant foxtail species in the study were yellow foxtail (Setaria lutescens), green foxtail (Setaria viridis), and giant foxtail (Setaria faberi). Other studies have shown decreased soybean yields caused by foxtail competition (18, 63, 86, 81, 82, 113, 116).

Soybeans can compete with foxtail for up to four to six weeks before a significant yield loss occurs (81,
Haloxynop is being developed as a postemergence herbicide to control several annual and perennial grass species in soybeans (30, 37, 62, 105, 109).

Injury symptoms from haloxynop appear as necrosis in meristematic tissue and necrosis or chlorosis in developing leaf tissue, accumulation of free sugar in the shoots or leaf, the appearance of purple leaf color due to anthocyanin accumulation, and inhibition of root growth and root respiration (24, 46). Because total lipid synthesis is inhibited, the suggested site of action of haloxynop is located where metabolic intermediates enter the krebs cycle and lipid synthesis, possibly somewhere between sucrose uptake and acetyl coenzyme A synthesis (24).

Haloxynop rates as low as 0.06 lbs/acre control foxtail (16). Other researchers have reported excellent control with haloxynop rates ranging from 0.06 to 0.225 lbs/acre (3, 4, 5, 6, 17, 30, 40, 59, 62, 79, 84, 95, 105, 109, 135).

Velvetleaf is native to India and was introduced into the United States in the 18th century for a potential ropemaking fiber crop (110, 125). Velvetleaf has escaped to become naturalized over much of the United States and the annual economic losses due to velvetleaf in corn and
soybeans in the U. S. have been estimated to exceed $340 million (57, 110). Velvetleaf seeds have been found to have 43% germination after being buried for 39 years (66, 121). A velvetleaf plant can produce 17,000 seeds per plant during one growing season (23). Populations of velvetleaf in soybeans reduce soybean dry matter, flowering node and seed production (31). Oliver (89) reported soybean yield reductions up to 27% from velvetleaf competition and Eaton et al (38) reported a 66% soybean yield reduction when velvetleaf was present in the field. Other researchers also report significant yield losses from velvetleaf competition (22, 23, 47, 114). Barrentine and Oliver (11) report that soybeans can compete with velvetleaf early, but by 8-10 weeks after emergence, velvetleaf competition reduces soybean growth and development.

Common cocklebur has been said to be soybeans' worst enemy and the most important and detrimental weed to soybeans grown in the United States (14, 42). One cocklebur plant may occupy a root profile area with a radius of 4.3 meters and a depth of 2.9 meters, grow to 152 centimeters in height, and have a top growth dry matter weight of 590 grams (29). Cocklebur competition can be a potential problem over the full range of soybean planting times because the competitive abilities and
growth rate of cockleburs are similar to those of soybeans (29, 39). Cockleburs have a high water requirement (107). With adequate moisture, soybeans can compete with low densities of cocklebur (less than 3000/ha), but without adequate moisture, there is a significant soybean yield reduction (136). Barrentine (10) reported that full-season competition by cocklebur at 3300, 6600, 13000, and 26000 plants/ha reduced the two-year average soybean yields 10, 28, 43, and 52 % respectively. Similar results of soybean yield reduction by cocklebur competition have been reported (42, 54, 74, 130).

Soybeans can compete with cocklebur for four weeks after emergence without significant yield reductions (10, 74, 134, 136). Staniforth and Weber (116) report that 50% of soybean yield loss could be prevented if cocklebur is controlled as late as the early soybean bloom stage as compared to no control.

Bentazon is a postemergence herbicide labelled for control of velvetleaf and cocklebur control in soybeans (142). Bentazon's mode of action is the inhibition of photosynthesis. Bentazon inhibits photosystem II of the photosynthetic electron transport pathway and inhibits oxygen evolution and Hill reaction activity (76).

Reductions in time, labor, fuel, and equipment
costs have made the practice of tank mixing herbicides a common one (103). A broader spectrum of weed species controlled can be attained by mixing a broadleaf and a grass herbicide together. It is important for the individual herbicides in the tank mix to control the targeted weeds without an unacceptable reduction in efficacy because of an interaction between the herbicides in the mix.

Antagonism is said to exist when the effect of the herbicides in a tank mix is less than the predicted effect based on the activity of each herbicide applied separately (26). The efficacy of many grass herbicides has been reported to decrease when they are tank mixed with bentazon (15, 19, 20, 33, 52, 85, 94, 100, 101, 102, 103, 104, 106, 123, 139).

There is some controversy as to whether combinations of haloxyfop and bentazon in a tank mix reduce haloxyfop activity. Williams and Wax (138) found reduced absorption of haloxyfop by German millet [Setaria italica (L.) Beauv] when applied in a mixture containing bentazon. Translocation from the treated area of quackgrass (Agropyron repens) was reduced in plants in which 0.56 kg/ha of bentazon was added in a tank mixture to 0.07 kg/ha of haloxyfop (137). Nalewaja et al (83, 84) and others (35, 92, 93) found decreased control of
foxtails by haloxyfop when bentazon was present in the tank mix. Gerwick and Noveroske (40) report a reduction in grass activity in combinations of bentazon and haloxyfop at lower rates than proposed label rates, and suggest that the antagonistic action of bentazon occurs because bentazon decreases the amount of haloxyfop that penetrates the leaf surface. Recent work by Wanamarta (131, 132) with bentazon and sethoxydim \(2-[1-(ethoxyimino)-butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexene-1-one\) supports this theory. However, Bronhara (16) reported no difference of giant foxtail control by haloxyfop when tank mixed with bentazon compared to when haloxyfop was applied separately. Other researchers report excellent control of foxtail by haloxyfop when combined with bentazon (32, 53, 60, 91).
Efficacy of Haloxyfop and Bentazon When Tank Mixed

MATERIALS AND METHODS

Field studies were conducted on an Albaton (fine, montmorillonitic (calcereous), mesic Vertic Fluvaquents) silty clay near Jefferson, SD, and on an Egan (fine, silty, mixed, mesic Udic Haplustoll) silty clay loam near Centerville, SD, in 1985 and 1986 and near Wakonda, SD, in 1986.

The experiments were arranged in a randomized complete block design with four replications. Plot size was 2.3 by 11.6 m with three soybean rows per plot. 'Corsoy 79' soybeans were planted in 76-cm rows at Jefferson on 5-31-85 and 5-21-86, at Centerville on 6-06-85 and 5-15-86, and at Wakonda on 6-12-86. Treatments were applied when soybeans were in the one- to two-trifoliate leaf stage. The foxtail was 10 to 25 cm tall and the broadleaves were 5 to 15 cm tall. Treatments consisted of a factorial combination of haloxyfop at 0.0, 0.112, 0.224, 0.336, and 0.445 kg a.i./ha, and bentazon at 0.0, 0.56, 1.12, 1.68, and 2.24 kg a.i./ha. In 1986, 2.24 kg a.i./ha of alachlor was applied to the Centerville site to control foxtail. Herbicides were mixed into an emulsion of water and crop oil concentrate (186:1 ratio) and
applied in a spray volume of 187 L/ha at a pressure of 290 kPa with a small-plot, tractor-mounted sprayer. The boom height was 46 cm above the weed canopy and ground speed was 4.83 km/hr. Plots were not cultivated.

Visual evaluations of weed control were taken 4 weeks after treatment and again at soybean senescence. Ratings were based on a 0 to 100 scale with 0 indicating no control and 100 representing complete control. Plant samples were taken approximately 5 weeks after treatment for dry weight determination from the area between two soybean rows the entire length of each plot. A plot combine was used to harvest soybeans from the entire plot in 1986 at the Centerville and Wakonda locations.

When the analysis of variance revealed a significant haloxyfop by bentazon interaction for visual ratings, the type of interaction was determined using Colby's method (26). Response surface models were developed for visual ratings and soybean yields using GLM and the Statistical Analysis System (SAS). The treatment means of the weed dry weights were compared using the Waller-Duncan k-ratio T test \( (P = 0.05 \text{ and } k\text{-ratio} = 100)\).
RESULTS AND DISCUSSION

A significant interaction occurred between the two years' data, and between locations within years, therefore each location within each year was analyzed separately.

A significant interaction occurred between rates of haloxyfop and rates of bentazon for all parameters measured except for velvetleaf dry weights at Jefferson in both years. The velvetleaf dry weights that did not show a significant interaction between levels of the two herbicides decreased significantly as the amount of bentazon applied increased (data not shown).

**Foxtail control**

The control of foxtail by tank mix combinations of haloxyfop and bentazon at four location x year sites is shown in Figure 1. Various levels of control resulted in each study but the response surfaces were similar except for the Jefferson location in 1985. Foxtail was controlled by haloxyfop alone at 0.112 kg/ha at all locations except Jefferson in 1985. Bentazon antagonized the control of foxtail by haloxyfop as determined by Colby's test. Antagonism resulted in all but 3 of the 64 observations. Foxtail control was maintained if the rate of haloxyfop was
Figure 1. Interaction of various rates of haloxyfop and bentazon on foxtail control. A - Wakonda 1986, B - Jefferson 1986, C - Jefferson 1985, D - Centerville 1985. In the equation, C = percent control, H = rate of haloxyfop, and B = rate of bentazon.
increased relative to the rate of bentazon.

The means of the foxtail dry weights from Jefferson and Wakonda in 1986 are shown in Table 1. The means of the foxtail dry weights from Jefferson and Centerville in 1985 did not have large enough differences to be separated and shown.

The dry weights of foxtail plants taken from plots treated with bentazon at the 0.56 kg/ha rate and any rate of haloxyfop were not significantly different from the vegetation taken from the corresponding treatment of haloxyfop alone at either location. However, plant weight increased when higher rates of bentazon were mixed with 0.112 kg/ha haloxyfop. The least amount of bentazon required for antagonism was 1.12 and 1.68 kg/ha for the haloxyfop rates of 0.112 and 0.224 kg/ha respectively. The 0.336 and 0.445 kg/ha rates of haloxyfop were not affected by the addition of bentazon except for the 0.336 kg/ha haloxyfop + 2.24 kg/ha bentazon combination at Jefferson (Table 1). Although this figure is statistically significant, it has no practical significance.

**Velvetleaf control**

Haloxyfop antagonized the control of velvetleaf by bentazon. The response surfaces generated from the control of velvetleaf by various combinations of haloxyfop and bentazon at four location x year sites are shown in
Table 1. Effect of interaction between haloxyfop and bentazon at various combinations on foxtail dry weight at Jefferson and Wakonda, SD, in 1986\(^a\).

<table>
<thead>
<tr>
<th>Rate of bentazon(^b)</th>
<th>Rate of haloxyfop (kg/ha)</th>
<th>Jefferson</th>
<th>Wakonda</th>
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<tr>
<td></td>
<td>0.00</td>
<td>0.112</td>
<td>0.224</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>63 a</td>
<td>0 c</td>
<td>0 a</td>
</tr>
<tr>
<td>0.56</td>
<td>49 a</td>
<td>13 bc</td>
<td>13 a</td>
</tr>
<tr>
<td>1.12</td>
<td>75 a</td>
<td>26 ab</td>
<td>1 a</td>
</tr>
<tr>
<td>1.68</td>
<td>42 a</td>
<td>41 a</td>
<td>1 a</td>
</tr>
<tr>
<td>2.24</td>
<td>69 a</td>
<td>51 a</td>
<td>1 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>349 a</td>
<td>20 d</td>
<td>21 b</td>
</tr>
<tr>
<td>0.56</td>
<td>549 a</td>
<td>83 cd</td>
<td>21 b</td>
</tr>
<tr>
<td>1.12</td>
<td>411 a</td>
<td>135 bc</td>
<td>15 b</td>
</tr>
<tr>
<td>1.68</td>
<td>418 a</td>
<td>193 b</td>
<td>56 a</td>
</tr>
<tr>
<td>2.24</td>
<td>316 a</td>
<td>310 a</td>
<td>68 a</td>
</tr>
</tbody>
</table>

\(^a\)Means in a column followed by a common letter are not significantly different at the 5% level using the Waller-Duncan k-ratio T test (\(p = 0.05\) and k-ratio = 100).

\(^b\)Haloxyfop is applied alone at the 0 rate of bentazon.
Figure 2. Velvetleaf control at all locations both years was affected similarly. Control of velvetleaf by bentazon alone ranged from fair to good. As determined by Colby's method, antagonism occurred at all combinations of haloxyfop and bentazon.

The means of the dry weights of the velvetleaf plants taken from Centerville in 1986 are shown in Table 2. The means of the velvetleaf plants from other locations and years did not have large enough differences to be separated and shown. Plot weight of velvetleaf plants treated with 0.56 kg/ha was significantly lower than the plot weight of the same rate of bentazon combined with any rate of haloxyfop. Plant weight from the 1.12 kg/ha bentazon and 0.112 kg/ha haloxyfop combination was not different from the weight of velvetleaf harvested from plots treated with 1.12 kg/ha bentazon alone. However, the plant weight increased significantly as the rate of haloxyfop was increased to 0.224 kg/ha, indicating a decrease in velvetleaf control. A similar increase in weed weight occurred in plots treated with 0.224 kg/ha + 1.68 kg/ha bentazon.

**Cocklebur control**

The response surfaces generated from the control of cocklebur by various combinations of haloxyfop and bentazon at four location x year sites are shown in Figure
Figure 2. Interaction of various rates of haloxyfop and bentazon on velvetleaf control. A = Centerville 1985, B = Centerville 1986, C = Jefferson 1985, D = Jefferson 1986. In the equation, C = percent control, H = rate of haloxyfop, and B = rate of bentazon.
Table 2. Effect of interaction between haloxyfop and bentazon at various combinations on velvetleaf dry weight at Centerville in 1986a.

<table>
<thead>
<tr>
<th>Rate of haloxyfopb (kg/ha)</th>
<th>Rate of bentazon (kg/ha)</th>
<th>Velvetleaf dry weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.00</td>
<td>0.56</td>
</tr>
<tr>
<td>0</td>
<td>284 a</td>
<td>50 c</td>
</tr>
<tr>
<td>0.112</td>
<td>275 a</td>
<td>233 b</td>
</tr>
<tr>
<td>0.224</td>
<td>291 a</td>
<td>208 b</td>
</tr>
<tr>
<td>0.336</td>
<td>253 a</td>
<td>150 b</td>
</tr>
<tr>
<td>0.445</td>
<td>303 a</td>
<td>419 a</td>
</tr>
</tbody>
</table>

aMeans in a column followed by a common letter are not significantly different at the 5% level using the Waller-Duncan k-ratio T test (p = 0.05 and k-ratio = 100).

bBentazon is applied alone at the 0 rate of haloxyfop.
3. Cocklebur control at all locations was affected similarly. Control of cocklebur with bentazon alone ranged from good to excellent. As with velvetleaf control, cocklebur control was decreased when haloxyfop was applied in combination with bentazon. Antagonism occurred in all 64 rate x year x location observations as determined by Colby's method.

The means of the dry weights of the cocklebur plants taken from Wakonda in 1986 are shown in Table 3. The means of the velvetleaf plants from other locations and years did not have large enough differences to be separated and shown. Only 0.112 kg/ha haloxyfop was required to antagonize the control of cocklebur by bentazon at the rates of 0.56 or 1.12 kg/ha. The antagonism was overcome by increasing the rate of bentazon to 1.68 kg/ha; however, when either 1.68 or 2.24 kg/ha bentazon was applied, antagonism again was evident if the rate of haloxyfop was increased to 0.224 kg/ha.

**Soybean yield**

Response surfaces generated from soybean yield data are shown in Figures 4 and 5. Foxtail was controlled by the preemergence treatment of alachlor at the Centerville location in 1986. Soybean yields increased as the rate of bentazon increased when applied alone (Figure 4). When haloxyfop was combined with bentazon, the soybean
Figure 3. Interaction of various rates of haloxyfop and bentazon on cocklebur control. A - Jefferson 1986, B - Wakonda 1986, C - Centerville 1986, D - Centerville 1985. In the equation, C = percent control, H = rate of haloxyfop, and B = rate of bentazon.
Table 3. Effect of interaction between haloxyfop and bentazon at various combinations on cocklebur dry weight at Wakonda in 1986a.

<table>
<thead>
<tr>
<th>Rate of bentazon (kg/ha)</th>
<th>0.00</th>
<th>0.56</th>
<th>1.12</th>
<th>1.68</th>
<th>2.24</th>
</tr>
</thead>
<tbody>
<tr>
<td>cocklebur dry weight (g)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate of haloxyfop (kg/ha)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>94 a</td>
<td>2 b</td>
<td>0 c</td>
<td>0 c</td>
<td>0 c</td>
</tr>
<tr>
<td>0.112</td>
<td>97 a</td>
<td>28 a</td>
<td>19 b</td>
<td>9 bc</td>
<td>5 c</td>
</tr>
<tr>
<td>0.224</td>
<td>82 a</td>
<td>35 a</td>
<td>23 b</td>
<td>15 ab</td>
<td>12 b</td>
</tr>
<tr>
<td>0.336</td>
<td>108 a</td>
<td>50 a</td>
<td>42 a</td>
<td>19 ab</td>
<td>15 ab</td>
</tr>
<tr>
<td>0.445</td>
<td>93 a</td>
<td>47 a</td>
<td>50 a</td>
<td>26 a</td>
<td>19 a</td>
</tr>
</tbody>
</table>

*Means in a column followed by a common letter are not significantly different at the 5% level using the Waller-Duncan k-ratio T test (p = 0.05 and k-ratio = 100).*

*bentazon is applied alone at the 0 rate of haloxyfop
Interaction of various rates of haloxyfop and bentazon on soybean yield at Centerville in 1986. In the equation, $H =$ rate of haloxyfop, and $B =$ rate of bentazon.

$$YLD = 5759 + 6738H - 1272H^2 + 1059B - 5457HB + 10142H^2B$$
Figure 5. Interaction of various rates of haloxyfop and bentazon on soybean yield at Wakonda in 1986. In the equation, YLD = grams/plot, H = rate of haloxyfop, and B = rate of bentazon.
yield decreased compared to the corresponding rate of bentazon alone. The antagonism of haloxyfop on bentazon reduced cocklebur control and therefore reduced the yield of soybeans.

Foxtail was the dominant weed in a mixed population of cocklebur and foxtail at Wakonda in 1986. Soybean yield increased as the rate of haloxyfop applied alone increased (Figure 5). Yield decreased slightly as the rate of bentazon applied alone increased. When the lower rates of haloxyfop were applied in combination with bentazon, soybean yield decreased as a result of decreased foxtail control. The highest rates of haloxyfop combined with the highest rates of bentazon produced the greatest soybean yield, indicating that the antagonism was overcome so that both foxtail and cocklebur were controlled.
CONCLUSIONS

The results of these studies confirm the results of many other studies reporting the antagonism of graminicides by bentazon. In addition to those reports, these studies indicate that the graminicides antagonize the control of broadleaf weeds such as cocklebur and velvetleaf by bentazon. To overcome the antagonism of bentazon on the graminicide, the recommendation has been to increase the rate of the graminicide. The studies indicate that in a mixed weed population, increasing the rate of one herbicide to overcome antagonism and improve the control of one weed species may increase the antagonism on the other herbicide and decrease the control of the secondary weed species. The highest rate of haloxyfop gave the best foxtail control when mixed with bentazon but in this mixture, the rate of haloxyfop was almost four times the proposed recommended use rate of 0.13 kg/ha. The highest rate of bentazon was three times the recommended use rate of 0.75 kg/ha but did not overcome the antagonism caused by haloxyfop. Soybean yields reflected the antagonism of both herbicides.

The combination of haloxyfop and bentazon in a tank mix application did not satisfactorily control the weeds. Increasing the rate of both herbicides increases
costs and cannot be economically justified when compared to applying the herbicides separately.
The Effect of Human Capital Variables on the Use of Conservation Tillage and Postemergence Herbicides.

MATERIALS AND METHODS

Surveys were mailed to 3000 farmers in eastern South Dakota in 1986 to determine the acres in conservation tillage and treated with postemergence herbicides. Also obtained was information pertaining to the farmer's age, health, education level, future plans, additional experience in ag-related jobs, and sources of herbicide information.

The Soil Conservation Society defines conservation tillage as any planting and harvesting system which retains at least 30% residue cover on the soil surface after planting (28). Previous studies indicate that producers tend to overestimate percent cover and actually have less than 30% of the soil covered with residue (88). The use of the moldboard plow is often considered as a part of conventional tillage but not as a part of the more recent technologies of minimum tillage. Therefore, for this study a farmer was recorded as a conservation tillage practitioner if the moldboard plow was used on less than 25% of the acres.

Farmers' responses to questions about age,
health, education level, experience in ag-related jobs, and future plans were compared with their use of conservation tillage and postemergence soybean herbicides. Chi-square statistics were used to indicate whether two variables were dependent on one another (determine the correlation of two variables). When the Chi-square distribution of the actual frequencies was higher at a desired significance level than the Chi-square distribution of the expected frequencies, the null hypothesis that the variables were independent was rejected.
RESULTS AND DISCUSSION

The number of returned and useable surveys was 650. Sixty percent of the growers used conservation tillage. Seventy-five percent of the farmers who used conservation tillage used soybean postemergence herbicides as compared to only 57% of the farmers who did not use conservation tillage used postemergence herbicides. The percentage of growers surveyed who used postemergence herbicides on their soybeans was 37%. The human capital variables dependently associated with the use of conservation tillage and postemergence herbicides are shown in Table 4.

The education level, health, length of expected farming future, and additional ag-related experience were associated dependently with the farmers' ages. As the age increased, fewer farmers in that specific age group had more than 12 years of education, good-to-excellent health, additional ag-related experience, or planned to farm more than 10 years into the future. The farm tenancy after retirement was independent of age. A summary of the percent of farmers in each human capital variable group compared to age, conservation tillage use, and soybean postemergence herbicide use is shown in Table 5. The age distribution of growers returning the survey is similar to
Table 4. Human capital variables that had actual frequencies significantly different than the expected (independent) frequencies when crosstabulated with conservation tillage and soybean postemergence herbicide use.

<table>
<thead>
<tr>
<th>USE OF CONS.</th>
<th>USE OF SOYBEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE</td>
<td></td>
</tr>
<tr>
<td>TILLAGE</td>
<td>***</td>
</tr>
<tr>
<td>EDUCATION LEVEL</td>
<td>**</td>
</tr>
<tr>
<td>HEALTH</td>
<td>*</td>
</tr>
<tr>
<td>YEARS UNTIL</td>
<td>***</td>
</tr>
<tr>
<td>RETIREMENT</td>
<td></td>
</tr>
<tr>
<td>RELATIVE FARMS</td>
<td></td>
</tr>
<tr>
<td>AFTER RETIREMENT</td>
<td>*</td>
</tr>
</tbody>
</table>

*** probability level of Chi-square value = .01
** probability level of Chi-square value = .05
* probability level of Chi-square value = .1
I the variables are independent - not associated
Table 5. Human capital variables crosstabulated with age, percent of farmers using conservation tillage, and percent of farmers using soybean postemergence herbicides

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NOT USING CONS.</td>
<td></td>
<td>31</td>
<td>31</td>
<td>41</td>
<td>47</td>
<td>50</td>
<td>40</td>
<td>--</td>
</tr>
<tr>
<td>USING CONS.</td>
<td></td>
<td>69</td>
<td>69</td>
<td>59</td>
<td>53</td>
<td>50</td>
<td>60</td>
<td>--</td>
</tr>
<tr>
<td>NOT USING POST H.</td>
<td></td>
<td>57</td>
<td>48</td>
<td>68</td>
<td>68</td>
<td>75</td>
<td>63</td>
<td>67</td>
</tr>
<tr>
<td>USING POST H.</td>
<td></td>
<td>43</td>
<td>52</td>
<td>32</td>
<td>32</td>
<td>25</td>
<td>37</td>
<td>75</td>
</tr>
<tr>
<td>EDUC. 0-12</td>
<td></td>
<td>53</td>
<td>37</td>
<td>61</td>
<td>85</td>
<td>85</td>
<td>65</td>
<td>56</td>
</tr>
<tr>
<td>EDUC. &gt;12</td>
<td></td>
<td>47</td>
<td>63</td>
<td>39</td>
<td>15</td>
<td>15</td>
<td>35</td>
<td>66</td>
</tr>
<tr>
<td>POOR HEALTH</td>
<td></td>
<td>1</td>
<td>4</td>
<td>8</td>
<td>12</td>
<td>19</td>
<td>10</td>
<td>52</td>
</tr>
<tr>
<td>EXCELLENT HEALTH</td>
<td></td>
<td>99</td>
<td>96</td>
<td>92</td>
<td>88</td>
<td>81</td>
<td>90</td>
<td>61</td>
</tr>
<tr>
<td>RETIRES IN 0-10 YRS</td>
<td></td>
<td>8</td>
<td>8</td>
<td>19</td>
<td>77</td>
<td>87</td>
<td>40</td>
<td>55</td>
</tr>
<tr>
<td>RETIRES IN &gt;10 YRS</td>
<td></td>
<td>91</td>
<td>91</td>
<td>81</td>
<td>23</td>
<td>13</td>
<td>60</td>
<td>64</td>
</tr>
<tr>
<td>RELATIVE FARMS AFTER</td>
<td></td>
<td>74</td>
<td>65</td>
<td>66</td>
<td>62</td>
<td>60</td>
<td>65</td>
<td>62</td>
</tr>
<tr>
<td>RELATIVE DOESN'T FARM AFTER</td>
<td></td>
<td>26</td>
<td>35</td>
<td>34</td>
<td>38</td>
<td>40</td>
<td>35</td>
<td>55</td>
</tr>
<tr>
<td>% OF TOTAL</td>
<td></td>
<td>15</td>
<td>21</td>
<td>22</td>
<td>26</td>
<td>16</td>
<td>--</td>
<td>60</td>
</tr>
</tbody>
</table>
the age distribution of all growers in eastern South Dakota (21).

**Conservation tillage use.**

The use of conservation tillage was dependent on age (Table 4). Sixty-nine percent of the farmers who were less than 30 years old used conservation tillage. As the age of the farmers increased, the use of conservation tillage decreased to 50% of farmers over 60 years of age (Table 5).

The use of conservation tillage by farmers with different education and health levels also changed significantly as those human capital variable levels changed. Fifty-six percent of the farmers with 0-12 years of schooling used conservation tillage. The number of conservation tillage users increased to 66% among the group that had acquired more than 12 years of education. Similarly, 52% of the farmers with poor-to-fair health used conservation tillage, as compared to 61% of the farmers with good-to-excellent health using conservation tillage (Table 5).

The use of conservation tillage was associated dependently with the future plans of growers. Of the farmers retiring in 10 years or less, 55% used conservation tillage as compared to 64% of the farmers planning to farm more than 10 years used conservation
tillage (Table 5).

Fifty-five percent of the farmers who will not have a relative farm the land after they retire used conservation tillage as compared to 62% of the farmers who will have a relative farm after they retire used conservation tillage (Table 5).

The use of conservation tillage was independent of farmers having worked at an ag-related job.

Postemergence herbicide use.

The frequency of postemergence herbicides use on soybeans as affected by the age of the farmer is shown in Table 5. The use of postemergence herbicides was higher among the younger farmers compared to older farmers.

The dependent association on education levels that existed for the use of conservation tillage also existed for the use of soybean postemergence herbicides (Table 5). Only 32% of the farmers that had 0-12 years of schooling used postemergence herbicides on their soybeans. The use of postemergence herbicide increased to 42% of the farmers who had greater than 12 years of schooling.

Twenty-eight percent of the farmers who will farm less than 10 years used soybean postemergence herbicides while 42% of the farmers who will farm longer than 10 years used soybean postemergence herbicides (Table 5). The
variable associations are significantly dependent and similar to those of conservation tillage.

The use of postemergence herbicides was independent of health and land tenancy after retirement. Experience in an ag-related job also had no effect.

Sources of information for weed control.

The farmers rated their use of different sources of information for new weed control technology and for general information about weed control as frequent, sometimes, or never. The percentages of farmers who used sources frequently or sometimes as opposed to never are shown in Table 6.

Farmers used elevator personnel/dealers and other farmers more than any other personal source to obtain either new or general herbicide information.

The percentage of farmers obtaining new information via the media was higher for each source than the percentage of farmers obtaining general information. Farmer magazines were used the most to obtain both kinds of information. As would be expected, most farmers used manufacturer-sponsored meetings for herbicide information.

The use of soybean postemergence herbicides was dependently associated with many of the information sources (Table 7). The percentage of farmers using postemergence herbicides was higher if they used these
Table 6. Use frequency of sources for new herbicide and general herbicide information.

<table>
<thead>
<tr>
<th>New Information</th>
<th>General Information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Personal Sources</strong></td>
<td><strong>Personal Sources</strong></td>
</tr>
<tr>
<td>elevator/dealers</td>
<td>95.4</td>
</tr>
<tr>
<td>other farmers</td>
<td>92.1</td>
</tr>
<tr>
<td>county agents</td>
<td>71.6</td>
</tr>
<tr>
<td>relatives</td>
<td>60.2</td>
</tr>
<tr>
<td>vets/bankers</td>
<td>41.9</td>
</tr>
<tr>
<td>university personnel</td>
<td>29.2</td>
</tr>
<tr>
<td>paid pest mgt. advisors</td>
<td>15.8</td>
</tr>
<tr>
<td><strong>Media Sources</strong></td>
<td><strong>Media Sources</strong></td>
</tr>
<tr>
<td>farmer magazines</td>
<td>90.4</td>
</tr>
<tr>
<td>dealer magazines</td>
<td>74.8</td>
</tr>
<tr>
<td>university newsletters</td>
<td>74.2</td>
</tr>
<tr>
<td>T. V. commercials</td>
<td>71.3</td>
</tr>
<tr>
<td><strong>Mass Meeting Sources</strong></td>
<td><strong>Mass Meeting Sources</strong></td>
</tr>
<tr>
<td>chemical co. sponsored</td>
<td>83.0</td>
</tr>
<tr>
<td>seed</td>
<td>77.1</td>
</tr>
<tr>
<td>extension</td>
<td>63.1</td>
</tr>
<tr>
<td>equipment</td>
<td>54.6</td>
</tr>
<tr>
<td>grower association</td>
<td>35.4</td>
</tr>
</tbody>
</table>
Table 7. Information source user groups that had a higher frequency of farmers using postemergence herbicides on soybeans when the source was used frequently/sometimes as opposed to never.

**Sources For New Information**

<table>
<thead>
<tr>
<th>Personal:</th>
<th>Media:</th>
<th>Meetings:</th>
</tr>
</thead>
<tbody>
<tr>
<td>county agent</td>
<td>dealer magazines</td>
<td>chemical co. sponsored</td>
</tr>
<tr>
<td>paid pest mgt advisor</td>
<td>farmer magazines</td>
<td>extension</td>
</tr>
<tr>
<td>relatives</td>
<td>T. V. commercials</td>
<td>grower association</td>
</tr>
<tr>
<td>university personnel</td>
<td></td>
<td>seed</td>
</tr>
</tbody>
</table>

**Sources For General Information**

<table>
<thead>
<tr>
<th>Personal:</th>
<th>Media:</th>
<th>Meetings:</th>
</tr>
</thead>
<tbody>
<tr>
<td>county agent</td>
<td>dealer magazines</td>
<td>chemical co. sponsored</td>
</tr>
<tr>
<td>paid pest mgt. advisor</td>
<td>farmer magazines</td>
<td>extension</td>
</tr>
<tr>
<td>relatives</td>
<td>T. V. commercials</td>
<td>grower association</td>
</tr>
<tr>
<td>university personnel</td>
<td></td>
<td>seed</td>
</tr>
<tr>
<td>elevator/dealers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>other farmers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
sources frequently or sometimes as opposed to never. However, farmers using the less-frequently used sources of information, such as county extension agents, university personnel, university newsletters, and meetings other than manufacturer-sponsored meetings, used more postemergence herbicides than farmers that did not use these sources. These sources do impact the adoption of new technology.
CONCLUSIONS

Overall, the adoption of conservation tillage and soybean postemergence herbicides may depend on soil erosion or specific weed problems, economic benefits, initial adjustment costs, and availability of new technology, but adoption also depends on human capital variables. Rahm and Huffman concluded from an Iowa study that investments in farmers' formal schooling and additional experience tend to increase adoption efficiency of reduced tillage (99). In this study, similar results were observed with farmers' education but not with other variables such as experience as portrayed by age or ag-related job experiences. The use of conservation tillage and postemergence herbicides decreased significantly as the age of the farmer increased and was independent of a farmer's experience in an ag-related job. Adoption was also found to be dependent on other human capital variables such as health, future plans, and sources of herbicide information.

A higher level of technology is probably required for conservation tillage than for conventional tillage systems. The education level may influence adoption of conservation tillage in that a farmer with more education may possess skills to interpret new, technical
information. A farmer who expects a long farming future because of age and good health, or who plans to have a relative farm the land after retirement, may want to preserve the productivity of the farm by adopting new technologies such as conservation tillage and the use of postemergence herbicides. The results of this survey indicate that the use of conservation tillage practices and postemergence herbicides will continue to increase as the farmers who are presently younger and more highly educated become a more significant portion of the farming population in the future.


