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Rotary Hoeing Substitutes for Two-Thirds Rate of Soil-Applied Herbicide[1]

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Abstract: Dose–response curves for acetochlor with and without timely rotary hoeing (two passes) were derived for corn (*Zea mays*) fields over 2 yr. The fields were dominated by green foxtail (*Setaria viridis*), which constituted 73 to 86% of the weed vegetation, but also contained minor populations of common lambsquarters (*Chenopodium album*), Pennsylvania smartweed (*Polygonum pensylvanicum*), and redroot pigweed (*Amaranthus retroflexus*). In the absence of herbicide, rotary hoeing achieved about 50% weed control. In the absence of rotary hoeing, weed control averaged > 90% at the full label rate of acetochlor (3 kg ai/ha on clay loam soil). With two timely rotary hoeings, however, this same level of control was achieved with only 1 kg/ha acetochlor. Given the suite of weed species present in these experiments, timely rotary hoeing substituted for 67% of the label rate of acetochlor. Timeliness of rotary hoeing operations also provided consistency of results from one year to the next.

Nomenclature: Acetochlor, 2-chloro-*N*-(ethoxymethyl)-*N*-(2-ethyl-6-methylphenyl)acetamide; common lambsquarters, *Chenopodium album* L. #[3] CHEAL; green foxtail, *Setaria viridis* (L.) Beauv. # SETVI; Pennsylvania smartweed, *Polygonum pensylvanicum* (L.) # POLPY; redroot pigweed, *Amaranthus retroflexus* L.; corn, *Zea mays* L.

Additional index words: Integrated weed management, interrow cultivation, preemergence herbicide, seedling emergence, timeliness.

INTRODUCTION

Many studies that included the effects of rotary hoes and interrow cultivators have reported maximum levels of weed control achieved by these implements as about 50 to 75% (e.g., Buhler et al. 1995; Gunsolus 1990). However, lower levels of control are more common. Even when the two types of implements are used in tandem, control may be low and also variable from year to year and site to site (Mulder and Doll 1993).

Success of many weed control operations depends upon the timing of implementation. Both rotary hoeing and interrow cultivation, if performed too early, merely disrupt soil and move weed seeds, which subsequently germinate, emerge, and plague the crop. Alternatively, if rotary hoeing or cultivation is performed too late, weeds may be too large to kill by these operations. Unfortunately, the proper timing of either technique for specific weed species is not well known.

Farm managers who rotary hoe or cultivate have differing concepts regarding the timing of those operations. The recent book ‘‘Steel in the Field’’ (Bowman 1997) describes this variability. In brief, most farm managers who use rotary hoes tend to do so according to the number of days elapsed after crop sowing, often between 5 and 14 d after sowing. Weed species composition and biology seemingly play no obvious role in this decision, with the exception that rotary hoeing may be delayed until inspection of soil in the field reveals roots (‘‘white threads’’) of germinating weed seeds. Whether initial observation of these roots is representative of 1% (minor cohort flush) or 100% (whole population) of the forthcoming weed community is entirely unknown.

Progress has been made recently to use weed biology more fully for making decisions on mechanical weed control for foxtails, such as giant foxtail (*Setaria faberi* Herrm.), as well as green (*Setaria viridis*) and yellow foxtail [*Setaria glauca* (L.) Beauv.] (Oriade and Forcella 1998). The degree of foxtail control achieved by either rotary hoeing or cultivating was independent of days elapsed after crop sowing, but they were related logically to levels of foxtail seedling emergence attained at the time of mechanical control (Figure 1). Briefly, control of foxtails was maximized by timely mechanical control, and the timely mechanical control for foxtail was defined

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

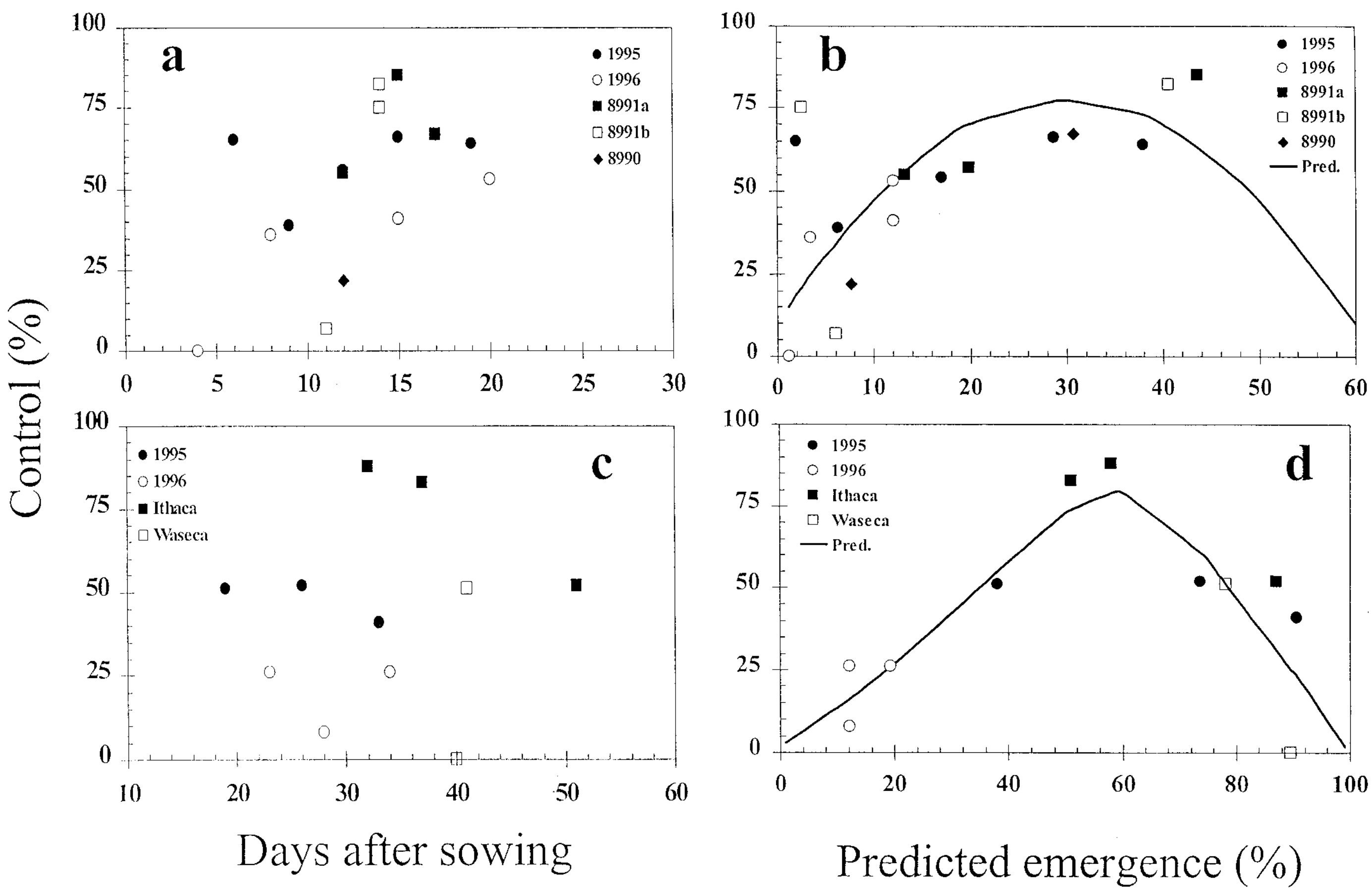

Figure 1. Relationships between time of rotary hoeing (a, b) or interrow cultivation (c, d) and percent control of foxtail (*Setaria*) species. Times of control are represented as days after crop sowing (a, c) and percent foxtail emergence (b, d) for both forms of mechanical control. Note that days after crop sowing seem unrelated to the success of mechanical control, whereas distinct trends appear for the relationships between efficacy and level of weed emergence at the time of control. Symbols representing 1995 and 1996 are for green foxtail derived from field data from Morris, MN; 8991a and 8990 are for giant foxtail from Rosemount, MN; and Ithaca is for yellow foxtail from Ithaca, NY. All data adapted from Oriade and Forcella (1998), except for Waseca data in c and d, which are derived from Johnson et al. (1998) in Waseca, MN.

as rotary hoeing at about 30% emergence and cultivating at 60% emergence.

The hypothesis tested in this study was that rates of a standard soil-applied herbicide, acetochlor, in foxtail-plagued corn (*Zea mays*) could be lowered if chemical weed control was supplemented with timely rotary hoeing. The objective, then, was to develop dose–response curves for acetochlor in the presence and absence of mechanical control using field plots of sufficiently large size for practical and reliable implementation of a rotary hoe. These two dose–response curves would allow comparison of the herbicide rates that provide equivalent control with and without rotary hoeing.

MATERIALS AND METHODS

Field studies were conducted during 1997 and 1998 at the North Farm of the West Central Experiment Station, University of Minnesota, Morris, MN (45.35°N, 95.53°W). Soil was a gently undulating (< 1 m topographic relief) Aastad clay loam (Pachic Udic Haploboroll; fine, mixed, mesic), with about 6% organic matter and pH 6.4 in the surface soil horizon.

The long-term crop management system was a corn/soybean rotation, with corn being the experimental crop. Soybean [*Glycine max* (L.) Merr.] residue was managed by chisel plowing in spring. Fertilizer for corn was broadcast at a rate equivalent to 120, 13, 13 kg/ha of N, P, and K, respectively, and incorporated during seedbed preparation by field-cultivating just prior to sowing corn (Pioneer hybrid ‘3893’) at 70,000 seeds/ha in rows spaced 76 cm apart. Dates for sowing and other management events are listed in Table 1.

The experimental design was a randomized complete block with split plots and three replications. Main treatments were preemergence acetochlor rates of 0, 0.3, 1, and 3 kg ai/ha. Herbicide was applied through a tractor-mounted 3-m boom equipped with 8003 flat-fan nozzles

Table 1. (a) Dates of management and sampling procedures during 1997 and 1998. (b) Monthly averages of minimum (Min) and maximum (Max) air temperatures and total monthly rainfall during the 1997 and 1998 growing seasons in Morris, MN.

(a) Procedure	1997	1998
Corn planting	May 6	April 24
Acetochlor application	May 13	April 24
First rotary hoeing	May 28	May 9
Second rotary hoeing	June 2	May 17
Interrow cultivation	June 10	May 21
Weeds sampled	July 16	July 9
Crop harvested	Oct. 1	Oct. 23

(b)	1997			1998		
	Air temperature			Air temperature		
Month	Min	Max	Rain	Min	Max	Rain
	C		mm	C		mm
April	−1.1	9.6	69	2.9	15.7	46
May	5.1	17.4	40	10.4	24.1	80
June	14.7	27.6	64	12.8	22.9	146
July	16.0	26.1	131	16.1	27.5	106
Aug.	14.1	25.1	100	15.6	27.8	91
Sept.	10.9	23.9	33	11.2	26.3	9

at 187 L/ha and 206 kPa pressure. Main plots were 9 by 113 m.

Main plots were split into two subplots, each 4.5 × 113 m, which either were rotary hoed or not. Rotary hoeing was done with a commercially available implement with the following characteristics: 4.5 m wide, with two gangs of hoes offset from one another by 18 cm (front/back) and 9 cm laterally. Each hoe was equipped with 16 spoon-shaped tines whose 1.6-cm-wide tips were spaced 10 cm apart along the circumference of each hoe. Because the plots were sufficiently large for realistic operation of a tractor-mounted rotary hoe, the implement was used at a speed of 20 to 25 km/h.

Rotary hoeing was performed twice, once at 15% predicted emergence and again at 30% predicted emergence of green foxtail, which dominated the experimental site. Emergence was predicted by the software program WeedCast (Forcella 1998), which used locally derived and daily values for rainfall and minimum and maximum temperature to generate predictions. The two passes of the rotary hoe used in these experiments insured control of early-emerging seedlings, as well as those emerging during the critical period for control, which is represented by 30% foxtail emergence (Figure 1). Interrow areas of all plots were cultivated at 60% emergence of green foxtail, the time that maximizes control of this species (Oriade and Forcella 1998).

Weeds were counted by species and clipped in 10 0.1-m^2 (25 × 40 cm) quadrats in each subplot in mid-July. Corn plants also were counted in this manner. Quadrats were spaced at 10-m intervals in each subplot to ascertain the variability of weed densities along the length of the subplots and across the entire experimental area. Each quadrat was centered on a crop row with the long axis parallel to the row, and they were positioned in a staggered manner on the two central rows of each six-row-wide subplot. Clipped weeds were aggregated within subplots, placed in paper bags, dried at 60 C for 1 wk, then weighed.

The two center crop rows were harvested by combine at maturity along the entire length of each subplot. Harvested grain was weighed, seed water contents were measured, and grain yields were calculated based on 15% seed water content.

All statistical analyses of treatment and subtreatment means employed ANOVA (Anonymous 1997). Dose–response curves for the effect of acetochlor on weed control (percent weed dry weight reduction) were developed using log-logistic curves (Tharp et al. 1999). Because of uneven variance across acetochlor rates, percent weed control data were arcsine-transformed prior to analyses. However, statistical results from analyses using transformed and original data were nearly identical. Thus, for simplicity, only results of analyses using original percent weed control data are presented.

RESULTS AND DISCUSSION

Green foxtail (mixed with some yellow foxtail) was the primary weed species in this study. Overall, green foxtail represented 73% of all weeds counted in 1997 and 86% in 1998. Averaged over all plots, densities of green foxtail, common lambsquarters (*Chenopodium album*), redroot pigweed (*Amaranthus retroflexus*), and Pennsylvania smartweed (*Polygonum pensylvanicum*) were 408, 45, 100, and 5 plants/m^2, respectively, in 1997 and 288, 27, 13, and 8 plants/m^2, respectively, in 1998.

Weed Dry Weight. Weed dry weights during mid-July differed significantly ($P < 0.10$) between years; therefore, dry weight data are presented separately by year. Dry weights decreased considerably with increasing acetochlor rate each year (Figure 2a). In the absence of acetochlor and rotary hoeing, weed dry weights were 260 g/m^2 in 1997 and 670 g/m^2 in 1998. Greater weed growth in 1998 was not due to higher densities (see above) but more likely was attributable to an earlier crop sowing date and good growing conditions relative to 1997. With 0.3 kg/ha of acetochlor, weed dry weights decreased to 220 g/m^2 in 1997 and 430 g/m^2 in 1998. This rate of acetochlor represents 10% of the label rate for a clay loam soil (Gunsolus et al. 1998). When 33% (1 kg/ha)

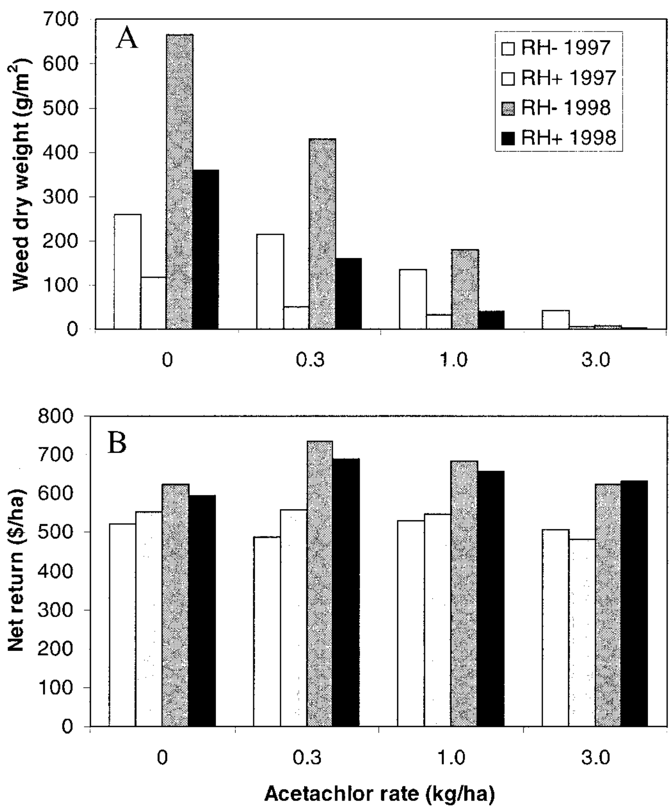

Figure 2. (a) Midseason weed dry weights in response to four acetochlor rates applied preemergence with and without two passes of a rotary hoe in 1997 and 1998 on clay loam soils in west-central Minnesota. The highest rate is the label rate for clay loam soil. (b) Partial net financial returns after weed control costs (acetochlor at $25.23/kg, spraying at $9.27/ha, rotary hoeing at $10.57/ha/pass, and interrow cultivation at $13.29/ha) were subtracted from gross returns based on corn grain yields and a grain price of $0.075/kg ($2.00/bu). $LSD_{0.05}$ values for weights among rates and between rotary hoeing treatments were 76 and 54 g/m² in 1997 and 68 and 48 g/m² in 1998. $LSD_{0.10}$ values for net returns were $44 and $31/ha in 1997 and $37 and $26/ha in 1998.

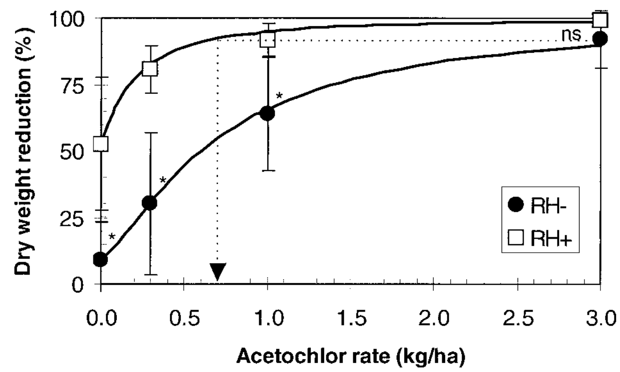

Figure 3. Dose–response curves for acetochlor with (RH+) and without (RH−) two passes of a rotary hoe on clay loam soil during 1997 and 1998 (data combined). Solid lines represent log-logistic dose–response curves. Asterisks (*) indicate significant differences between rotary hoeing treatments, whereas ns indicates that the difference between mean values is not significant ($P > 0.05$). Vertical bars represent ± 1 standard deviation unit. The thin dotted line and arrow represent the level of weed control at 3 kg/ha of acetochlor without rotary hoeing that was achieved with < 1 kg/ha acetochlor plus rotary hoeing.

of the labeled acetochlor rate was applied, weed dry weights were reduced to 130 g/m² in 1997 and 180 g/m² in 1998. With the full label rate (3 kg/ha), weed weights were less than 40 g/m² in both years. Least significant differences ($P = 0.05$) for comparisons among these dry weights were 76 g/m² in 1997 and 68 g/m² in 1998.

Rotary hoeing decreased weed weights both in the absence and presence of acetochlor (Figure 2a). The effect of rotary hoeing on weed dry weight reduction was significant ($P < 0.05$) in all acetochlor treatments except the highest rate, where weed growth was negligible. The contribution of rotary hoeing to reduction of weed dry weights was calculated by dividing mean weed weights with rotary hoeing by mean weed weights without rotary hoeing (Figure 2a). The proportion of weed control contributed by rotary hoeing was typically greater than 0.5, and it tended to rise as acetochlor rate increased. This contribution to weed control by the rotary hoe is due to direct mortality of young weed seedlings at the time of rotary hoeing and possibly also to slight incorporation of the herbicide by the rotary hoeing process. Incorporation of acetochlor is not recommended unless dry conditions persist after application, which was the case during May 1997 (Table 1).

Weed Control. Weed control in each subplot was calculated as percent dry weight reduction in relation to the subplot with the highest weed weights in each block. In most but not all instances, the subplot in each block with the highest weed weight was the treatment that lacked both acetochlor and rotary hoeing. ANOVA indicated that the weed control by year interaction was not significant ($P = 0.5$); therefore, data were combined across years. However, the effects of rotary hoeing and acetochlor rate and the interaction of these two variables were all highly significant ($P < 0.01$). The interaction indicated that the effect of rotary hoeing decreased as weed control from acetochlor rose above 90%.

The calculated weed control values were plotted against acetochlor rate separately for the two subtreatments with and without rotary hoeing (Figure 3). Dose–response predictions based on log-logistic relationships of acetochlor rate (least squares regression) and weed control were plotted on the same graph. Average weed control was 92% in the presence of the full label rate of acetochlor in the absence of rotary hoeing. In the presence of rotary hoeing, this same level of weed control was achieved by < 1 kg/ha of acetochlor, which is less than one-third the label rate. Thus, two timely passes of a rotary hoe, valued at about $10/ha/pass (Lazarus 1997), in addition to 1 kg/ha of acetochlor, provided at least the same level of weed control as 3 kg/ha of acetochlor without rotary hoeing. As acetochlor is valued at about $25/kg (a.i.) (Gunsolus et al. 1998), a potential savings of at least $30/ha could arise if 1 kg/ha of acetochlor plus two rotary hoeings ($25 + $20/ha) substituted for the label rate of 3 kg/ha of acetochlor ($75/ha).

Best-fit log-logistic response curves also are shown in Figure 3. These curves are represented by the following general equation (Tharp et al. 1999): $DWR = 100 - (\delta + ((\alpha - \delta)/(1 + \exp(\beta + \ln((x + 0.01)/GR_{50})))))$, where DWR is average weed dry weight reduction at herbicide dose x (kg/ha) as a percentage of maximum dry weight, δ is the minimum dry weight, α is the maximum dry weight, β is the rate of change at the inflection point, and GR_{50} is the herbicide dose at which weed dry weight is reduced by 50%. Values for δ, α, β, and GR_{50} were 0, 91, 1.4, and 0.7, respectively ($r^2 = 0.88$, $P < 0.01$) without rotary hoeing and 0, 47, 1.3, and 0.2 ($r^2 = 0.81$, $P < 0.01$) with rotary hoeing. Note that GR_{50} values differed by a factor of 3.5 between the rotary hoeing treatments.

Corn Stand, Yield, and Partial Returns. Neither acetochlor rate nor rotary hoeing affected corn plant density ($P > 0.1$), which averaged about 57,000 plants/ha. Corn grain yields were reduced in the absence of rotary hoeing in 1997 (7,442 vs. 8,046 kg/ha, $LSD_{0.05} = 533$), but yields among the four increasing herbicide rate treatments (7,485, 7,501, 7,953, 8,036 kg/ha) did not vary significantly. In contrast, rotary hoeing had no significant effect in 1998 on corn yield (9,509 vs. 9,502 kg/ha), but increasing acetochlor rates did affect yields (8,440, 9,724, 9,830, and 10,000 kg/ha, $LSD_{0.05} = 507$). Interactions between herbicide rate and rotary hoeing were not significant in either year.

Partial returns also were calculated using costs of $9.27/ha for herbicide application, $25.23/kg for acetochlor (a.i.), $10.57/ha pass for rotary hoeing, $13.29/ha for interrow cultivation, and $0.075/kg ($2/bu) as the price of corn grain. Generally, differences among treatments were small and often not significant statistically. Nevertheless, some trends were apparent. In 1997 when weed weights were relatively low and rotary hoeing increased corn yields, maximum net returns formed a broad plateau across the 0 through 1 kg/ha acetochlor plus rotary hoeing treatments (Figure 2b). In 1998, when rotary hoeing had little effect on corn yields, the 0.3 kg/ha acetochlor treatment had the highest net return followed by the 1 kg/ha acetochlor treatment. Thus, averaged over years, rotary hoeing in combination with a reduced rate of acetochlor (as low as 0.3 kg/ha) was the most profitable treatment.

Conclusions based on this and related research are as follows. (1) Rotary hoeing provided an appreciable enhancement to preemergence herbicide applications for control of summer annual weeds such as green foxtail and possibly also common lambsquarters, redroot pigweed, and Pennsylvania smartweed. Full label application rates on heavy soils can be reduced by 67% if two passes of a rotary hoe supplemented acetochlor. (2) Timely operation of the rotary hoe probably was crucial for uniformity of efficacies and the success of reduced-rate practices. Efficacy of rotary hoeing was consistent across years because it was timed to occur at specific stages of weed development, 15 and 30% predicted emergence of the dominant weed species (Oriade and Forcella 1998). Direct measurement of weed emergence was not necessary. Emergence was estimated from existing software that predicts emergence percentages of several weed species based on readily available weather, soil, and management variables (Forcella 1998). Unfortunately, timeliness of mechanical control operations in terms of weed emergence has not been defined for species other than foxtails. Such timeliness guidelines may be valuable to individuals interested in chemical weed control, nonchemical weed control, herbicide-resistance management, and integrated weed management.

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