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# Integration of cover crops with postemergence herbicides in no-till corn and soybean

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The integration of cover crops with selected postemergence herbicides was evaluated on the basis of weed control and grain yields in no-till soybean and corn. Soybean was planted into wheat residue, whereas corn was planted into hairy vetch residue. Full, half, and quarter rates and sequential herbicide applications were made. The wheat cover crop did not increase weed suppression but increased soybean grain yields. Half rates of thifensulfuron plus quizalofop-P as single or split applications were as effective as full rates in reducing weed weight in soybean. Soybean grain yields were similar in the half- and full-rate treatments in 1994, but yield was highest in the full-rate treatment in 1995. The hairy vetch cover crop did not increase weed suppression but lowered corn stands and grain yields in 1995 and enhanced corn grain yields in 1996. Full, half, and quarter rates (1996 only) of nicosulfuron plus primisulfuron were equally effective in reducing weed weight. Corn grain yields were similar at all herbicide rates in 1995 but were inversely related to herbicide rate in 1996. Split herbicide applications did not improve weed suppression over single applications of the same herbicide rate in either crop. Results indicate that cover crops can improve crop productivity and reduced rates of environmentally benign herbicides can minimize the herbicide requirements in no-till corn and soybean.

**Nomenclature:** Glyphosate; nicosulfuron; primisulfron; quizalofop-P; thifensulfuron; corn, *Zea mays* L.; hairy vetch, *Vicia villosa* Roth; soybean, *Glycine max* L.; wheat, *Triticum aestivum* L.

**Key words:** Conservation tillage, water quality, integrated crop management, weed control, cover crops, reduced herbicide rates, split applications.

Integrated crop management (ICM) can be an economically viable management strategy designed to synergistically control weeds and other pests, manage soil fertility, and promote soil and water conservation (Elmore 1996; Swanton and Murphy 1996). In many regions with rolling topography and erodible soils, no-till has been a successful means of maintaining crop productivity while substantially reducing soil erosion, labor, and the energy use associated with tillage (Chengere and Lal 1995; Seta et al. 1993). No-till, however, often depends on herbicides for weed control. Concerns about herbicides include cost, contamination of surface and groundwater, injury of succeeding rotation crops due to persistent herbicides, development of resistant weeds, and unknown long-term human health effects. In particular, several triazine and chloroacetamide herbicides, which are the most widely used herbicides in no-till corn and soybean production, are known or suspected carcinogens and contaminants of groundwater and surface water (Logan 1990). Crop management approaches that maintain the soil and energy conservation benefits of no-till while reducing the use of herbicides that may pose environmental risks are needed. Tools available for ICM in temperate regions include using cover crops, selecting herbicides with lower environmental risks, and using novel herbicide application techniques.

Cover crops can enhance soil and water conservation (Chengere and Lal 1995; Corak et al. 1991), soil fertility (Doran et al. 1987; Ebelar et al. 1984), and crop productivity (Frye and Blevins 1989; Hanson et al. 1993). Research also has shown that fall-planted, spring-killed small grain and legume cover crops can suppress weeds in subsequent corn and soybean, but weed suppression is often inconsistent and short-lived (Burgos and Talbert 1996; Curran et al. 1994; Teasdale et al. 1991; Yenish et al. 1996). Although cover crops in no-till production systems can help control weeds, supplementary control methods are generally needed.

Innovative use of low-rate postemergence herbicides may complement the weed control achieved with cover crops and reduce the environmental risk involved with the triazine and chloroacetamide herbicides. Sulfonyl urea herbicides, for example, tend to be applied at very low rates, have low mammalian toxicities, and are not serious groundwater contaminants when compared with the triazine and chloroacetamide herbicides commonly used in no-till (Monaco et al. 2002). Substituting the sulfonyl urea herbicides for the triazine and chloroacetamide herbicides would substantially diminish the environmental risks often associated with no-till. Studies have demonstrated that low-rate herbicides, such as nicosulfuron and primisulfuron in corn (Dobbels and Kapusta 1993; Mekki and Leroux 1994) and thifensulfuron and quizalofop-P in soybean (Monks et al. 1993; Nelson and Renner 1998), can provide acceptable weed control and economic returns even if applied at below label rates. In addition, sequential split-rate herbicide applications can improve herbicide efficacy when herbicides are applied at or below label rates (Nandula et al. 1995; Ramsdale and Messersmith 2002).

The research reported here was part of a project designed to develop management systems for no-till corn and soybean that would use low-impact herbicides applied at or below



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TABLE 1. Postemergence herbicide rates and application timing in soybean and corn.

| Herbicide application | Soybean | | | | Corn | | | |
|---|---|---|---|---|---|---|---|---|
| | Thifensulfuron | Quizalofop-P | 1994 | 1995 | Nicosulfuron | Primisulfuron | 1995 | 1996 |
| | g ai $ha^{-1}$ | | d after planting[a] | | g ai $ha^{-1}$ | | d after planting[b] | |
| Full | 4.4 | 48 | 45 | 37 | 36 | 26 | 35 | 37 |
| Half (H) | 2.2 | 24 | 37 | 30 | 18 | 13 | 27 | 29 |
| Quarter (Q) | 1.1 | 12 | 32 | 25 | 9 | 6.5 | 21 | 24 |
| H+H | 2.2 + 2.2 | 24 + 24 | 37, 45 | 30, 37 | 18 + 18 | 13 + 13 | 27, 35 | 29, 37 |
| Q+Q | 1.1 + 1.1 | 12 + 12 | 32, 45 | 25, 37 | 9 + 9 | 6.5 + 6.5 | 21, 35 | 24, 37 |

[a] Planting dates: May 11, 1994, May 5, 1995.
[b] Planting dates: April 20, 1995, April 25, 1996.

label rates. We hypothesized that (1) cover crop residues would provide early-season weed suppression and thereby increase the efficacy of reduced rates of postemergence herbicides and (2) the efficacy of reduced rates of postemergence herbicides would be increased when the herbicides were applied in split applications.

## Materials and Methods

### Field Preparation

Studies were conducted at the Ohio Agricultural Research and Development Center, Wooster, OH, in 1994 and 1995 for soybean and in 1995 and 1996 for corn. Different fields were used each year, but the soil in all the cases was a moderately well-drained Wooster silt loam (Typic fragiudalf) with 2.9% organic matter and a pH of 6.9 to 7.2. All fields had been in no-till for a minimum of 5 yr. The previous crop in the corn experiments was wheat, whereas the soybean experiments were preceded by those of corn. Both preceding crops were grown for production.

The experiments were arranged as factorial, randomized complete blocks with two cover crop regimes (cover crop and no cover) and five herbicide treatments (described below). All treatments were replicated four times. Plots were 3.7 m wide and 9.1 m long. Cover crops were established in fall before crop planting. Glyphosate (841 g ai $ha^{-1}$) was applied to the entire study site before cover crop establishment. For the corn experiments, hairy vetch was direct drilled (18-cm centers; 22 kg seeds $ha^{-1}$) in mid-August. For the soybean experiments, wheat (GR84) was direct drilled (100 kg seeds $ha^{-1}$) in late September.

One week before planting the cash crops, a solution of glyphosate (841 g ai $ha^{-1}$) plus 2,4-DA (560 g ai $ha^{-1}$) was applied to all plots using a tractor-mounted sprayer delivering water at 234 L $ha^{-1}$. Corn (Dekalb 524) was planted (four rows per plot; 76-cm row spacing; 86,000 seeds $ha^{-1}$) with a no-till planter[1] on April 20, 1995, and April 25, 1996. 'Century 84' soybean was planted (556,000 seeds $ha^{-1}$) with a no-till drill[2] (18-cm row spacing) on May 11, 1994, and May 5, 1995. Fertilizer was applied beside the furrow at corn planting at a rate of 20:67:67 kg $ha^{-1}$ (N–P–K), and N was side-dressed at a rate of 112 kg $ha^{-1}$ when the corn reached the 10-leaf stage. Soil tests indicated that no supplemental fertilizer was needed in the soybean fields.

### Herbicides and Application Timing

Tank mixes of quizalofop-P plus thifensulfuron (in soybean) and nicosulfuron plus primisulfuron (in corn) were applied postemergence for the control of annual grass and broadleaf weeds. Herbicides were applied at full (F), half (H), and one-quarter (Q) of the labeled rate for the weeds present, as well as split applications of the half rate followed by an additional half rate (H + H), and the quarter rate followed by an additional quarter rate (Q + Q). Specific application rates and intervals for each herbicide are given in Table 1. Preliminary experiments indicated that the efficacy of reduced rates was optimized by applying the reduced-rate herbicide as an early-postemergence rather than a conventionally timed postemergence application. Full rates, however, were most effective when applied conventionally timed as a postemergence. Therefore, application timing was staggered to optimize the performance of the reduced rate and split application treatments. The Q treatment and the first application of the Q + Q treatment were applied approximately 3 to 6 d after the first sign of weed emergence, when weeds were no more than 2 cm tall. The H treatment and the first application of the H + H treatment were applied 10 to 14 d after the first sign of weed emergence, when weeds were 4 to 6 cm tall. The F treatment and the second application of the Q + Q and the H + H treatments were applied when weeds were 8 to 12 cm tall in the F treatment plots. We acknowledge that this application approach confounds the effects of herbicide rate and herbicide timing. However, this approach is necessary to optimize the performance of the individual herbicide programs but occurs at the expense of nonconfounded experimental design (Ramsdale and Messersmith 2002). No postemergence herbicides were applied to the untreated check (W). All postemergence herbicides were applied using a tractor-mounted sprayer with 4-L tanks pressurized by $CO_2$ to 228 kPa, to deliver water at 187 L $ha^{-1}$. All tank mixes contained 0.25% nonionic surfactant. Crop seeds were not treated with insecticides to prevent the occurrence of herbicide by insecticide interactions (Reynolds et al. 1991).

### Measurements and Statistical Analysis

Early-season control of the dominant weeds was rated visually using a scale of 0 to 100, with 0 being no control (based on the untreated check plots) and 100 being complete elimination of weeds. Ratings were made approximately 5 wk after the final herbicide application. Late-season weed fresh weight was estimated in early September by harvesting the aboveground portions of two quadrats per plot. In corn, quadrats were 122 by 76 cm and were placed at two randomly chosen locations between the second and third row of each plot. In soybean, quadrats were 91 by 91



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TABLE 2. Effect of a wheat cover crop on weed fresh weight and grain yield in solid-seeded soybean in 1994 and 1995 at Wooster, OH. Data combined over herbicide treatments.

| Cover crop | 1994 | | 1995 | |
|---|---|---|---|---|
| | Weed fresh weight[a] | Grain yield[b] | Weed fresh weight | Grain yield |
| | kg $m^{-2}$ | Mg $ha^{-1}$ | kg $m^{-2}$ | Mg $ha^{-1}$ |
| None | 0.56 | 1.8 | 2.9 | 2.6 |
| Wheat | 0.50 | 2.3 | 2.7 | 3.2 |
| P value | 0.797 | 0.050 | 0.615 | 0.0001 |

[a] Measurements were taken 103 and 109 d after planting in 1994 and 1995, respectively. Means include weedy checks. Species composition: 70% giant foxtail, 30% common ragweed in 1994; 75% common ragweed, 25% giant foxtail in 1995.

[b] Yields adjusted to 13% moisture.

cm and were placed in two randomly chosen locations in the middle portion of each plot. Except where specified, trends in early-season visual weed control ratings and fresh weed weights were similar. Therefore, only fresh weed weight data will be presented. Crop yields were estimated by mechanically harvesting the middle two rows of the corn plots (7.5 m after end trimming) and a 2.4- by 7.5-m area in the soybean plots. Harvested grains were rescreened to remove chaff, and yields were corrected to 15.5 and 13% moisture content for corn and soybean, respectively.

Data were analyzed by year using analysis of variance, and differences between treatment means were determined by single–degree of freedom contrasts. Contrary to the original hypothesis, the relative performance of the herbicide treatments was consistent over cover crop treatments. Therefore, only the main effects of the cover crops and the herbicide rate application sequences are presented. The weedy checks are included in the means for the cover crop main effects.

## Results and Discussion

### Cover Crop Effects

In soybean, the dry biomass of the wheat cover crop averaged 3.4 Mg $ha^{-1}$ in 1994 and 3.6 Mg $ha^{-1}$ in 1995 (data not shown). In the wheat cover crop treatments, early-season common ragweed (*Ambrosia artemisiifolia*) control in 1995 was on average 6% higher ($P < 0.05$; visual ratings—data not shown), and soybean grain yields were 31 and 24% higher in 1994 and 1995, respectively, compared with no-cover treatments (Table 2). The wheat cover crop had no effect on total weed fresh weight in either year.

The wheat cover crop in our study did not provide the same level of weed suppression in soybean as reported in other studies. For example, Moore and Gillespie (1994) reported that a wheat cover crop reduced redroot pigweed (*Amaranthus retroflexus* L.) biomass by up to 66% and common lambsquarters (*Chenopodium album* L.) biomass by up to 94% in the early- to midseason but had no effect on late-season weed biomass in either species. Moore and Gillespie (1994) also found that rye (*Secale cereale* L.) may be a more effective weed-suppressive cover crop than wheat, perhaps because of its documented allelopathic activity (Weston 1996). Dead rye residues have been shown to provide significant levels of weed suppression in a range of weed species in no-till soybean (Brecke and Shilling 1996; Lieble et al. 1992), corn (Burgos and Talbert 1996; Johnson et al. 1993; Yenish et al. 1996), sunflower (*Helianthus annus* L.) (Brecke and Shilling 1996), and transplanted tomato (*Lycopersicon esculentum* Mill.) (Masiunas et al. 1995; Smeda and Weller 1996). These studies suggest that rye may be a more suitable cover crop for weed suppression than wheat.

In corn, the dry biomass of the hairy vetch cover crop averaged 4.5 Mg $ha^{-1}$ in 1995 and 4.1 Mg $ha^{-1}$ in 1996 (data not shown). Fresh weed weight was over three times higher in the hairy vetch cover crop compared with no-cover treatments in 1996, although fresh weed weight was relatively low in both treatments compared with that in 1995 (Table 3). Corn populations were 20% lower in the hairy vetch compared with no-cover plots in 1995. Corn grain yield was 12% lower with hairy vetch compared with the no-cover treatments in 1995 but was 6% higher with hairy vetch in 1996.

The lack of weed suppression by hairy vetch residue is consistent with the results reported in other studies (Burgos and Talbert 1996; Curran et al. 1994; Hoffman et al. 1993; Teasdale 1993; Teasdale and Daughtry 1993; Yenish et al. 1996). White et al. (1989) found that although aqueous hairy vetch extracts inhibited the germination and seedling

TABLE 3. Hairy vetch cover crop effects on weed fresh weight, corn population, and grain yield in 1995 and 1996 at Wooster, OH. Data combined over herbicide treatments.

| Cover crop | 1995 | | | 1996 | | |
|---|---|---|---|---|---|---|
| | Weed fresh weight[a] | Corn population | Grain yield[b] | Weed fresh weight | Corn population | Grain yield |
| | kg $m^{-2}$ | plants $ha^{-1}$ | Mg $ha^{-1}$ | kg $m^{-2}$ | plants $ha^{-1}$ | Mg $ha^{-1}$ |
| None | 0.26 | 84,600 | 13.5 | 0.04 | 80,800 | 8.5 |
| Hairy vetch | 0.31 | 68,400 | 11.9 | 0.13 | 80,000 | 9.0 |
| P value | 0.420 | 0.0001 | 0.004 | 0.050 | 0.004 | 0.020 |

[a] Measurements were taken 110 and 117 d after planting in 1995 and 1996, respectively. Species composition: 45% giant foxtail, 45% common lambsquarters, 10% other species in 1995; 50% giant foxtail, 40% common lambsquarters, 10% other species in 1996. Means include weedy checks.

[b] Yield adjusted to 15.5% moisture.



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TABLE 4. The effect of herbicide (thifensulfuron + quizalofop-P) rate and application interval on weed fresh weight and grain yield in solid-seeded no-till soybean in 1994 and 1995. Data are combined over cover-crop treatments.

| Herbicide application | 1994 | | 1995 | |
|---|---|---|---|---|
| | Weed fresh weight[a] | Grain yield[b] | Weed fresh weight | Grain yield |
| | kg $m^{-2}$ | Mg $ha^{-1}$ | kg $m^{-2}$ | Mg $ha^{-1}$ |
| Full (F) | 0.6 | 2.5 | 2.3 | 3.4 |
| Half (H) | 0.2 | 2.4 | 2.5 | 2.8 |
| Quarter (Q) | 1.8 | 1.2 | 3.4 | 2.6 |
| H+H | 0.2 | 2.8 | 2.5 | 3.1 |
| Q+Q | 0.2 | 3.1 | 2.0 | 3.3 |
| Weedy (W) | 2.9 | 0.8 | 4.0 | 2.1 |
| Contrasts | P value | | | |
| *Herbicide rates* | | | | |
| W vs. Q, H, F | 0.0001 | 0.0001 | 0.0024 | 0.0003 |
| Q vs. H, F | 0.0002 | 0.0002 | 0.0242 | 0.0233 |
| H vs. F | 0.241 | 0.932 | 0.644 | 0.01 |
| *Split applications* | | | | |
| F vs. H+H | 0.615 | 0.898 | 0.659 | 0.276 |
| H vs. Q+Q | 0.523 | 0.279 | 0.811 | 0.27 |

[a] Measurements were taken 103 and 109 d after planting in 1994 and 1995, respectively. Species composition: 70% giant foxtail, 30% common ragweed in 1994; 75% common ragweed, 25% giant foxtail in 1995.
[b] Yield adjusted to 13% moisture.

growth range of crop and weed species, hairy vetch residues suppressed weeds in the soil only when the residues were incorporated. Consequently, consistent weed suppression by hairy vetch residues in no-till probably cannot be expected.

In addition to allelopathy, cover crops in no-till can suppress weeds by changing the microclimate of the soil surface. For example, Teasdale and Mohler (1993) showed that hairy vetch and rye residues of 5.0 Mg $ha^{-1}$ or more reduced light transmittance to the soil surface by 80% or more shortly after the cover crops were desiccated with paraquat and mowed (rye only). The shading effect of the cover crops was less pronounced under lower residue levels and gradually declined as the residues decomposed. Hairy vetch residues ranging from 6.4 to 9.2 Mg $ha^{-1}$ reduced the maximum temperature of the soil surface by up to 3.3 C and the amplitude of diurnal temperatures by approximately 4 C. The authors concluded that the observed reductions in soil temperatures and the amplitude of the diurnal soil temperature fluctuations may not be sufficient to prevent weed seed germination. Species such as giant foxtail (*Setaria faberi*), common lambsquarters, and common ragweed, as found in our study, germinate well at temperatures ranging from 10 to 30 C (Mester and Buhler 1991; Roman et al. 1999; Shrestha et al. 1999). These data suggest that weed species that have a wide germination temperature window may be less affected by cover crops than species that require warm soil temperature or have narrow germination temperature windows. Far-red rich light, which is present under green canopy shade, also can inhibit germination (Smith 1995). Desiccated cover crop residues will only lower the red to far-red ratio slightly (Teasdale and Mohler 1993) and probably will not influence germination (Gallagher and Cardina 1998). Likewise, the light reaching the soil surface under the residue conditions outlined in Teasdale and Mohler (1993) and in our study was likely sufficient to initiate germination in light-sensitive species (Gallagher and Cardina 1998).

Higher soybean grain yields with the wheat cover crop may be related to early-season soil water conservation, improved water use efficiency under high-residue conditions (Corak et al. 1991), or enhanced nitrogen fixation due to indirect effects of the wheat residue on *Rhizobium* spp. colonization and nodulation (Freire 1984). We attribute the low corn populations in the 1995 hairy vetch cover crop treatments to improper planter settings that did not account for the extra soil penetration needed in high-residue situations. In 1996, however, planter depth was adjusted independently for the hairy vetch and noncover treatments, which resulted in more equivalent corn populations in the two systems. Likewise, the lower grain yields in the hairy vetch than the no-cover treatments in 1995 were probably due to the significantly lower corn populations in the cover crop system. In 1996, the enhanced corn productivity in hairy vetch compared with the no-cover system may have been due to improved nitrogen fertility (Doran et al. 1987), increased soil water or higher water use efficiency, or both (Corak et al. 1991; Teasdale 1993).

## Herbicide Rate and Application Sequence Effects—Soybean

Weed fresh weight was significantly lower in all the herbicide treatments than in the untreated check (W) (Table 4). The F and H treatments reduced weed fresh weight more than the Q treatment. Weed suppression by the F and H treatments was similar. There was no evidence that split applications (Q + Q or H + H) significantly reduced weed fresh weight compared with the single application of H or F, respectively.

Soybean grain yields were significantly higher in all the herbicide treatments compared with the untreated check (W). Grain yields in the F and H treatments were higher than in the Q treatment. The H and F treatments had similar grain yields in 1994, but the F treatment yielded significantly higher than the H treatment in 1995, even though fresh weed weights were similar between these two treat-



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TABLE 5. The effect of herbicide (nicosulfuron + primisulfuron) rate and application interval on weed fresh weight and corn grain yield in 1995 and 1996. Data are combined over cover-crop treatments.

| Herbicide application | 1995 | | 1996 | |
|---|---|---|---|---|
| | Weed fresh weight[a] | Grain yield[b] | Weed fresh weight | Grain yield |
| | kg $m^{-2}$ | Mg $ha^{-1}$ | kg $m^{-2}$ | Mg $ha^{-1}$ |
| Full (F) | 0.01 | 14.0 | 0.06 | 8.0 |
| Half (H) | 0.19 | 12.9 | 0.00 | 9.1 |
| Quarter (Q) | 0.47 | 12.6 | 0.05 | 9.9 |
| H+H | 0.02 | 12.8 | 0.11 | 8.9 |
| Q+Q | 0.16 | 13.2 | 0.01 | 8.9 |
| Weedy (W) | 0.86 | 10.6 | 0.31 | 7.4 |
| Contrasts | P value | | | |
| *Herbicide rates* | | | | |
| W vs. Q, H, F | 0.0001 | 0.0018 | 0.0002 | 0.0001 |
| Q vs. H, F | 0.0008 | 0.606 | 0.705 | 0.0049 |
| H vs. F | 0.127 | 0.820 | 0.467 | 0.062 |
| *Split applications* | | | | |
| F vs. H+H | 0.922 | 0.688 | 0.548 | 0.170 |
| H vs. Q+Q | 0.828 | 0.591 | 0.165 | 0.692 |

[a] Measurements were taken 110 and 117 d after planting in 1995 and 1996, respectively. Species composition: 45% giant foxtail, 45% common lambsquarters, 10% other species in 1995; species composition: 50% giant foxtail, 40% common lambsquarters, 10% other species in 1996.
[b] Yield adjusted to 15.5% moisture.

ments. Visual weed control rating made 5 wk after the final herbicide application indicated that common ragweed control was significantly higher in the F treatment (79%) than in the H (68%) treatment.

Thifensulfuron plus quizalofop-P was an effective postemergence herbicide combination for no-till soybean planted into both wheat residue and no-cover environments. Weed control and soybean grain yields were sustained with thifensulfuron plus quizalofof-P at rates of 2.2 plus 24 g ai $ha^{-1}$ or higher. These results are consistent with the results reported by Monks et al. (1993), where 2 g ai $ha^{-1}$ of thifensulfuron provided equivalent or better weed control of common cocklebur (*Xanthium strumarium* L.) and common lambsquarters than 3 or 4 g ai $ha^{-1}$. Likewise, control of common lambsquarters and redroot pigweed was reported to be 83% or higher with 2.2 g ai $ha^{-1}$ of thifensulfuron (Nelson and Renner 1998). Jordan et al. (1993) reported that 20 g ai $ha^{-1}$ quizalofop-P provided 78% or greater control of large crabgrass (*Digitaria sanguinalis* L.).

## Herbicide Rate and Application Sequence Effects—Corn

Fresh weed weight was significantly lower in the herbicide treatments than in the untreated check (W) (Table 5). In 1995, fresh weed weight was lower in the F and H treatments than in the Q treatment but was similar among the F, H, and Q treatments in 1996. The F and H treatments provided a similar level of weed suppression in both years. There was no evidence that split herbicide application in the Q + Q or the H + H treatments reduced weed fresh weight compared with the H and the F treatments, respectively.

Corn grain yields were significantly higher in the herbicide treatments than in the untreated check (W). Grain yields were similar in the Q treatment compared with the H and F treatments in 1995 but were significantly higher in the Q treatment compared with the F and H treatments in 1996. Likewise, the F and H treatments had similar grain yields in 1995, but the H treatment yielded significantly higher than the F treatment in 1996. Split herbicide applications did not improve grain yields.

Nicosulfuron plus primisulfuron was an effective postemergence herbicide combination for no-till corn planted into both hairy vetch residue and no-cover environments. Half rate (18 + 13 g $ha^{-1}$) of this herbicide mixture provided adequate weed control to maintain crop yields compared with the full rate (36 + 26 g $ha^{-1}$) treatment. There was evidence, however, that nicosulfuron plus primisulfuron rates could be reduced to as low as 9 + 6.5 g $ha^{-1}$ in some cases in 1996 (Table 5). In this case, weed control was high in all the herbicide treatments, and corn grain yields were inversely related to herbicide rate. These data suggest that crop injury may have occurred at the higher herbicide rates, although there were no visible signs of crop injury. Alternatively, crop injury may have been due to application timing, with the higher herbicide rates applied later in the season than the reduced rates.

Others have reported effective weed control with reduced rates of nicosulfuron. For example, 17 g ai $ha^{-1}$ nicosulfuron resulted in a similar level of yellow foxtail (*Setaria glauca*), redroot pigweed, and Pennsylvania smartweed (*Polygonum pensylvanicum* L.) control as the rates of 35 to 70 g ai $ha^{-1}$ (Kapusta et al. 1994; Mekki and Leroux 1994; Rabaey and Harvey 1997). Reduced nicosulfuron rates, however, were less effective on more tolerant species such as woolly cupgrass (*Eriochloa villosa* Thunb.) (Rabaey and Harvey 1997). These studies indicate the importance of gauging herbicide rates to the sensitivity of the targeted weed species.

## Integrated Strategies to Enhance Sustainability

Our results suggest that a productive no-till corn and soybean system having much reduced impact on the environment is realistic in our region. Although cover crops in our study did not improve weed control as hypothesized,



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they did improve crop yields in three of the four trials. Additional benefits of cover crops in no-till include the added protection of soils during heavy rains and nitrogen fixation in legume species. Limitations associated with cover crops include a narrow window of opportunity for establishment in some species. For example, in the north-central region of the United States, hairy vetch requires a late-summer to early-autumn establishment and an adequate spring growth period to achieve high biomass production. This may limit adoption of hairy vetch to regions with longer growing seasons or to systems that include a summer-harvested small grain.

The low–environmental impact postemergence herbicides used in this study are viable alternatives to the more controversial triazine and chloroacetamide herbicides commonly used in no-till. In addition, reduced rates of the herbicides tested in this study can provide sufficient weed control to maintain crop yields, although weed escapes tend to increase as herbicide rates are lowered. Minimizing herbicide rates will reduce the pesticide load on the environment and weed control costs. Concerns about using herbicides at rates that are marginally effective include increased potential for weed seed production associated with weed escapes (Norris 1999) and the potential for more rapid development of herbicide resistance (Gressel 1995).

In our study, split herbicide applications did not improve weed control or crop yields compared with the single herbicide applications at equivalent rates. Generally, the full and half rates of the herbicides used in this study controlled the target weeds quite well, leaving little margin for improvement with the split applications. Split applications, however, would give a grower the option to access their weed control needs after the first application, thereby tailoring the rate and chemistry of any subsequent herbicide to the specific weed infestation that may be present. Such an approach could substantially reduce the amount of herbicide applied and the cost of chemical weed control.

Weed control with the quarter rates, however, probably was not adequate and may have been improved by split applications. Buhler and Werling (1989) also found that single application of imazaquin plus metolachlor provided a high level of weed control in no-till soybean, which was not improved by a split application at an equivalent rate. Weed control with clomazone and clomazone–metribuzin tank mixes, however, was improved when application was split between an early preplant and a preplant application compared with a single preplant application (Werling and Buhler 1988). The authors indicate that split applications may be useful when competition from early- and late-emerging weeds can be expected. In hard red spring wheat, split applications of half rates of imazamethabenz or ICA 0604 provided equivalent or better control of wild oat (*Avena fatua* L.) than full rates, thereby improving net returns over conventional production practices (Ramsdale and Messersmith 2002). These authors emphasized that split applications were an effective means to control late-emerging wild oat. In summary, these studies suggest that split herbicide applications can, in some cases, improve the efficacy of reduced-rate herbicide programs and control multiple cohorts of weeds.

## Sources of Materials

[1] John Deere 7000 conservation planter, John Deere Co., 1 John Deere Place, Moline, IL 61265.

[2] Great Plains 1005NT drill, Great Plains Manufacturing, Inc., 1525 East North Street, P.O. Box 5060, Salina, KS 67402.


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