Open access • Journal Article • DOI:10.1614/WT-D-10-00049.1

Winter Wheat Response to Preplant Applications of Aminocyclopyrachlor — Source link

Andrew R. Kniss, Drew J. Lyon

Published on: 15 Feb 2011 - Weed Technology (Weed Science Society of America 810 East 10th St., Lawrence, KS 66044-7050)

Topics: Aminocyclopyrachlor

Winter Wheat Response to Preplant Applications of Aminocyclopyrachlor

Authors: Kniss, Andrew R., and Lyon, Drew J.

Source: Weed Technology, 25(1) : 51-57

Published By: Weed Science Society of America

URL: https://doi.org/10.1614/WT-D-10-00049.1

Weed Technology 2011 25:51–57

Winter Wheat Response to Preplant Applications of Aminocyclopyrachlor

Andrew R. Kniss and Drew J. Lyon*

Field studies were conducted in Wyoming and Nebraska in 2007 through 2009 to evaluate winter wheat response to aminocyclopyrachlor. Aminocyclopyrachlor was applied at rates between 15 and 120 g ai ha^{-1} 6, 4, and 2 mo before winter wheat planting (MBP). Redroot pigweed control was 90% with aminocyclopyrachlor rates of 111 and 50 g ha^{-1} when applied 4 or 2 MBP. Aminocyclopyrachlor at 37 g ha^{-1} controlled Russian thistle 90% when applied 6 MBP. At Sidney, NE, winter wheat yield loss was $>$ 10% at all aminocyclopyrachlor rates when applied 2 or 4 MBP, and at all rates $>$ 15 g ha^{-1} when applied 6 MBP. At Lingle, WY, $>$ 40% winter wheat yield loss was observed at all rates when averaged over application timings. Although the maturing wheat plants looked normal, few seed were produced in the aminocyclopyrachlor treatments, and therefore preharvest wheat injury ratings of only 5% corresponded to yield losses ranging from 23 to 90%, depending on location. The high potential for winter wheat crop injury will almost certainly preclude the use of aminocyclopyrachlor in the fallow period immediately preceding winter wheat.

Nomenclature: Aminocyclopyrachlor; redroot pigweed, *Amaranthus retroflexus* L., AMARE; Russian thistle, *Salsola tragus* L. SASKR; winter wheat, *Triticum aestivum* L.

Key words: 6-Amino-5-chloro-2-cyclopropyl-4-pyrimidin methyl ester, crop injury, DPX-KJM44, DPX-MAT28, fallow, herbicide, soil residual.

Se llevaron a cabo estudios de campo en Wyoming y Nebraska de 2007 hasta 2009, para evaluar la respuesta del trigo de invierno al aminocyclopyrachlor. Este herbicida fue aplicado a dosis entre 15 y 120 g ia ha−1 a los 6, 4, y 2 meses antes de la siembra del trigo (MBP). El control de *Amaranthus retroflexus* fue del 90% con dosis de 111 y 50 g ha−1 de aminocyclopyrachlor, cuando se aplicó a 4 y 2 MBP, respectivamente. El aminocyclopyrachlor aplicado a 37 g ha−1 controló *Salsola tragus* en un 90% cuando se aplicó 6 MBP. En Sidney, Nebraska, la pérdida de rendimiento del trigo fue $>$10% en respuesta a todas las dosis de aminocyclopyrachlor cuando se aplicó 2 ó 4 MBP, y a todas las dosis $>$15 g ha−1 cuando se aplicó 6 MBP. En Lingle, Wyoming, se observó una pérdida de rendimiento del trigo $>$40% en respuesta a todas las dosis, cuando se promediaron los momentos de aplicación. Aun cuando las plantas de trigo al madurar se veían normales, se produjeron pocas semillas en los tratamientos con aminocyclopyrachlor y por lo tanto, estimados visuales de daño pre-cosecha en el trigo de sólo 5% correspondieron a pérdidas de rendimiento que variaron de 23 a 90%, dependiendo del sitio. El alto potencial de daño al cultivo, seguramente impedirá el uso de aminocyclopyrachlor en el periodo de barbecho inmediatamente previo a la siembra del trigo de invierno.

A general trend for declining summer fallow hectares has been observed in the United States since 1970; however, this practice is still utilized on approximately 6 million hectares (USDA-ERS 2007). The primary function of summer fallow in winter wheat growing areas of the United States is to store water in the soil for the subsequent crop. Weed control during the fallow period is of utmost importance to prevent water usage by weeds because in most years winter wheat yield is highly correlated with the amount of water in the soil profile at the time of planting (Nielsen et al. 2002). Prevention of weed seed production is another valuable goal of summer fallow. Use of no-till practices during the fallow period can result in significantly greater soil water at the time of winter wheat planting and a corresponding increase in wheat yields compared to conventionally tilled fallow (Nielsen et al. 2002).

When fallow tillage is reduced or eliminated, winter wheat growers are much more reliant on herbicides for weed control. Many of the herbicides used in winter wheat–fallow systems have short soil persistence (Derksen et al. 2002). Several herbicide applications may be required during the fallow period to control multiple weed flushes. Glyphosate is perhaps the most commonly used herbicide for weed control in no-till and reduced-till fallow systems, and it has no practical soil residual activity. Herbicides that provide residual weed control can be advantageous in no-till fallow by reducing the number of herbicide applications required. Residual herbicides might also reduce the selection pressure for glyphosate-tolerant and glyphosate-resistant weed populations resulting from multiple applications of glyphosate. Several herbicides with soil residual activity are registered for use in fallow prior to winter wheat planting, including atrazine, chlorsulfuron plus metsulfuron, and triasulfuron. Weed resistance to triazine and sulfonylurea herbicides is common (Heap 2010); therefore, introduction of a residual synthetic auxin herbicide to this market would aid in herbicide resistance management by diversifying the available herbicide options.

Aminocyclopyrachlor is a new pyrimidine herbicide (Finkelstein et al. 2009) that has activity on many annual and perennial broadleaf weeds. Aminocyclopyrachlor provides control of several species that can be troublesome in the winter wheat–fallow rotation of the High Plains region of the United States such as kochia [*Kochia scoparia* (L.) Schrad.] (Montgomery et al. 2009) and field bindweed (*Convolvulus arvensis* L.) (Westra et al. 2009). Aminocyclopyrachlor has a reported half-life of 72 to 128 d in bare ground field soils (Finkelstein

---

DOI: 10.1614/WT-D-10-00049.1

* Assistant Professor, Department of Plant Sciences, University of Wyoming, Laramie, WY 82071; Professor, Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Scottsbluff, NE 69361. Corresponding author's E-mail: akniss@uwyo.edu

Table 1. Dates of herbicide applications, wheat planting, and evaluations for three field experiments.

Location	Herbicide applications					
	6 MBP[a]	4 MBP	2 MBP	Wheat planting	Wheat injury evaluation	Wheat harvest
Sidney #1	Apr. 17, 2007	May 15, 2007	Jul. 17, 2007	Sep. 9, 2007	Jun. 18, 2008	Jul. 14, 2008
Sidney #2	Apr. 2, 2008	May 20, 2008	Jul. 19, 2008	Sep. 10, 2008	Jun. 16, 2009	Jul. 20, 2009
Lingle	Mar. 26, 2008	May 6 2008	Jul. 1, 2008	Sep. 18, 2008	May 12, 2009	Jul. 24, 2009

[a] Abbreviations: MBP, months before winter wheat planting.

et al. 2009). Few reports exist on the response of field crops to aminocyclopyrachlor. Grass species can vary widely in their response to soil residues of aminocyclopyrachlor (Vassios et al. 2009). Westra et al. (2008) indicated that spring wheat was less tolerant to aminocyclopyrachlor compared to alfalfa (*Medicago sativa* L.), soybean [*Glycine max* (L.) Merr.], sunflower (*Helianthus annuus* L.), and corn (*Zea mays* L.), although few details were provided on the level of injury that was sustained by these crops. The weed spectrum, grass selectivity, and soil residual properties of aminocyclopyrachlor make it a potentially useful herbicide for winter wheat–fallow rotations. Given the relative lack of information about crop response to aminocyclopyrachlor soil residues, field studies were conducted in Nebraska and Wyoming in 2007 through 2009 to evaluate winter wheat response to aminocyclopyrachlor applied in the fallow period prior to wheat planting.

Materials and Methods

Field studies were initiated at the High Plains Agricultural Laboratory near Sidney, NE, in 2007 and 2008, and at the Sustainable Agriculture Research and Extension Center near Lingle, WY, in 2008 to evaluate winter wheat response to aminocyclopyrachlor applied prior to planting. At all three locations, a factorial treatment arrangement of the methyl-ester formulation of aminocyclopyrachlor (DPX-KJM44[1]) rates (15, 30, 60, and 120 g ha^{-1}) and application timings (6, 4, and 2 mo before planting [MBP]) (Table 1) plus a nontreated control was used. The study was arranged in a randomized complete block design with three (Sidney) or four (Lingle) replications.

In 2007, the study at Sidney was conducted on an Alliance silt loam with organic matter content of 3.5% and a pH of 6.5. In 2008, the study at Sidney was conducted on a Duroc loam soil with organic matter content of 3.4% and pH of 6.2. In both years the previous year's crop was no-till corn, and plots were 3 m wide by 12 m long. Herbicides were applied at Sidney with an ATV-mounted sprayer delivering 124 L ha^{-1} at 4.8 km h^{-1} with flat fan nozzles.[2] Prior to each aminocyclopyrachlor treatment, the entire plot area was sprayed with glyphosate[3] at 630 g ha^{-1} to control any emerged weeds. The 6 MBP application timing at Sidney in 2007 was delayed until sufficient quantities of aminocyclopyrachlor could be obtained, and consequently the actual time between application and planting was approximately 5 months. The winter wheat cultivar Millennium was seeded at 62 kg ha^{-1} in 2007, and the cultivar Pronghorn was seeded at 56 kg ha^{-1} in 2008. Seeding depth in both years was 3 cm, and soils were not fertilized prior to or during the study.

Soil at the Lingle site was a Mitchell silt loam with organic matter content of 2.1% and pH of 8.0, and the plots were 3 m wide by 9 m long. The Lingle trial was conducted in no-till fallow that had been winter wheat the previous year. Herbicides were applied at Lingle with a CO_2-pressurized knapsack sprayer delivering 140 L ha^{-1} at 4.8 km h^{-1} with flat fan nozzles.[4] Glyphosate[5] was included at a rate of 840 g ha^{-1} with each aminocyclopyrachlor treatment to control any emerged weeds. The winter wheat cultivar Genou was seeded at 67 kg ha^{-1} at a depth of 3 cm. The trial at Lingle was not fertilized.

Russian thistle control was evaluated visually by estimating the overall ground cover of living plants approximately 30 d after the 6 MBP application timing at Sidney in both years. Russian thistle did not emerge following subsequent herbicide applications; therefore, control was not evaluated at subsequent timings. Redroot pigweed continued to emerge throughout the season, and thus control was estimated for all application timings 20 to 30 d prior to wheat planting. Weed densities were too low to obtain reliable weed control estimates at Lingle (either visually or by counts); therefore, weed control is not presented for this location.

Weed density in the growing wheat crop was less than 0.5 plant m^{-2} at all three locations, and thus herbicide applications were not required to keep the trials weed free. At both locations, wheat injury was evaluated after emergence in the fall, early the following spring, and again just prior to (Lingle) or shortly after (Sidney) seed head emergence (Table 1). No evidence of injury was observed at the first two evaluation dates, and thus no data are presented for these evaluation timings. Injury symptoms present at the final evaluation date included trapped seed heads, reduced head size, and delayed crop development. Plots at both sites were harvested with a small plot harvester to calculate wheat yield.

Statistical Analysis. Weed control, wheat injury, and wheat yield loss data were subject to ANOVA. Where significant interactions with location were observed, locations were analyzed separately. Significant treatment effects were further analyzed using nonlinear regression. The two- or three-parameter log-logistic model, and two-parameter Michaelis–Menten model were fit to weed control, winter wheat yield, and crop injury data. The model with the lowest bias-corrected Akaike information criterion (AICc) (Spiess and Neumeyer 2010) was chosen to estimate the aminocyclopyrachlor dose required to control 90% of weeds or cause a 10, 20, and 50% wheat yield loss.

The three-parameter log-logistic model is similar to that described by Seefeldt et al. (1995), but the lower limit is constrained to 0, so that the equation takes the form:

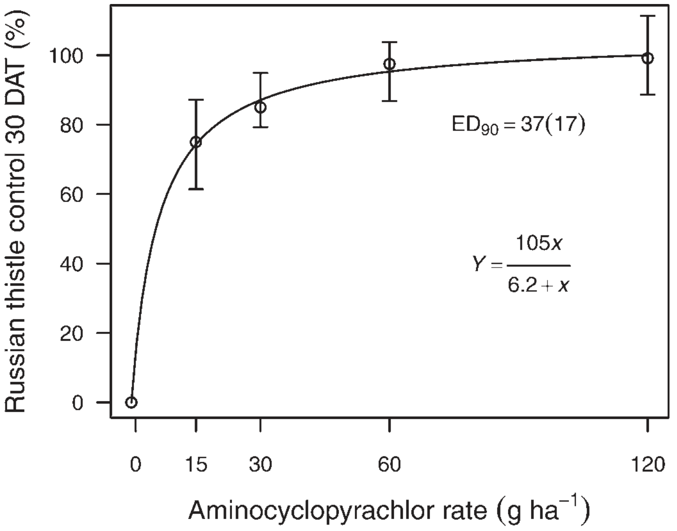

Figure 1. Russian thistle control and ED_{90} value 30 d after treatment with aminocyclopyrachlor applied 6 mo before winter wheat planting averaged over two experiments at Sidney, NE. Bars represent the standard error associated with the model predicted response for each aminocyclopyrachlor rate.

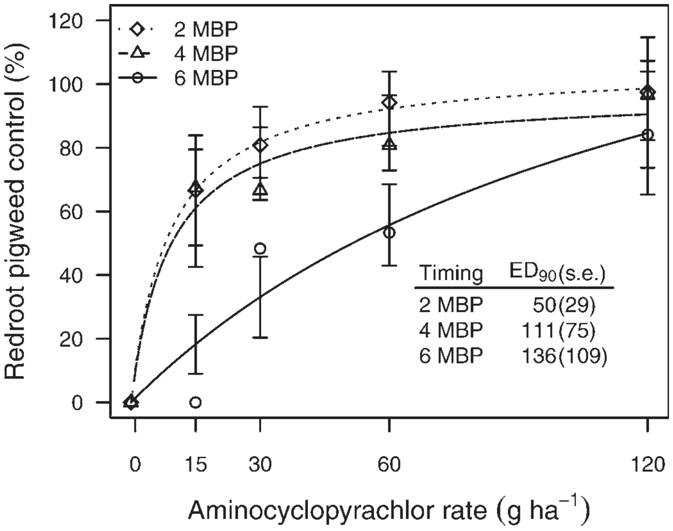

Figure 2. Redroot pigweed control and ED_{90} values 20 to 30 d prior to winter wheat planting as influenced by application timing and aminocyclopyrachlor rate averaged over two experiments at Sidney, NE. Bars represent the standard error associated with the model predicted response for each aminocyclopyrachlor rate. Parameter estimates (with standard errors in parentheses) as described in Equation 2: 6 MBP, $Y_{max} = 176$ (86), $K = 129$ (104); 4 MBP, $Y_{max} = 97$ (13), $K = 9$ (6); 2 MBP, $Y_{max} = 106$ (12), $K = 9$ (5).

$$Y = d/\{1 + \exp[b(\log x - \log e)]\} \qquad [1]$$

where Y is the response (either weed control or percentage wheat yield loss); d is the upper asymptote; b is the slope around e; x is the rate of aminocyclopyrachlor; and e is the rate required to cause 50% of the maximum response. The two-parameter log-logistic model is constrained by setting $d = 100$. This model is biologically relevant because no weed control or crop response will be observed when a herbicide is not applied, and at very high rates of a herbicide, weed control and crop yield loss may approach 100%.

The Michaelis–Menten model is often used in enzyme kinetics but has been previously proposed in a different parameterization to estimate crop yield losses due to weed competition (Cousens 1985). The model parameterization used here is the original Michaelis–Menten form:

$$Y = (Y_{max}x)/(K + x) \qquad [2]$$

where Y_{max} is the upper limit on the right side, or the theoretical maximum weed control or yield loss that might occur at very high rates of aminocyclopyrachlor; K is the dose of aminocyclopyrachlor required to cause 50% of the theoretical maximum (or $Y_{max}/2$); and Y and x are the same as in Equation 1. All statistical analyses were conducted using the R language, nonlinear regressions were conducted using the drc package in R, and AICc information for the models was extracted using the qpcR package (R Development Core Team 2009; Ritz and Spiess 2008; Ritz and Streibig 2005).

Results and Discussion

Weed Control with Aminocyclopyrachlor. Weeds present at the first Sidney location (2007) included Russian thistle, redroot pigweed, tumble pigweed (*Amaranthus albus* L.), and puncturevine (*Tribulus terrestris* L.). Weeds present at the second Sidney location (2008) included Russian thistle, redroot pigweed, and kochia. Although only 1 yr of data was collected for tumble pigweed, control was consistently lower than redroot pigweed (data not shown). Also with only 1 yr of data, puncturevine and sandbur control with aminocyclopyrachlor was rate dependent, but never exceeded 83 or 77% control, respectively.

Russian thistle emerged following the earliest aminocyclopyrachlor application timing (6 MBP) but no further emergence occurred after the 4 MBP applications at the first Sidney location, and no further emergence occurred after the 2 MBP applications at the second Sidney location; therefore, Russian thistle control was evaluated approximately 30 d following the 6 MBP application timing at both Sidney locations. There was no location by aminocyclopyrachlor rate interaction effect ($P = 0.6613$), but a significant effect of aminocyclopyrachlor rate was observed ($P = 0.0003$). Aminocyclopyrachlor at 15 g ha^{-1} provided 74% control of Russian thistle (Figure 1). The ED_{90} value for Russian thistle control with aminocyclopyrachlor was 37 g ha^{-1}.

No location interaction effects were significant for redroot pigweed control ($P > 0.60$). Application timing ($P = 0.0002$) and aminocyclopyrachlor rate ($P < 0.0001$) were both significant, while the interaction between these two factors was not ($P = 0.6034$). As expected, later application timings provided greater control of redroot pigweed when evaluated 20 to 30 d prior to winter wheat planting (Figure 2). ED_{90} values decreased as the aminocyclopyrachlor was applied closer to wheat planting. When 120 g ha^{-1} of aminocyclopyrachlor was applied 6 MBP, less than 90% of redroot pigweed was controlled. Conversely, when applied 4 and 2 MBP, 90% of redroot pigweed was controlled at rates of 111 and 50 g ha^{-1},

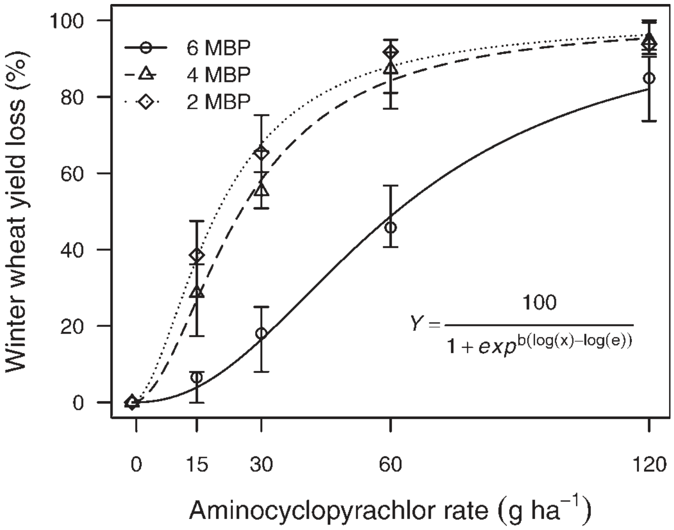

Figure 3. Winter wheat yield loss resulting from aminocyclopyrachlor applied 6, 4, or 2 mo before planting (MBP) averaged over two experiments at Sidney, NE. Bars represent the standard error associated with the model predicted response for each aminocyclopyrachlor rate. Parameter estimates (with standard errors in parentheses) as described in Equation 1: 2 MBP, $b = -2.3$ (0.36), $e = 61.4$ (4.4); 4 MBP, $b = -1.9$ (0.30), $e = 25.2$ (2.0); 6 MBP, $b = -1.8$ (0.32), $e = 19.9$ (1.8).

Table 2. Aminocyclopyrachlor rate required to reduce winter wheat yield by 10, 20 and 50% when applied at three application timings, Sidney, NE, 2008 to 2009.

	Aminocyclopyrachlor dose (standard error in parentheses)		
Application timing	10% yield loss	20% yield loss	50% yield loss
Months before wheat planting		g ha^{-1}	
6	23 (4.0)[a]	33 (4.1)	61 (4.4)
4	8 (1.7)	12 (1.8)	25 (2.0)
2	6 (1.5)	9 (1.7)	20 (1.8)

[a] Yield loss estimates derived by fitting yield data to Equation 1. See Figure 1 for parameter estimates.

respectively. Herbicide applications in fallow often begin in mid- to late May in this region of Nebraska and Wyoming; therefore, growers would likely benefit from this level of weed control at the time of winter wheat planting from a herbicide applied 4 MBP.

Winter Wheat Response to Aminocyclopyrachlor. When data from the Lingle site and both Sidney sites were combined for analysis, there was a significant location by aminocyclopyrachlor rate interaction ($P < 0.01$). No interaction was observed when data from both Sidney locations were combined. Therefore the Sidney data were combined over years for analysis, and the Lingle data were analyzed separately. At Sidney, the effects of application timing and aminocyclopyrachlor rate were both significant ($P < 0.001$), but the interaction between the two factors was not ($P = 0.7696$). The two-parameter log-logistic model (Equation 1) resulted in the lowest AICc, and therefore the best fit to the yield data at Sidney. Since both application timing and aminocyclopyrachlor rate were significant at this location, the effect of aminocyclopyrachlor rate on winter wheat yield loss was analyzed for each application timing (Figure 3). The greatest wheat yield reduction was observed when aminocyclopyrachlor was applied 2 MBP, although differences in effective doses between 2 and 4 MBP were less than 5 g ha^{-1} (Table 2). Wheat yield at Sidney was greatest when aminocyclopyrachlor was applied 6 MBP, but loss still exceeded 10% compared to the nontreated control when the aminocyclopyrachlor rate was > 23 g ha^{-1} at this timing (Figure 3; Table 2).

The aminocyclopyrachlor rate required to cause a 10 or 20% yield loss when applied 2 or 4 MBP was estimated to be 12 g ha^{-1} or less (Table 2). Since 15 g ha^{-1} was the lowest (nonzero) rate used in this study, these estimates should be interpreted with caution. Although the yield loss estimates may be less accurate at these timings, based on these data it is indeed likely that a measurable yield loss would be expected at rates between 6 to 12 g ha^{-1} if applied within 4 months of planting. The aminocyclopyrachlor rate that caused a 50% winter wheat yield loss ranged from 20 to 61 g ha^{-1}, depending on whether the application was made 2 to 6 MBP, respectively.

At Lingle, there was a significant effect of aminocyclopyrachlor rate on winter wheat yield ($P < 0.001$), but the application timing effect was not significant ($P > 0.1$). Consequently, nonlinear regression models were fit to yield data at this location when averaged over application timings (Figure 4). Equation 2 resulted in a lower AICc, and thus a better fit, to the Lingle yield data compared to the log-logistic model. Two versions of Equation 2 were fit, the first for which the $Y_{\max}$ parameter (or theoretical maximum yield loss) was constrained to 100, and the second for which the $Y_{\max}$ parameter was estimated. AICc values for these two models

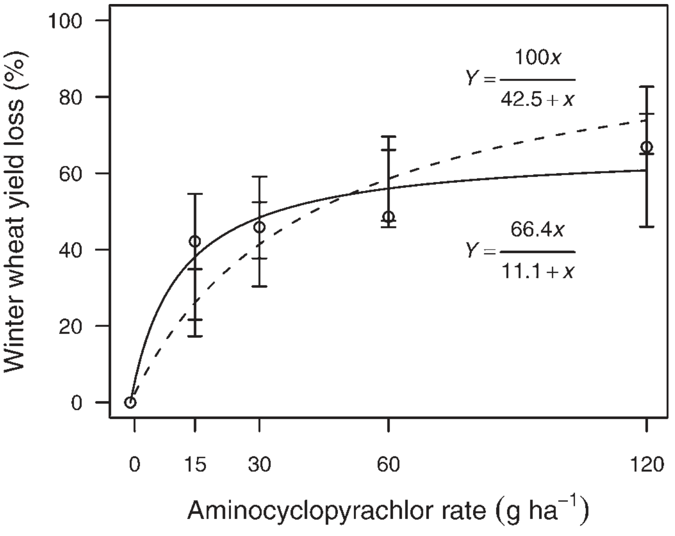

Figure 4. Winter wheat yield loss compared to the nontreated control resulting from aminocyclopyrachlor averaged over three application timings, Lingle, WY, 2009. Data were fit to Equation 2 with $Y_{\max}$ constrained to 100 (dotted line) or estimated (solid line). Bars represent the standard error associated with the model predicted response for each aminocyclopyrachlor rate.

Table 3. Aminocyclopyrachlor rate required to cause 10, 20, and 50% winter wheat yield losses when averaged over three application timings, Lingle, WY, 2009.

Model	Aminocyclopyrachlor rate (standard error in parentheses)		
	10% yield loss	20% yield loss	50% yield loss
	g ha^{-1}		
Model 1: upper limit = 100	5 (1.1)	11 (2.4)	43 (9.6)
Model 2: upper limit = 66.4	2 (1.6)	5 (4.0)	34 (28.1)

were 526.6 and 525.0, respectively. Based on the AICc statistic, the second model (for which $Y_{\max}$ was estimated) would be preferred. However, constraining the yield loss to 100% provides a more biologically meaningful model. The different values of $Y_{\max}$ resulted in a wide variation in the K parameter, which represents the aminocyclopyrachlor rate that will cause 50% of the maximum theoretical yield loss. However, when the rate required to cause a 50% wheat yield reduction compared to the nontreated control was extracted from the model, the values ranged from 34 to 43 g ha^{-1} (Table 3). Since both models provided similar yield loss estimates, it can be assumed that these estimates are fairly reliable. Similar to the Sidney location, the aminocyclopyrachlor rate required to cause 10 or 20% yield loss was estimated to be less than 12 g ha^{-1} when averaged over application timings at Lingle.

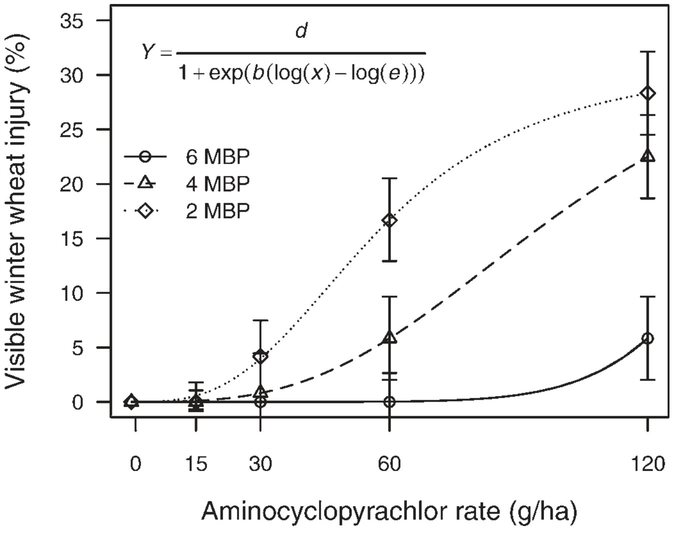

Figure 5. Winter wheat injury in response to aminocyclopyrachlor applied at 6, 4, or 2 mo before planting (MBP) averaged over two experiments at Sidney, NE. Bars represent the standard error associated with the model predicted response for each aminocyclopyrachlor rate. Parameter estimates (with standard errors in parentheses) as described in Equation 1: 6 MBP, d = 56.9 (nonestimable), b = −6.3 (20.6), e = 169.0 (nonestimable); 4 MBP, d = 35.1 (58.6), b = −3.2 (3.7), e = 100.0 (125.4); 2 MBP, d = 31.5 (4.5), b = −3.0 (0.94), e = 57.6 (8.6).

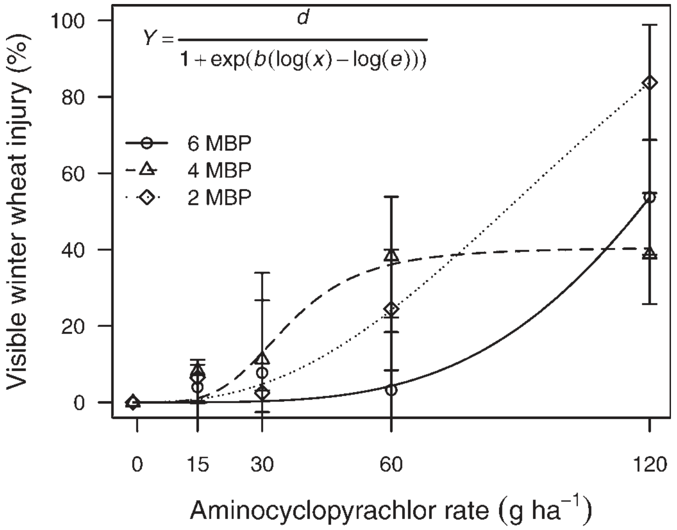

Figure 6. Winter wheat injury in response to aminocyclopyrachlor applied at 6, 4, or 2 mo before planting (MBP) at Lingle, WY, 2009. Bars represent the standard error associated with the model predicted response for each aminocyclopyrachlor rate. Parameter estimates (with standard errors in parentheses) as described in Equation 1: 6 MBP, d = 301 (2522), b = −3.9 (4.3), e = 177 (523); 4 MBP, d = 41 (8.6), b = −4.1 (5.6), e = 36 (8.1); 2 MBP, d = 176 (754), b = −2.5 (4.4), e = 125 (413).

A significant application timing by aminocyclopyrachlor rate interaction effect was observed for crop injury when averaged over both years at Sidney ($P < 0.001$) and at Lingle ($P < 0.05$). Crop injury was variable at both locations (Figures 5 and 6). Crop injury estimates were generally much lower than the yield losses. For example, at the 30 g ha^{-1} rate of aminocyclopyrachlor, crop injury averaged less than 5% at Sidney (Figure 5), and less than 15% at Lingle (Figure 6); however, yield losses at this application rate exceeded 40%, except at the 6 MBP application timing at Sidney. Field observations were consistent with this discrepancy because winter wheat generally looked healthy throughout the season. However, when the trials were harvested, it became evident that very little seed was actually produced. Auxin has been described previously by many workers as important in fruit and seed development (Gillaspy et al. 1993; Taiz and Zeiger 2002). One commercial use of auxin is the induction of parthenocarpy (seedless fruit production) by applying auxin to nonpollinated flowers (Taiz and Zeiger 2002). Gillaspy et al. (1993) reviewed several articles that link increased auxin levels in the ovules or ovaries to parthenocarpic fruit development. They concluded that it is likely an accumulation of auxin in the ovary will cause initiation of fruit development without fertilization. A similar mechanism may have been involved in these field studies, in which the presence of the pyrimidine herbicide aminocyclopyrachlor in the developing wheat head may have caused the initiation of fruit production prior to fertilization. Such an initiation would prevent seed production in an otherwise normal-looking wheat plant. Future research in this area may be warranted to elucidate the mechanism by which seed production is inhibited.

When the injury evaluation was zero, wheat yield loss ranged from negative values (when plots yielded greater than the mean for nontreated control) up to nearly 90% (Figure 7). As crop injury increased, yield losses increased, particularly at the two Sidney locations. At all three sites, a 20% yield loss was predicted when crop injury estimates were

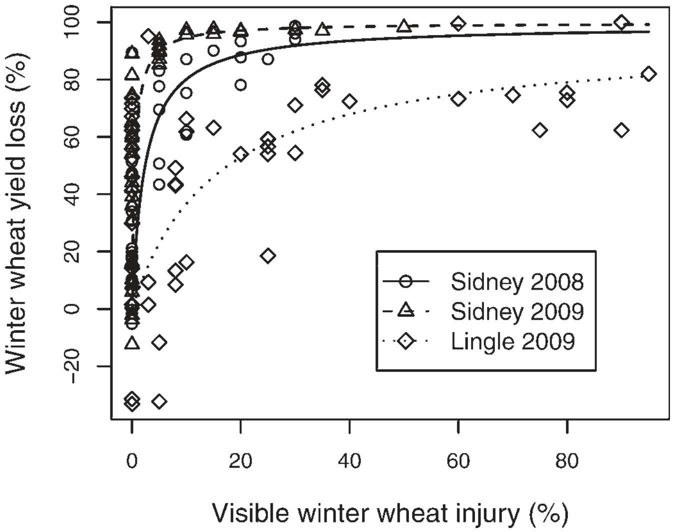

Figure 7. Relationship between winter wheat yield loss and injury symptoms in response to aminocyclopyrachlor applied prior to wheat planting for three field experiments. Parameter estimates (and standard errors) as described in Equation 2: Sidney 2008, $Y_{\max} = 99$ (19.4), $K = 2.4$ (2.42); Sidney 2009, $Y_{\max} = 100$ (15.5), $K = 0.55$ (1.34); Lingle 2009, $Y_{\max} = 95$ (19.2), $K = 16$ (9.5).

less than 5%. A wheat injury rating of 5% corresponded to yield losses of 67, 90, and 23% at Sidney in 2008, Sidney in 2009, and Lingle in 2009, respectively. Similarly, a 10% wheat injury rating corresponded to yield losses of 80, 95, and 37%. Individual bias may have played a role in the differences between Sidney and Lingle locations because these trials were evaluated by different authors (Donald 2006). Other possible explanations for the differences between the Sidney and Lingle locations include soil characteristics (such as soil pH and organic matter) or wheat growth stage at the time of the final injury evaluation.

The results of this research indicate that although residual weed control can be achieved, the potential for aminocyclopyrachlor to injure winter wheat is too great. The lack of visible injury symptoms in winter wheat makes the use of aminocyclopyrachlor in fallow systems particularly risky. This injury potential is notable because the winter wheat crop may exhibit little to no visual injury symptoms prior to head emergence or harvest. A soil bioassay to determine whether enough soil residual aminocyclopyrachlor remains to cause winter wheat yield reduction will be quite difficult, unless another sensitive species is used that shows injury symptoms much earlier in its life cycle. However, there are certain scenarios in which low foliar injury symptoms and high seed inhibition may be useful. These scenarios include suppression of annual grass weeds in a perennial grass stand such as downy brome (*Bromus tectorum* L.) in Western rangelands, or establishment of perennial grasses on disturbed lands where seed production may not be a necessity for establishment. Rinella et al. (2010) recently demonstrated in the greenhouse that a similar approach may be successful at reducing Japanese brome seed production by applying dicamba and picloram postemergence. The soil residual properties of aminocyclopyrachlor may offer advantages compared to postemergence herbicides for this use.

Sources of Materials

[1] DPX-KJMM44 (aminocyclopyrachlor-methyl ester), DuPont Crop Protection, Wilmington, DE 19805.

[2] Flat fan nozzles, TeeJet XR110015, Spraying Systems Co., Wheaton, IL 60189.

[3] Roundup UltraMax, Monsanto Company, St. Louis, MO 63167.

[4] Flat fan nozzles,TeeJet DG110015, Spraying Systems Co., Wheaton, IL 60189.

[5] Roundup WeatherMax, Monsanto Company, St. Louis, MO 63167.

Acknowledgments

The authors wish to recognize Robert Higgins and David Claypool for their able assistance in conducting these field studies. Partial financial support for this work was provided by DuPont Crop Protection, as well as funds provided through Hatch Act, USDA.

Literature Cited

Cousens, R. 1985. A simple model relating yield loss to weed density. Ann. Appl. Biol. 107:239–252.

Derksen, D. A., R. L. Anderson, R. E. Blackshaw, and B. Maxwell. 2002. Weed dynamics and management strategies for cropping systems in the northern Great Plains. Agron. J. 94:174–185.

Donald, W. W. 2006. Between-observer differences in relative corn yield vs. rated weed control. Weed Technol. 20:41–51.

Finkelstein, B. L., R. G. Armel, S. A. Bolgunas, D. A. Clark, J. S. Claus, R. J. Crosswicks, C. M. Hirata, G. J. Hollinghaus, M. K. Koeppe, P. L. Rardon, V. A. Wittenbach, and M. D. Woodward. 2009. DuPont DPX-MAT28 herbicide. Technical Bulletin. Reorder No.: K15023. E.I. du Pont de Nemours and Company. 8 p.

Gillaspy, G., H. Ben-David, and W. Gruissem. 1993. Fruits: a developmental perspective. Plant Cell 5:1439–1451.

Heap, I. 2010. The International Survey of Herbicide Resistant Weeds. http://www.weedscience.org. Accessed: March 4, 2010.

Montgomery, D., C. Evans, and D. Martin. 2009. Control of kochia with DPX-KJM44 along Oklahoma highway rights-of-way. Proc. Weed Sci. Soc. Am. 49:493.

Nielsen, D. C., M. F. Vigil, R. L. Anderson, R. A. Bowman, J. G. Benjamin, and A. D. Halvorson. 2002. Cropping system influence on planting water content and yield of winter wheat. Agron. J. 94:962–967.

R Development Core Team. 2009. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing, http://www.R-project.org.

Rinella, M. J., M. R. Haferkamp, R. A. Masters, J. M. Muscha, S. E. Bellows, and L. T. Vermeire. 2010. Growth regulator herbicides prevent invasive annual grass seed production. Invasive Plant Sci. Manag. 3:12–16.

Ritz, C. and A. N. Spiess. 2008. qpcR: an R package for sigmoidal model selection in quantitative real-time polymerase chain reaction analysis. Bioinformatics 24:1549–1551.

Ritz, C. and J. C. Streibig. 2005. Bioassay analysis using R. J. Statistical Software 12(5). http://www.jstatsoft.org/.

Seefeldt, S. S., J. E. Jensen, and E. P. Feurst. 1995. Log-logistic analysis of herbicide dose-response relationships. Weed Technol. 9:218–227.

Spiess, A. N. and N. Neumeyer. 2010. An evaluation of R^2 as an inadequate measure for nonlinear models in pharmacological and biochemical research: a Monte Carlo approach. BMC Pharmacol. 10:6. http://www.biomedcentral.com/1471-2210/10/6.

Taiz, L. and E. Zeiger. 2002. Auxin: The Growth Hormone. Pages 423–460 *in* L. Taiz and E. Zeiger. Plant Physiology. 3rd ed. Sunderland, MA: Sinauer Associates.

[USDA-ERS] U.S. Department of Agriculture Economic Research Service. 2007. Major Land Uses. http://www.ers.usda.gov/data/majorlanduses/. Accessed: February 25, 2010.

Vassios, J. D., C. Douglass, M. Bridges, B. Lindenmayer, and S. Nissen. 2009. Native grass tolerance to aminopyralid and DPX-KJM44. Proc. Weed Sci. Soc. Am. 49:153.

Westra, P., R. Wilson, and M. Edwards. 2008. Agronomic crop responses to KJM-44 herbicide. Proc. Western Soc. Weed Sci. 61:62.

Westra, P., S. Nissen, D. Shaner, B. Lindenmayer, and G. Brunk. 2009. Invasive weed management with aminocyclopyrachlor in the Central Great Plains. Proc. Weed Sci. Soc. Am. 49:407.

Received March 23, 2010, and approved October 26, 2010.