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Spring Wheat (*Triticum aestivum*) Management Can Substitute for Diclofop for Foxtail (*Setaria* spp.) Control[1]

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Abstract. **The goal of this research was to determine whether crop management practices could substitute for a herbicide for managing mixed populations of green and yellow foxtail in hard red spring wheat. Crop yield and foxtail growth were measured in two years of field research in North Dakota. Spring wheat yields were as great or greater when early seeding date or 2× seeding rate were substituted for POST diclofop[3] at 0.75 kg ai ha^{-1} for managing foxtail in spring wheat. Yield of spring wheat competing with foxtails was greater for the high seeding rate (2× = 270 kg ha^{-1}) than both the normal (1× = 130 kg ha^{-1}) and low (0.5× = 70 kg ha^{-1}) seeding rates for early or middle seeding dates, but not for the late seeding date. For both early and middle seeding dates, wheat yield at the 2× seeding rate without diclofop was equal to or greater than that of the 1× seeding rate with diclofop. Late-seeded wheat did not yield well in competition with dense foxtail stands for any treatment combination. Early and middle seeding dates favored the relative increase of green foxtail over yellow foxtail in wheat, whereas late seeding favored yellow foxtail over green foxtail. Economic analysis demonstrated that early seeding date was the most critical factor in determining the stochastic dominance of treatments without diclofop over treatments with diclofop. Seeding rate was much less important than seeding date in determining the ranking of treatments in stochastic dominance analysis. Nomenclature: Diclofop, (±)-2-[4-(2,4-dichlorophenoxy)phenoxy]propanoic acid; green foxtail, *Setaria viridis* (L.) Beauv. #[4] SETVI; yellow foxtail, *Setaria glauca* (L.) Beauv. # SETLU; spring wheat, *Triticum aestivum* L. 'Wheaton.'**

Additional index words: **Crop management, economics, planting, seeding rate, seeding date, stochastic dominance, sustainable agriculture, diclofop.**

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[3]Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

[4]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821-3133.

INTRODUCTION

Green and yellow foxtail are widespread annual grasses that can reduce spring wheat yield in the northern Great Plains of the United States (9, 10, 12) and Prairie Provinces of Canada (15). Foxtails generally reduce yield only at high density (≥ 100 to 1600 shoots/m^2) (8, 21).

Changing crop management has encouraged foxtail infestations to increase. Control of wild oat (*Avena fatua* L.) and broadleaf weed infestations with herbicides has created a void that favors foxtail infestations (2, 4). Increased use of chisel plowing, which has replaced moldboard plowing, also favors foxtail establishment (13). Before 2,4-D [(2,4-dichlorophenoxy)acetic acid] was introduced, broadleaf weeds were managed by adjusting wheat seeding dates and rates, thus increasing crop competitiveness with weeds (6, 13, 14).

When weather conditions delay spring wheat seeding, late seeded wheat often does not establish quickly or well enough to compete against dense green foxtail infestations (13, 22). Under these conditions, foxtails emerge with wheat and grow more quickly under the warm conditions experienced by late seeded spring wheat (22). For example, in competition with green foxtail, spring wheat planted in early May yielded more than when seeded in late May or early June in Saskatchewan (22). In contrast, wheat seeding date was not correlated with green foxtail competition in Manitoba (8).

Greater than normal seeding rates controlled weeds and increased spring wheat yield limited by weed competition (7, 14). Wheat yield increased 16% when seeding rate was increased from 80 to 120 kg ha^{-1} without other weed control measures, but yield increased 35% when weeds were controlled by hand pulling (14). Conversely, in some studies, increasing wheat seeding rate from 70 to 120 kg ha^{-1} did not affect wheat yield or green foxtail shoot dry weight (1).

Published studies of foxtail control deal with the effect of wheat seeding date (5, 8, 22), wheat seeding rate (1, 6, 13), and herbicides (3, 11, 20) alone. Green foxtail is highly susceptible to diclofop applied to young seedlings, even at below label rates (20). The effect of combining these management practices on wheat yield and foxtail control needs to be studied to help improve the profitability of producing wheat by reducing reliance on external inputs. In addition, most published studies of foxtail control in wheat have concerned green foxtail (1, 2, 8), not yellow foxtail.

The objectives of the research were: a) to determine the extent that wheat seeding date and seeding rate can substitute for diclofop to control dense mixed stands of green and yellow foxtail and b) to conduct economic analysis involving ranking the profitability of these alternative foxtail management strategies.

Table 1. Dates of field operations or observations.

	Seeding date					
	1986			1987		
Observation	Early	Middle	Late	Early	Middle	Late
Field cultivated and harrowed	5/14	5/18	6/12	4/28	5/14	5/31
Seeded and fertilized	5/16	5/29	6/13	4/29	5/15	6/2
Observed foxtail emergence	5/7–7/3	5/7–7/3	5/7–7/3	5/4–6/30	5/4–6/30	5/4–6/30
Applied MCPA plus bromoxynil	6/30	6/30	7/7	—	—	—
Applied 2,4-D	—	—	—	6/15	6/15	6/15
Applied difenzoquat	6/17	6/17	6/17	6/15	6/15	6/15
Applied diclofop	6/24	6/30	6/30	6/19	6/19	6/22
Determined foxtail density and shoot dry weight	8/23–8/24	8/25–8/26	8/25–8/26	8/3	8/8	8/22
Harvested wheat	8/27	8/27	—[a]	8/5	8/10	8/24

[a]Excessive rain prevented harvest.

MATERIALS AND METHODS

Agronomic practices. The treatments were wheat seeding date (early, middle, and late compared to normal seeding dates) and seeding rate (0.5× = 70 kg ha^{-1}, 1× = 130 kg ha^{-1}, and 2× = 270 kg ha^{-1}) as main plots, and diclofop rate (0 and 0.75 kg ha^{-1}) as subplots. Seeding dates were chosen to bracket when farmers seeded in 1986 and 1987 in eastern North Dakota based on seeding progress reports. In general, spring wheat is usually seeded between May 1 (early seeding) and June 10 (late seeding) in eastern North Dakota, but yields decrease when wheat is seeded after May 20 (middle seeding) even without weed competition (10). Usually a shorter growing season, high temperature, and water stress near crop maturity are factors that presumably limit yield potential of late-seeded spring wheat (13).

The experiment was a randomized complete block design with three replications (blocks) in a split-plot arrangement. Subplots measured 3 by 7 m.

Field experiments were conducted in 1986 and 1987, 5 km north of Fargo on a Fargo silty clay (fine, montmorillonitic, frigid vertic Haplaquolls) with 2.5% sand, 51.7% silt, 45.8% clay, 4.5% organic matter, and pH of 7.9. The site was chisel plowed in fall and was field cultivated and harrowed for seedbed preparation in spring (Table 1).

'Wheaton' hard red spring wheat seed was treated with carboxin[5] (5,6-dihydro-2-methyl-1,4-oxathiin-3-carboxanilide) plus thiram (tetramethylthiuram disulfide) at 100 g per 45 kg of seed. Wheat was seeded 8-cm deep in 17.5-cm-wide rows with a double disc grain drill[6]. Phosphorus was side banded with the seed and nitrogen was deep banded between rows at rates recommended by soil test for a yield goal of 3300 kg ha^{-1}.

Broadleaf weeds and wild oats were controlled with herbicides so that management effects on foxtail control could be studied (Table 1). Diclofop at 0 and 0.75 kg ha^{-1} was applied to subplots separately from broadleaf herbicides. Herbicides were applied with a bicycle wheel sprayer at a speed of 5 km h^{-1} and a spray volume of 130 L ha^{-1} with flat fan nozzles[7] at 210 kPa.

Measurements. Foxtail plant emergence in nontreated check plots was determined at 2- to 3-d intervals between May 27 and July 3, 1986, and between May 4 and June 30, 1987, in three randomly placed circular quadrats (0.2 m^2) per subplot. Three to 4 d before wheat harvest, three circular quadrats (0.2 m^2) were randomly placed once in each plot, and all foxtail plants in each quadrat were counted, clipped, cleaned of adhering soil, and separated into green and yellow foxtails. Plants were oven-dried at 70 C for 72 h, and total shoot dry weight m^{-2} was determined.

Grain was harvested in a 1.4 by 7 m area with a small plot combine[8] (Table 1). Prolonged rains prevented harvest of the late seeding in 1986. Wheat yield was calculated after seed cleaning and grain moisture was adjusted to 13%.

Statistical analysis. Data were subjected to analysis of variance[9]. Data are presented separately for each year because there were significant year by treatment interactions. Path correlation coefficient analysis was used to model the relative contributions of wheat density and total green plus yellow foxtail shoot density and dry weight (predictor variables) to variation in wheat yield (response variable) (18). Correlation and regression subroutines were used for calculating standardized partial correlation coefficients (p) and simple correlation coefficients (r). Each data set for each year were separately subjected to path correlation coefficient analysis, and direct and indirect effects were estimated for the path diagram chosen.

Economic analysis. The primary objective of the economic analysis was determining if early seeding dates or higher seeding rates without diclofop were economically superior to similar treatments with diclofop. Superiority is evaluated by ranking distributions of net return ha^{-1} for all treatments using stochastic dominance with respect to a function (SDWF)[10]. This approach involves pairwise comparisons of cumulative net return prob-

[5]Vitavax-200. Uniroyal Chemical Company, Inc., World Headquarters, Middlebury, CT 06740.

[6]Haybuster 107 double disc drill with deep banding nitrogen attachment. Haybuster Manufacturing, Inc., Jamestown, ND 58401.

[7]Teejet flat fan spray nozzle 8001 from Spraying Systems Co., Wheaton, IL 60187.

[8]Hege Equipment, Inc., Colwich, KS 67030.

[9]SPSS/PC$^+$ ver. 4.0 (MANOVA subroutine), SPSS Inc., 444 N. Michigan Ave., Chicago, IL 60611.

[10]Abbreviations: SDWF = stochastic dominance with response to a function.

ability distributions for a particular set of alternative treatments. SDFW ranks risky alternatives that fall within an interval defined by upper and lower risk aversion coefficients (23). The rankings of distributions are then used to determine whether treatments with diclofop dominate treatments without diclofop.

Net return ha^{-1} for all treatments was estimated as follows:

$$NR_{ijkt} = P_t * Y_{ijkt} - CS_{jt} - CF_t - CD_t$$

where NR_{ijkt} is the net return to land, management and production inputs other than seed, fertilizer and herbicide and Y_{ijkt} is yield ha^{-1} for wheat with seeding date i, seeding rate j and diclofop rate k in year t. P_t is the market price of wheat in year t, CS_{jt} is the per hectare cost of treated seed with seeding rate j in year t, CF_t is the per hectare cost of fertilizer (urea and/or phosphate) in year t, and CD_t is the per hectare cost of diclofop applied at rate k in year t. Costs for wild oat and broadleaf weed control herbicides were ignored. Subscripts i, j, k, and t represent: i = 1, 2, 3 for early, middle, and late seeding dates, respectively; j = 1, 2, 3 for seeding rates of 70, 130, and 270 kg ha^{-1}, respectively; and k = 1 is for the zero rate of diclofop and k = 2 is for a diclofop rate of 0.75 kg ha^{-1}.

Unit prices of wheat, seed, urea, phosphate, and diclofop and custom application rates for fertilizer and herbicide used to calculate net returns ha^{-1} are given in Table 2. Most unit prices and costs are for the Red River Valley in North Dakota.

Stochastic dominance analysis. SDWF is a nonparametric method that compares several distributions of a particular variable (16, 17, 23). SDWF ranks the distributions for decision makers having risk preferences that fall within an interval defined by upper and lower risk aversion coefficients (23). SDWF is used to rank distributions of net return ha^{-1} for all treatments at three risk aversion intervals: [–0.005, 0.005] for risk neutrality, [0.005, 0.025] for moderate risk aversion, and [0.025, 0.049] for strong risk aversion. These risk aversion coefficients are larger than ones commonly used in SDWF applications because the return units for this analysis are in \$ ha^{-1} rather than \$ per farm. Eighteen net return distributions are ranked. Nine of the distributions are for treatments without diclofop and the other nine distributions are for treatments with diclofop. Both sets of nine distributions are made up of three seeding dates each with three seeding rates. Since the experiment has three replications for each treatment and two years of data, there are six observations for each of the 18 distributions.

Table 2. Unit prices and costs for estimating net return ha^{-1} (\$).

Expenditure	Units	Prices and costs in 1986	1987
Wheat	\$ kg^{-1}	0.094	0.104
Seed treatment	\$ kg^{-1}	0.242	0.242
Urea fertilizer	\$ kg^{-1}	0.507	0.507
Phosphate fertilizer	\$ kg^{-1}	0.463	0.441
Fertilizer application	\$ ha^{-1}	6.84	6.84
Diclofop	\$ kg a.e.$^{-1}$	33.07	32.34
Herbicide application	\$ ha^{-1}	14.82	14.82

RESULTS AND DISCUSSION

Spring wheat yield. Wheat seeding date was more important than seeding rate for achieving the greatest yields in competition with green and yellow foxtail infestations without diclofop treatment (Figures 1 and 2). As seeding date was delayed past the mid-seeding, yield of foxtail-infested wheat decreased for all seeding rates. Increasing wheat seeding rate generally increased yield within a seeding date. Nevertheless, increasing seeding rate at the late seeding date did not compensate for the low yield potential of late-seeded wheat. In 1986, early seeded wheat yielded 1690, 1110, and 1040 kg ha^{-1} at 2×, 1×, and 0.5× seeding rates, respectively, in competition with foxtails. In 1987, early seeded wheat produced 2100, 1420, and 1150 kg ha^{-1} at the 2×, 1×, and 0.5× seeding rates, respectively.

Combining early seeding with the 2× seeding rate substituted for herbicide treatment to achieve maximum yield in competition with foxtails (Figures 1 and 2). In both years, yields for early- and middle-seeded wheat at the 2× seeding rate without diclofop were greater than seeding at the 1× rate plus diclofop. Diclofop control of foxtails increased yield above that of nontreated wheat for early-seeded wheat at 0.5× and 1× seeding rates, but not at the 2× seeding rate. Diclofop also increased yield of middle-seeded wheat at the 0.5× and 1× seeding rates in 1986 and at the 1× seeding rate in 1987. Late-seeded wheat could not be harvested in 1986 due to delayed maturity and untimely rainfall. Diclofop treatment tended to increase yield of late-seeded wheat at two of three seeding rates in 1987, although yields were greatly reduced compared to earlier seeding dates (Figure 2).

Spring wheat density. In both years, wheat density increased as seeding rate increased within a seeding date (Figures 1 and 2). Wheat yield responded in a similar fashion in competition with foxtails. Wheat density decreased as seeding was delayed for all seeding rates in 1986 (Figure 1), but not in 1987 (Figure 2). In 1987, wheat density for the middle seeding was greater than the early seeding. In 1987, a warm postseeding period with greater than average rainfall probably favored wheat emergence after the middle seeding date (top two panels of Figure 3). Wheat seeding began 2 wk earlier in 1987 than in 1986 because May 1987 was warmer than 1986 (Figure 3). May temperature in 1986 was similar to the 30-yr average (13.5 C), whereas May temperature in 1987 was greater than average (16 C). Total May rainfall was greater in 1987 than in 1986 (8.4 versus 3.5 cm), but June rainfall in 1987 was much less than the 30-yr average (8.6 cm). In both years, high temperatures during the late seeding probably reduced wheat emergence (7).

Foxtail emergence and density. Generally, foxtail densities measured at harvest (Figures 1 and 2) were much greater than in commercial fields surveyed before harvest (9). Maximum densities reached soon after emergence (Figure 3) were greater than maximum densities recorded shortly before wheat harvest (Figures 1 and 2) because foxtail populations suffered mortality after peaking early in the growing season. The greatest mean foxtail densities soon after emergence were about 500 and 3000 plants m^{-2} in 1986 and 1987, respectively (Figure 3).

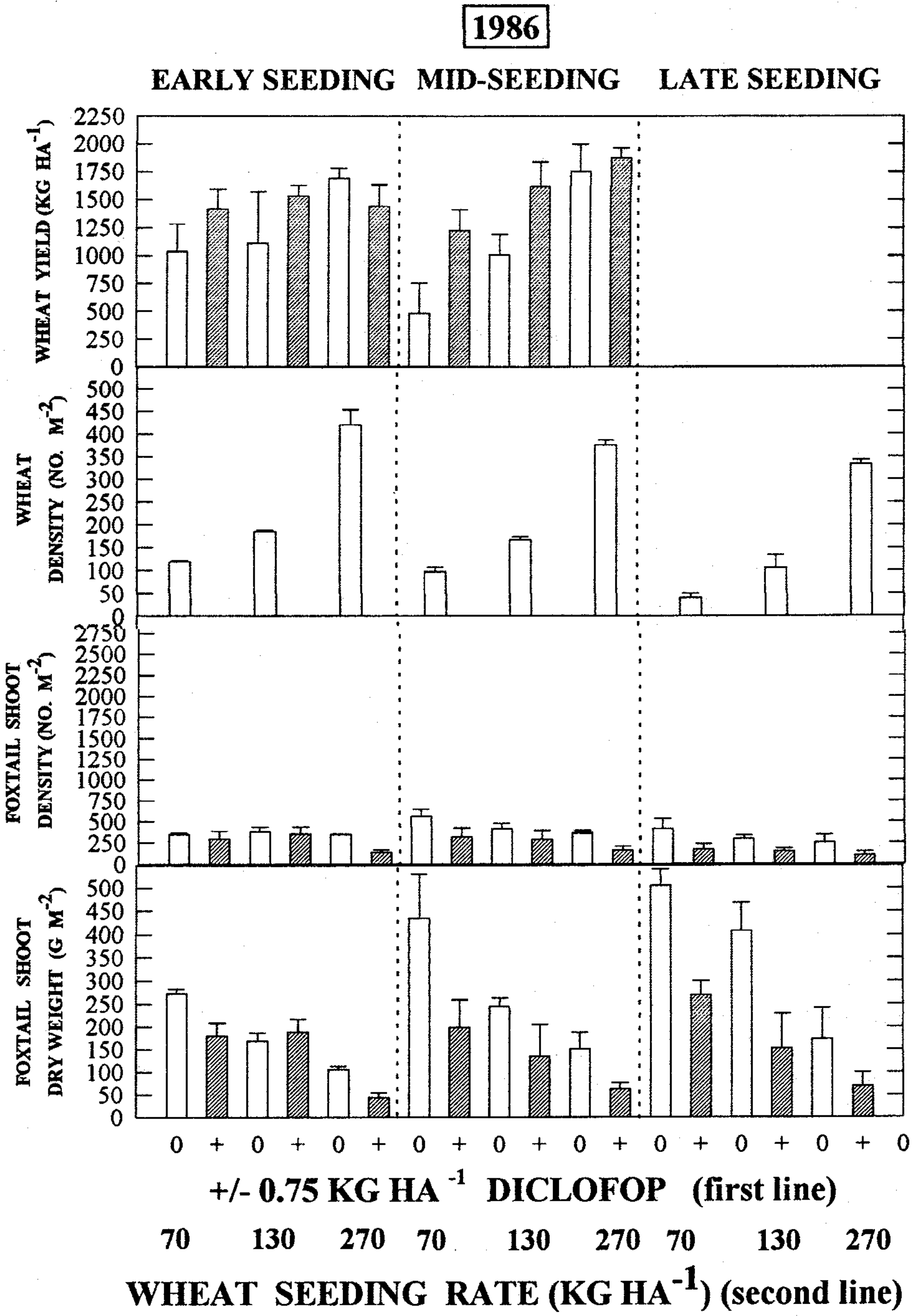

Figure 1. Effect of spring wheat seeding date, seeding rate, and diclofop treatment on spring wheat yield and density and total green plus yellow foxtail shoot density and dry weight in 1986. Wheat stand was measured early in the growing season, whereas the foxtail measurements were made shortly before wheat harvest. Means ± standard errors are presented.

Foxtail density and emergence differed between years on the same site, probably because of differences in environmental conditions (Figure 3) and, possibly, the size of the foxtail seed bank. Foxtail density recorded after seeding was greater for early- and middle-seeded wheat than for late-seeded wheat. Foxtail emergence at the experimental site peaked after the soil temperature warmed sufficiently to permit germination and seed received enough moisture to germinate and emerge (Figure 3). Heavy rainfall preceded the major peak of foxtail emergence in both years, but especially in 1987. These observations support the suggestion that rainfall favors foxtail emergence more than air temperature (4, 7, 19, 21). Foxtail emergence in early- and

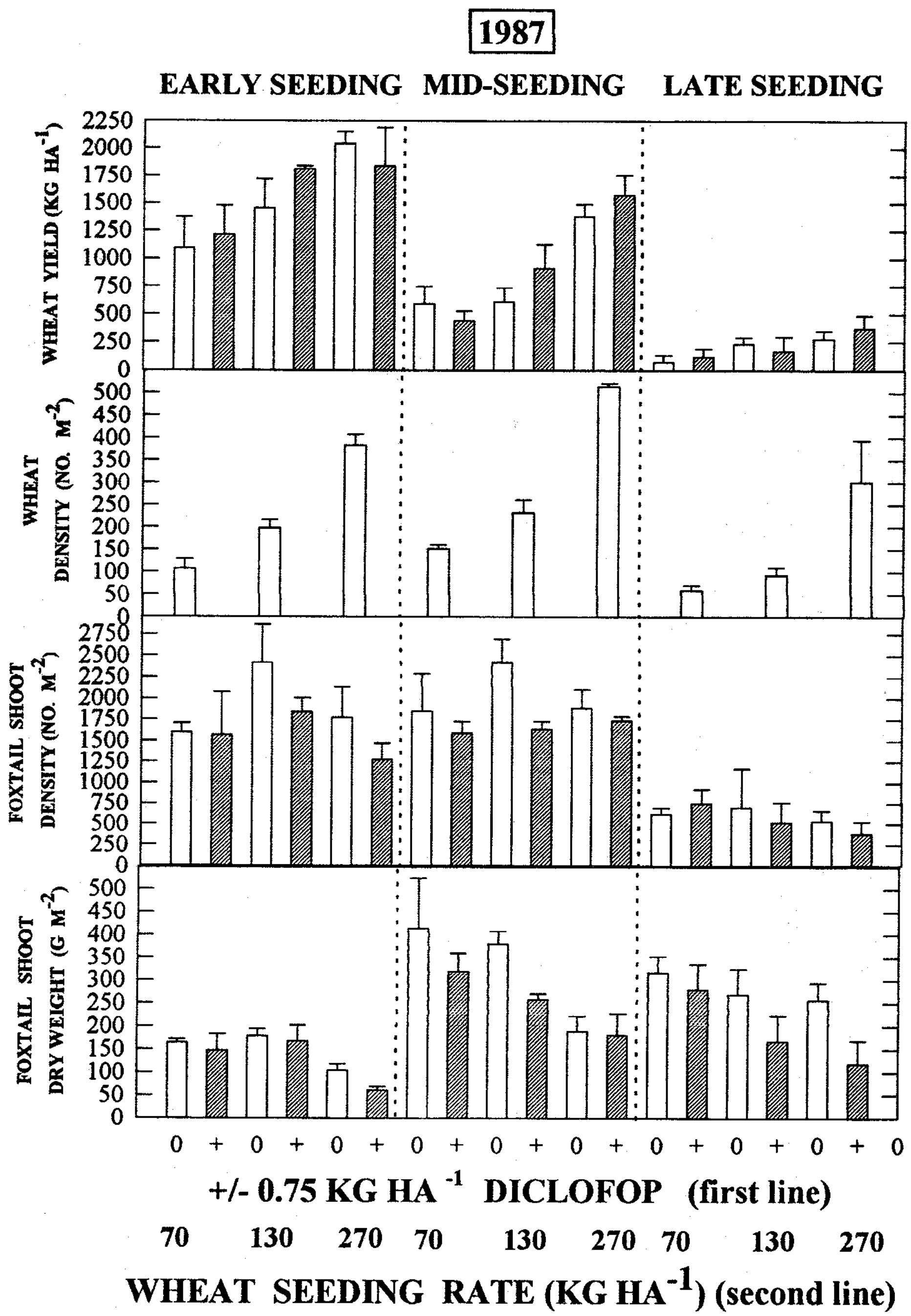

Figure 2. Effect of spring wheat seeding date, seeding rate, and diclofop treatment on spring wheat yield and density and total green plus yellow foxtail shoot density and dry weight in 1987. Wheat stand was measured early in the growing season, whereas the foxtail measurements were made shortly before wheat harvest. Means ± standard errors are presented.

middle-seeded wheat peaked after seedbed preparation, which normally kills emerged seedlings. In contrast, fewer foxtails successfully emerged after late-seeding wheat (Figure 3), probably because the soil foxtail seed bank near the soil surface was depleted after those seedlings emerging with the peak flush were killed by seedbed preparation.

The diclofop rate used was 3/4's of the registered rate. In both years, diclofop did not consistently decrease foxtail density compared to nontreated plots within the same wheat seeding date and rate (Figures 1 and 2). However, diclofop visibly damaged and stunted surviving foxtails, as reductions in shoot dry weight m^{-2} show. Foxtails may have received an insufficient dose to be

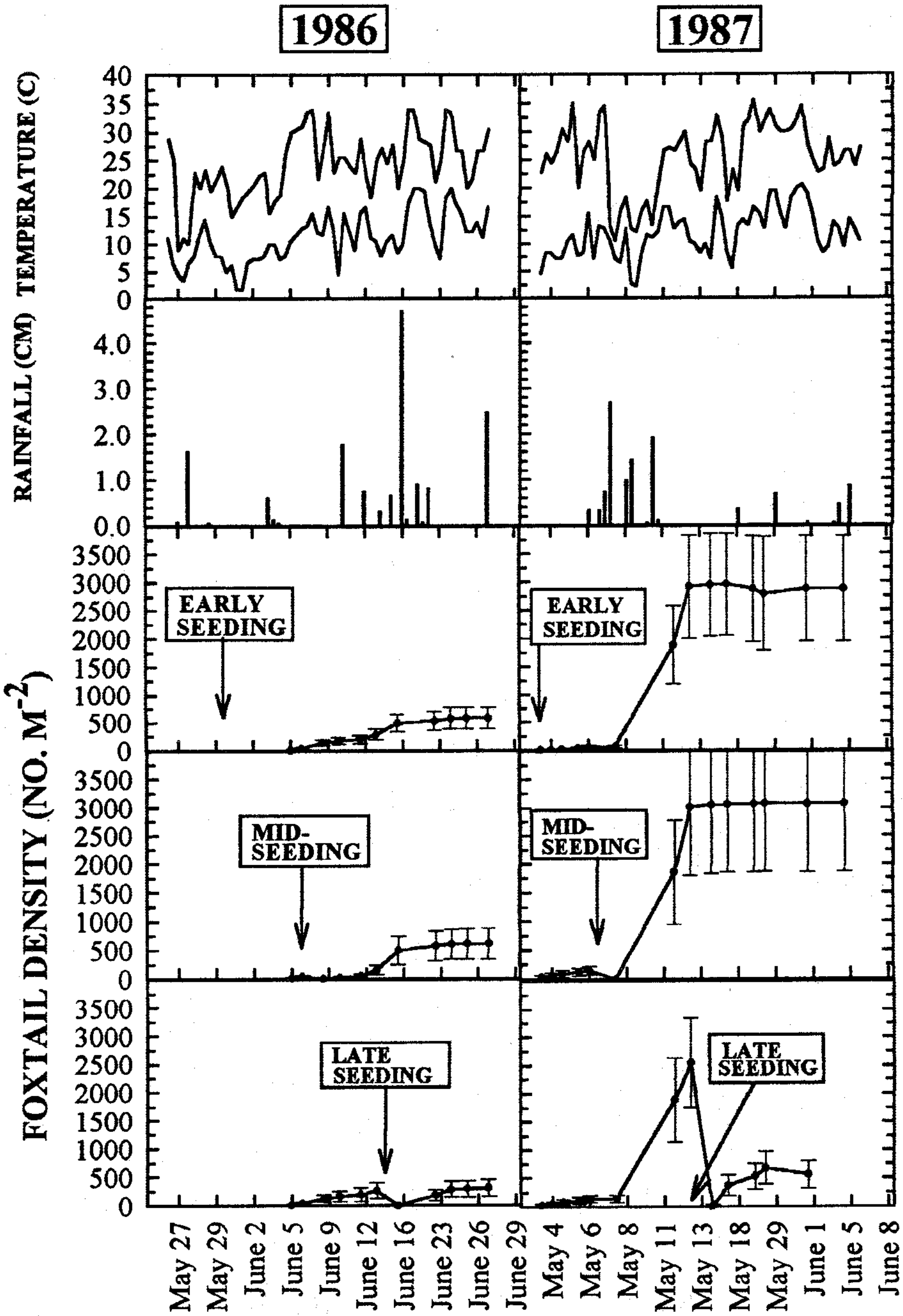

Figure 3. Maximum and minimum air temperature (top panel) and rainfall (second panel) early in the growing season near Fargo in 1986 and 1987. Data were obtained from the Hectar weather station approximately 5 km from the experimental site. The impact of spring wheat seeding date on total green plus yellow foxtail shoot emergence at about 3-d intervals early in the growing season in 1986 and 1987 averaged over spring wheat seeding rate (third to last panel for each progressively later wheat seeding date). Downward arrows show the seeding dates. Means ± standard errors are presented.

killed because the canopy of early- and middle-seeded wheat likely reduced spray coverage of foxtails. Diclofop reduced foxtail shoot dry weight more at mid-seeding at the low seeding rate than at higher seeding rates, presumably because of greater spray penetration and coverage of foxtail in a more open crop canopy. Because foxtails were sprayed at the four-leaf stage, they may have been more tolerant of diclofop than if sprayed earlier. In other research (20), foxtail control decreased and diclofop rates had to be increased to achieve acceptable control as diclofop application was delayed past the two- to three-leaf stage.

Foxtail shoot dry weight. In both years, foxtail shoot dry weight m^{-2} measured at wheat harvest was lowest for early-seeded

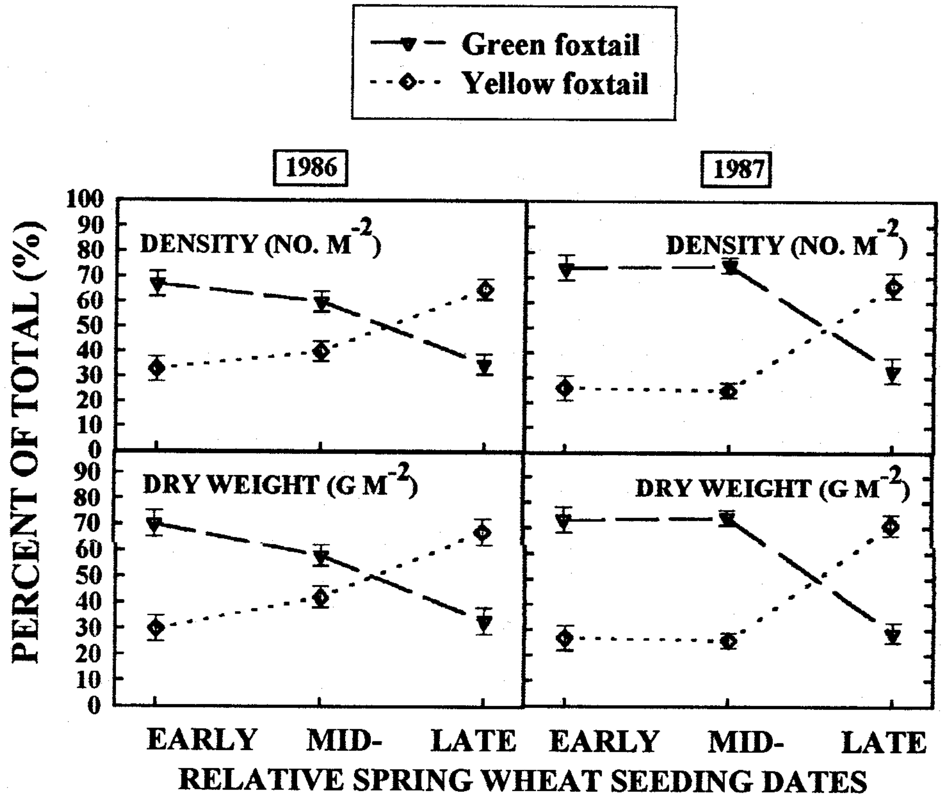

Figure 4. The impact of spring wheat seeding date on the relative proportion of green and yellow foxtail averaged over spring wheat seeding rates and diclofop treatments in 1986 and 1987. Means ± standard errors for foxtail shoot density and dry weight m^{-2} are presented.

wheat at the 2× seeding rate with diclofop (Figures 1 and 2). Foxtail shoot dry weight m^{-2} was greatest for late-seeded wheat at the 0.5× seeding rate without diclofop in 1986. In contrast, foxtail shoot dry weight m^{-2} was greatest for mid-seeded wheat at the 0.5× seeding rate without diclofop in 1987.

Early-seeded wheat reduced foxtail shoot dry weight m^{-2} more than late-seeded wheat within a seeding rate either with or without diclofop (Figures 1 and 2). Increasing wheat seeding rate also decreased foxtail shoot dry weight m^{-2} for the middle- and late-seeded wheat either with or without diclofop. However, increasing wheat seeding rate decreased foxtail shoot dry weight m^{-2} only between the 1× and 2× seeding rates for early-seeded wheat. Diclofop reduced foxtail shoot dry weight m^{-2} for all seeding rates for middle- and late-seeded wheat, but reductions were less consistent across seeding rate for early-seeded wheat (Figure 1 and 2).

Proportions of different foxtail species. In both years, early- or middle-wheat seeding dates favored green foxtail over yellow foxtail, whereas late-seeding date favored yellow foxtail over green foxtail whether density or shoot dry weight m^{-2} were measured (Figure 4). When both species are present in wheat, repeated use of delayed seeding may favor the buildup of yellow foxtail populations at the expense of green foxtail. Green foxtail was more widespread than yellow foxtail in wheat field surveys (9), perhaps because farmers seed early to increase yield.

Path correlation coefficient analysis. Foxtail control measures increased wheat yield through direct and indirect effects on wheat stand, foxtail density, and foxtail shoot dry weight m^{-2} (Figures 1 and 2). As expected, wheat yield was positively correlated with wheat stand and negatively correlated with either foxtail shoot density or dry weight (data not presented). However, such correlations do not identify which of these three *predictor variables* most influenced wheat yield, the *response variable.*

Path correlation coefficient analysis was conducted to determine which direct or indirect[11] predictor variables most influenced wheat yield (18). The path correlation coefficient diagram presented in Figure 5 and Table 3 are an a priori model of cause-and-effect relationships between these confounded variables. Unlike multiple regression analysis, path correlation coefficient analysis does not assume that model predictor variables are independent. Rather, changes in one predictor variable are

[11]Predictor variables can both directly and indirectly act on response variables. For example, wheat density can directly effect wheat yield via partial correlation coefficient p_{14}. Likewise, wheat density can indirectly effect wheat yield via its effect on foxtail density (r_{12}) which in turn directly effects wheat yield (p_{24}). The indirect effect of wheat density via foxtail density would be calculated as r_{12}*p_{24}.

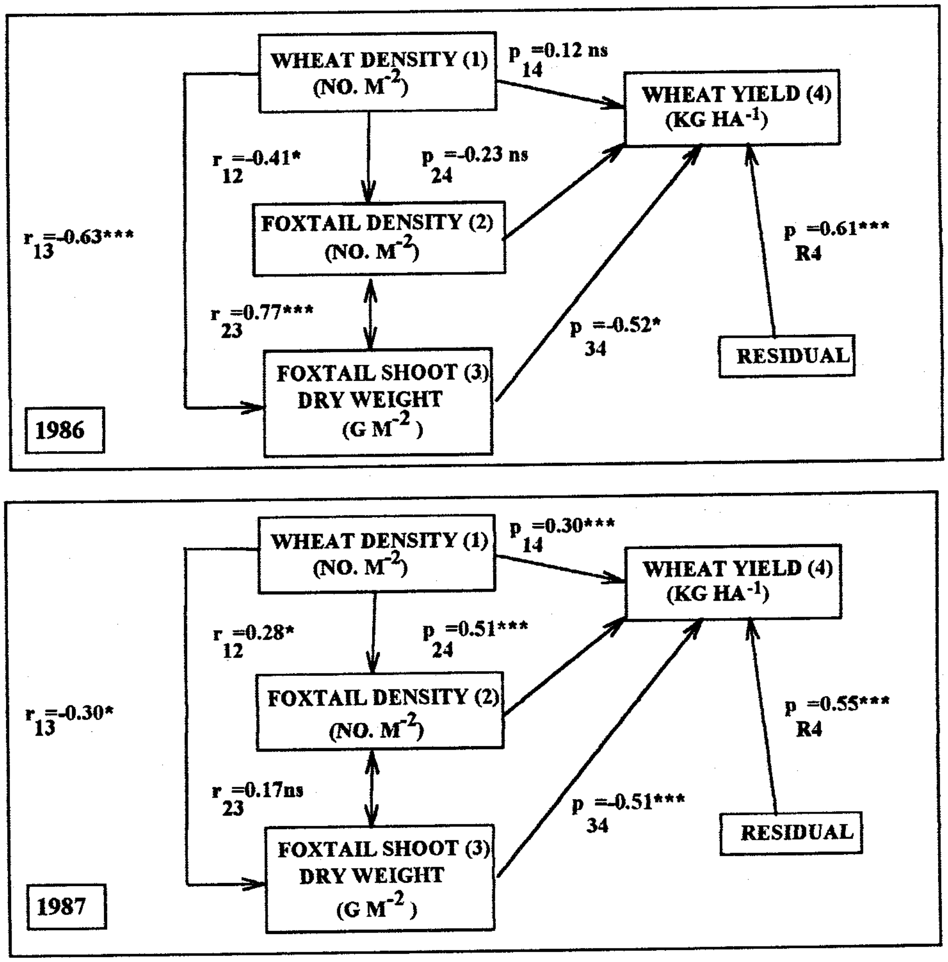

Figure 5. Path correlation coefficient diagram showing causal relationships between the three predictor variables, wheat shoot density (no. m^{-2}), foxtail shoot density (no. m^{-2}), and foxtail shoot dry weight (g m^{-2}), and the response variable, spring wheat yield (kg ha^{-1}). Note that not all causal relationship are bidirectional. p_{ij} are partial correlation coefficients and r_{ij} are correlation coefficients. The variable residual is the undetermined portion ($1 - R^2$).

assumed to cause changes in other predictor variables for a given data set, as hypothesized in the path correlation coefficient diagram (i.e., predictor variables are "confounded" and change in an interdependent compensatory way). The path correlation coefficient diagram in Figure 5 is subjective. However, such path correlation coefficient analysis relates likely cause-and-effect relationships between several interdependent variables in a way that simple correlation coefficients cannot. Arrows in the path correlation coefficient diagram between wheat density, foxtail density, and foxtail shoot dry weight m^{-2} are single headed because it is assumed that foxtail density and shoot dry weight do not influence wheat density (Figure 5). Arrows between foxtail shoot density and shoot dry weight are double-headed because changes in these two variables are assumed to compensate for one another (i.e., when foxtail are sparse, shoot weights per plant likely increase and when foxtail is dense, shoot weight per plant decreases).

The path coefficients for the direct effect of foxtail shoot dry weight m^{-2} on wheat yield (p_{34}) (Figure 5) were significant and negative both years, whereas the path coefficients for the direct effect of either wheat (p_{14}) or foxtail shoot density (p_{24}) on wheat yield were inconsistent (i.e., path correlation coefficients were nonsignificant in 1986 and positive in 1987) (Table 3 and Figure 5). Path correlation coefficient analysis also demonstrated that wheat stand had a significant negative indirect effect on wheat yield via foxtail shoot dry weight m^{-2} both years. The indirect effect of wheat stand on wheat yield via effects on foxtail density was inconsistent between years.

Economic analysis. Net returns with and without diclofop for different seeding rates and seeding dates are given in Table 4. The results of SDWF summarize the ranking of treatments for farmers with different preferences (Table 5). Most and least dominant treatments are reported for three farmer risk preferences: risk neutral, moderately risk averse, and highly risk averse. For risk-averse farmers, foxtail management practices that increase returns but also increase variability of returns are less attractive than those that increase returns somewhat less but also have lower variability of returns. Risk-averse farmers are

Table 3. Path correlation coefficient analysis of the relationships between spring wheat yield (kg ha^{-1}) and wheat density (no. m^{-2}), foxtail shoot density (no. m^{-2}), and foxtail shoot dry weight (g m^{-2}) for mixed stands of green and yellow foxtail near Fargo, N.D. See Figure 5 for the path correlation coefficient diagram and the text for an explanation of path correlation coefficient conventions.

Path of association[a]	1986[b]	1987[b]
Wheat density →[a] wheat yield		
Direct effect, p_{14}[b]	0.12 ns	0.30***
Indirect effect via foxtail shoot density, $r_{12}*p_{24}$	0.10	0.14
Indirect effect via foxtail shoot dry weight, $r_{13}*p_{34}$	0.33	0.14
Correlation coefficient, r_{14}	0.54***	0.59***
Foxtail shoot density → wheat yield		
Direct effect, p_{24}	−0.23 ns	0.51***
Indirect effect via foxtail shoot dry weight, $r_{23}*p_{34}$	−0.40	−0.09
Correlation coefficient, r_{24}	−0.63***	0.50***
Foxtail shoot dry weight m^{-2} → wheat yield		
Direct effect, p_{34}	−0.52*	−0.51***
Indirect effect via foxtail shoot density, $r_{23}*p_{24}$	−0.18	0.09
Correlation coefficient, r_{34}	−0.78***	−0.51***
Sample size	36	54

[a]p_{ij} = path correlation coefficients, r_{ij} = correlation coefficients, "→" represents a path with the direction of the path indicated by the arrow.

[b]Path coefficients or correlation coefficients were either not different from zero (ns) or were different from zero at p ≤ 0.001 (***), p ≤ 0.01 (**), and p ≤ 0.05 (*).

most likely to choose foxtail management on the basis of consistent, high efficacy.

To simplify the interpretation of the SDWF results, the 18 treatments for each risk preference are divided into three equally-sized categories: upper third, middle third, and lower third of the rankings. Each category contains six rankings. Table 5 lists the most dominant and least dominant treatments, average of the sum of ranks of treatments without (first number) and with diclofop (second number), and characteristics of treatments in the upper, middle, and lower thirds of the ranking for each risk preference. The average of the sum of ranks is a rough indicator of the relative ranking of treatments with diclofop to treatments without diclofop within each of the three categories. The smaller the average of the sum of ranks, the higher the ranking of the treatments.

The most dominant treatment (early seeding date, 2× seeding rate without diclofop) and the least dominant treatment (late seeding date, 0.5× seeding rate with diclofop) are the same for all three risk preferences. Within each category (upper, middle, and lower thirds) and for all risk preferences, the average sum of the ranks is lower for treatments without diclofop than for treatments with diclofop. This implies treatments without diclofop tend to dominate treatments with diclofop within each category in terms of the distribution of net returns. The simple sum of the ranks (not shown in Table 5) is substantially smaller for treatments with diclofop than for treatments without diclofop, namely: 46 versus 83 for risk neutrality, 53 versus 70 for moderate risk aversion, and 70 versus 104 for strong risk aversion.

Treatments without diclofop in the upper third of the rankings have an early or medium seeding date and a 0.5×, 1×, or 2× seeding rate for risk neutrality and a 0.5× or 2× seeding rate for moderate and strong risk aversion. Treatments without diclofop in the middle third of the rankings have a 1× seeding rate for risk neutral preferences, an early or medium seeding date for moderate and strong risk averse preferences, and a 0.5× or 1× seeding rate for all three risk aversion levels. Moving from the upper to the middle third of the rankings causes the early or medium seeding date to be replaced by a medium seeding date for risk neutral preferences.

Treatments without diclofop in the lower third of the rankings have a late seeding date and a 0.5×, 1×, or 2× seeding rate for all three risk preferences. Moving from the middle to the lower third of the rankings causes the early or medium seeding date to be replaced with a late seeding date for all three risk preferences. Although the rank for each treatment within a category is somewhat different across risk preferences, between five and six (6 being the maximum) treatments are common in each of the three categories.

Table 4. Average net return to land, management, and nonherbicide related inputs for three seedings, three seedings, and two trials (1986 and 1987) with and without diclofop. Each value is the average of three observations.

		Average net return in					
		Trial 1 (1986)			Trial 2 (1987)		
		Seeding date			Seeding date		
Herbicide treatment	Seeding rate	Early	Middle	Late	Early	Middle	Late
	kg ha^{-1}	$ ha^{-1}					
With diclofop	70	62.66	49.03	−96.04	70.88	−5.66	37.21
	130	57.82	65.37	−108.44	119.84	27.56	−42.37
	270	14.03	62.85	−137.28	94.05	81.67	−54.12
Without diclofop	70	78.51	50.50	−56.41	112.42	50.26	0.14
	130	70.59	60.35	−68.81	125.50	47.50	12.11
	270	79.20	92.42	−97.65	155.11	83.49	−19.85

Table 5. Ranking of treatments according to stochastic dominance with respect to a function. See Materials and Methods for an explanation of this table.

Farmer's risk preference	Combinations of foxtail management practices that would be either most or least preferred by farmers for different risk preferences[a]		Average of sum of ranks and characteristics of management practices in the upper, middle, and lower thirds of rankings[a,b]		
	Most dominant treatment	Least dominant treatment	Upper third	Middle third	Lower third
Risk neutral	E seeding date, 2× seeding rate, no diclofop	L seeding date 0.5× seeding rate, with diclofop	2.25, 4.0[b] E or M seeding date with 0.5×, 1×, or 2× seeding rate	7.5, 8.25[b] M seeding date with 0.5× or 1× seeding rate	5.5, 14.0[b] L seeding date with 0.5×, 1×, or 2× seeding rate
Moderately risk averse	E seeding date, 2× seeding rate, no diclofop	L seeding date, 0.5× seeding rate, with diclofop	2.0, 3.0 E or M seeding date with 0.5× or 2× seeding rate	5.0, 7.33 E or M seeding date with 0.5× or 1× seeding rate	10.0, 13.0 L seeding date with 0.5×, 1×, or 2× seeding rate
Strongly risk averse	E seeding date, 2× seeding rate, no diclofop	L seeding date, 0.5× seeding rate, with diclofop	2.67, 4.33 E or M seeding date with 0.5× or 2× seeding rate	8.6, 10.0 E or M seeding date with 0.5× or 1× seeding rate	13.0, 15.0 L seeding date with 0.5×, 1×, or 2× seeding rate

[a]E, M, or L for seeding date represents an early, middle, or late date.

[b]The first number is the average sum of ranks of treatments without diclofop, and the second number is the average sum of ranks of treatments with diclofop. The smaller the number, the higher the ranking of treatments in that category.

The early wheat seeding date and 2× rate without diclofop dominates all other treatments regardless of risk preferences. All treatments without diclofop in the upper and middle thirds of the distribution rankings have an early or medium seeding date, and all treatments without diclofop in the lowest third of distribution rankings have a late seeding date. Delaying seeding date causes treatments without diclofop to lose their dominance over treatments with diclofop even when seeding rate is increased. Increasing seeding rate does not seem to compensate for delaying seeding date. Early seeding date appears to be the most critical factor in determining the dominance of treatments without diclofop over treatments with diclofop. Seeding rate appears to be much less important than seeding date in determining treatment ranking.

The present study confirms earlier research (7) that delayed seeding substantially decreases wheat yield in competition with foxtails (Figures 1 and 2). In addition, late wheat seeding favored yellow foxtail over green foxtail which predominated at earlier seeding dates (Figure 5). That the 2× seeding rate increased wheat yields in competition with foxtails compared to the 1× seeding rate also was consistent with earlier studies (6, 14). The results show that a crop management strategy of early wheat seeding at a 2× rate can help manage foxtails in wheat without herbicides (Figures 1 and 2). This nonherbicidal management strategy reduces the need to apply a herbicide, such as diclofop, for foxtail control if more aggressive weeds are absent or controlled.

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