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Stability of corn (*Zea mays*)–foxtail (*Setaria* spp.) interference relationships

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Variation in interference relationships have been shown for a number of crop–weed associations and may have an important effect on the implementation of decision support systems for weed management. Multiyear field experiments were conducted at eight locations to determine the stability of corn–foxtail interference relationships across years and locations. Two coefficients (I and A) of a rectangular hyperbola equation were estimated for each data set using nonlinear regression procedures. The I and A coefficients represent percent corn yield loss as foxtail density approaches zero and maximum percent corn yield loss, respectively. The coefficient I was stable across years at two locations and varied across years at four locations. Maximum yield loss (A) varied between years at one location. Both coefficients varied among locations. Although 3 to 4 foxtail plants m^{-1} row was a conservative estimate of the single-year economic threshold (T_e) of foxtail density, variation in I and A resulted in a large variation in T_e. Therefore, the utility of using common coefficient estimates to predict future crop yield loss from foxtail interference between years or among locations within a region is limited.

Nomenclature: Foxtail, *Setaria faberi* Herrm.; *S. viridis* (L.) Beauv.; *S. glauca* (L.) Beauv.; corn, *Zea mays* L.

Key words: Competition, bioeconomic model, economic threshold, integrated weed management.

Foxtails are among the most troublesome weeds in corn in the central United States (Bridges 1992). Knake and Slife (1962) reported 25% yield loss caused by more than 150 giant foxtail plants m^{-1} row across 3 yr in Illinois. Giant foxtail at greater than 100 plants m^{-1} row resulted in 40% yield loss in Michigan (Fausey et al. 1997). In contrast, Langton and Harvey (1994) reported that 168 giant foxtail plants m^{-1} row did not cause yield loss in an experiment in Wisconsin. Variation in crop–weed interference relationships among years and locations has been shown by several authors (Bauer et al. 1991; Chikoye et al. 1995; Cousens et al. 1988; Knezevich et al. 1994, 1995; Lindquist et al. 1996; Lotz et al. 1996). Further research is needed to evaluate the stability of corn–foxtail interference relationships.

Decision support software is becoming a popular method of making large amounts of information available to farmers in a user-friendly format. Weed management decision support tools range in sophistication from herbicide selection models based on efficacy to threshold-based bioeconomic models (Martin et al. 1997). Bioeconomic models use a single-year economic threshold (T_e) to determine when a management tactic is required (e.g., King et al. 1986; Lybecker et al. 1991, 1994; Swinton and King 1994; Wilkerson et al. 1991). T_e is the weed density at which cost of control equals the value of predicted crop yield loss if the weed is not controlled (Coble and Mortensen 1992; Cousens 1987). T_e can be estimated using (Marra and Carlson 1983):

$$T_e = C/(Y_{wf}PE_fY_{L,O} - Y_{L,M}), \quad [1]$$

where C is total cost of the management tactic and its application (\$ ha^{-1}), Y_{wf} is weed-free crop yield (kg ha^{-1}), P is crop price (\$ kg^{-1}), E_f is efficacy (proportion of plants killed) of the management tactic, and Y_L is the proportional yield loss at a given weed density (Cousens 1985):

$$Y_L = (IN)/[1 + (IN)/A], \quad [2]$$

TABLE 1. Experimental details and mean weed-free yield for seventeen corn–foxtail interference data sets.

Location	Foxtail species[a]	Year	Plot size[b]	Hybrid[c]	Planting date	Seeding rate	Irr.[d]	Weed-free yield[e]
			m, m		Day of year	Seeds m^{-2}		kg ha^{-1}
Lincoln, NE	SETFA	1993	15, 4.6	P3379	137	5.1	N	9,761 (198)
Fort Collins, CO	SETVI	1993	9, 3	P3615	124	7.4	Y	7,639 (192)
		1994	9, 3	P3615	133	7.4	Y	9,090 (249)
West Lafayette, IN	SETFA	1993	10.7, 3	D591	138	6.4	N	9,670 (310)
		1994	10.7, 3	D591	154	5.9	N	9,876 (696)
Urbana, IL	SETFA	1957	8, 2	US13	155	3.2	N	6,287
		1958	8, 2	US13	133	3.2	N	5,200
		1959	6.6, 2	IL1996	125	3.2	N	6,149
East Lansing, MI	SETFA	1994	10.5, 3	P3573	130	5.9	N	7,018 (997)
		1995	9, 3	P3573	128	5.9	N	11,455 (268)
Rosemount, MN	SETFA	1993	7.5, 3	P3787	133	6.4	N	7,551 (214)
Madison, WI	SETFA	1993	15, 3	P3751	138	8.0	N	12,560 (536)
		1994	14, 3	P3751	126	8.0	N	11,127 (504)
Morris, MN	SETLU	1995	15, 3	P3893	137	6.9	N	9,988[f]
		1996	15, 3	P3893	134	6.9	N	18,594
Brookings, SD	SETFA	1995	15, 3	P3769	144	6.9	N	13,889
		1996	15, 3	P3769	136	6.9	N	16,098

[a] SETFA, giant foxtail (*S. faberi*); SETVI, green foxtail (*S. viridis*); SETLU, yellow foxtail (*S. glauca*).

[b] Length, width.

[c] P, Pioneer International; US, United States public; IL, Illinois public; D, DeKalb released hybrids.

[d] Irrigated (Y), not irrigated (N).

[e] Mean (± standard error).

[f] No true weed-free treatments were included in the Morris, MN, and Brookings, SD, experiments, so maximum observed yield was used.

where I is yield loss as weed density (N) approaches zero and A is the asymptote. $Y_{L,O}$ is yield loss without management and $Y_{L,M}$ is yield loss after management has removed $E_f \cdot N$ weeds. Substitution of Equation 2 into Equation 1 and rearrangement results in a quadratic equation:

$$0 = (1 - E_f)(T_e I/A)^2 + (2 - E_f - Y_{wf}PAE_f/C) \cdot (T_e I/A) + 1 \qquad [3]$$

which can be solved algebraically for T_e (Cardina et al. 1995; Cousens 1987).

Because all of the parameters used to calculate T_e must be estimated, variation in parameter estimates will cause variation in T_e. The objective of our research was to evaluate the stability of corn–foxtail interference relationships across the north-central U.S. Estimates of I and A over years and locations were used to quantify the variation in calculated T_e, assuming C, P, Y_{wf}, and E_f are constant.

Materials and Methods

Field Experiments

Experiments were conducted at eight locations (Lincoln, NE; Fort Collins, CO; West Lafayette, IN; East Lansing, MI; Rosemount, MN; Madison, WI; Morris, MN; and Brookings, SD; herein referred to by their state code) to evaluate the influence of giant, green, or yellow foxtail on corn yield (Table 1). Foxtail density treatments (0, 10, 30, 60, or 200 plants m^{-1} row) were arranged in a randomized complete block with four replications. Adapted corn hybrids were planted in rows spaced 0.76 m apart at a locally recommended population density, and fertilizer was applied based on soil nutrient analysis. Foxtail densities were obtained by seeding into the crop row (NE, CO, IN, SD, and Morris, MN) or by thinning a natural population (WI, MI, and Rosemount, MN). Broadleaf weeds were controlled using a postemergence application of bentazon at 1.1 kg ai ha^{-1}, interrow cultivation, or removal by hand. Crop yield was determined at maturity by harvesting the center two rows in each plot. Grain weight was corrected to 15% moisture content.

Plots at WI were treated with alachlor impregnated on dry fertilizer at 0.37, 0.75, 1.49, or 2.25 kg ai ha^{-1} to obtain the desired weed densities. Weed-free control plots were sprayed with alachlor at 2.25 kg ai ha^{-1} in a broadcast treatment (Langton and Harvey 1994). Foxtail density and weed pressure (visual estimate of the percentage of the total vegetative volume that is made up of weeds) were estimated as predictors of corn yield loss at this location.

Foxtail densities at Rosemount, MN, were established using granular propachlor applied preemergence at 0, 22, 32, 42, 52, 62, 72, 82, 92, and 100% of the recommended rate of 4.5 kg ai ha^{-1}. Plots were not cultivated at this location, and weed density counts were averaged from four permanently established circular subplots (each 0.79 m^{-2}) in each plot. Therefore, density is reported as plants m^{-2} rather than plants m^{-1} crop row. To determine corn yield at Rosemount, MN, ears within subplots were harvested and shelled. The grain was cleaned, dried, and weighed then corrected to 15% moisture content.

Knake and Slife (1962) evaluated the effect of competition from various densities of giant foxtail at Urbana, IL, from 1957 to 1959. In these experiments, corn was planted in rows spaced 1.1 m apart and at a substantially lower population than is currently practiced (Table 1). Nevertheless, their data were included in our analysis for comparison.

Statistical Analyses

Corn yield loss was calculated by dividing yield from weedy plots by the mean weed-free yield for that year and

TABLE 2. Fit of corn yield loss on foxtail density (or pressure) and calculated single-year economic threshold weed density (T_e) for data sets collected at eight locations. No relationship between yield loss and foxtail density was found for 1993 NE and WI data sets.

Location (years)	Coefficient estimate[a]				T_e[b]
	df	I	A	r^2	Plants m^{-1}
CO (1993, 1994)	38	0.56 (0.17)	27.76 (2.93)	0.70	12.1
IN (1993)	18	Slope = 0.06 (0.03)[c]		0.34	94.1
IN(1994)	27	1.87 (0.80)	54.94 (8.41)	0.59	3.2
IL[d] (1957, 1958, 1959)	16	1.36 (0.28)	24.00 (2.13)	0.84	5.2
MI (1994, 1995)	46	1.22 (0.64)	60.48 (26.36)	0.28	4.8
MN (1993)	39	Slope = 0.57 (0.04)[c]		0.84	9.9
WI, Density (1994)	22	1.21 (0.54)	33.03 (4.96)	0.61	5.4
WI, Pressure (1994)	22	2.49 (1.63)	37.15 (9.39)	0.56	2.5
MN, Morris (1995)	19	0.13 (0.02)	100.00 (24.73)	0.16	43.4
MN, Morris (1996)	19	0.29 (0.04)	100.00 (24.73)	0.65	19.5
SD, Brookings (1995)	19	1.96 (1.50)	47.65 (9.63)	0.54	3.1
SD, Brookings (1996)	19	0.11 (0.02)	47.65 (9.63)	0.45	55.2

[a] Estimate (± asymptotic standard error).

[b] Single-year economic threshold, $T_e = C/Y_{wf}PY_LE_f$, where $C = \$49.40$ ha^{-1}, $P = \$0.1021$ kg^{-1}, $E_f = 0.9$, and $Y_{wf} = 10{,}115$ kg ha^{-1} (mean of all weed-free yields reported in Table 1). No threshold weed density could be calculated for the Nebraska and 1993 Wisconsin locations (i.e., weed control would not be economically profitable regardless of weed density).

[c] Results of a linear regression with the intercept forced through the origin (the intercept did not vary from 0).

[d] Data reported by Knake and Slife (1962). The r^2 reported for Illinois does not necessarily represent the true quantity of variation explained by the model because only treatment means were available for analysis.

location, then regressed on weed density using Equation 2. If this equation provided an acceptable fit to the data, its coefficients (I and A) were compared among years using the extra sum of squares principle (Lindquist et al. 1996; Ratkowsky 1983). Data sets were pooled within a location when I and A did not differ between years, and estimates of I and A were then compared among those locations with homogeneous variance (residuals, as tested using SAS PROC DISCRIM). Data from the IL location were presented as means (Knake and Slife 1962), so yield loss relationships were not compared among years for that location. The IL data were pooled to obtain estimates of I and A for that location.

Variation in T_e

To determine the influence of variation in I and A on single-year economic threshold foxtail density, T_e was calculated using mean estimates of I and A for each data set as reported in Table 2. Where the rectangular hyperbola did not provide an adequate fit to the yield loss relationship, the slope of the linear regression (if significant) was used to calculate Y_L. Cost of the management tactic, price of the crop, efficacy of the management tactic, and weed-free crop yield were set to constant values of \$49.40 ha^{-1} (\$20 acre^{-1}), \$0.1021 kg^{-1} (\$2.60 bu^{-1}), 0.9 (90% of plants removed), and 10,115 kg ha^{-1} (161 bu acre^{-1}), respectively.

Results and Discussion

Stability of Corn–Foxtail Interference

Equation 2 provided a good fit to all data sets except those collected in 1993 from NE, IN, WI, and Rosemount, MN (statistics not shown). A linear equation adequately described the 1993 IN and Rosemount, MN, data, but not the 1993 NE or WI data, indicating that yield was not reduced at any of the observed densities in those site-years (Figure 1). Lack of yield reduction from weeds has been shown for other weed species (Bussler et al. 1995; Lindquist et al. 1995, 1996).

Estimates of I and A did not vary between years at CO or MI, but estimates of I varied significantly between years at IN, SD, and Morris, MN, locations (Table 3). Between-year variation in I and A was not compared for the IL data sets, but there appeared to be little variation in the yield loss–giant foxtail density relationships at that location (Figure 1). Because no relationship was observed between yield loss and weed density at WI in 1993, statistical comparisons of I and A between years at that location were not possible. However, it is clear that the yield loss–giant foxtail density relationship differed. Equation 2 also provided an acceptable fit to the yield loss–foxtail pressure data from WI (1994 only, Figure 1), although foxtail density resulted in a smaller residual sums of squares and larger r^2 value (Table 2). Results suggest that foxtail pressure may be an acceptable predictor of yield loss observed within a season. However, because yield loss was not observed at any foxtail density or pressure in 1993 (Figure 1), use of pressure may be no better for predicting yield loss among years and locations than weed density.

Between-year variation in crop–weed interference relationships may result from variation in the relative time of emergence of the crop and weed, differential response of the crop and weed to different weather conditions among years, shifts in the resource (e.g., light or water) that is most limiting, or variation in crop density or other management practice. Experiments in CO were irrigated, which may have eliminated among-year variation in available soil water and contributed to the stability of I and A at that location. Estimates of I and A from MI were stable only because of the large variability in yield loss observed in 1994 (Figure 1). Precipitation during the growing season was abnormally high at IN, NE, and WI in 1993. At NE and WI, yield loss was not observed at any foxtail density, and a significant loss was observed only at the highest weed densities in IN. If both soil water and nutrients were not limiting, corn–

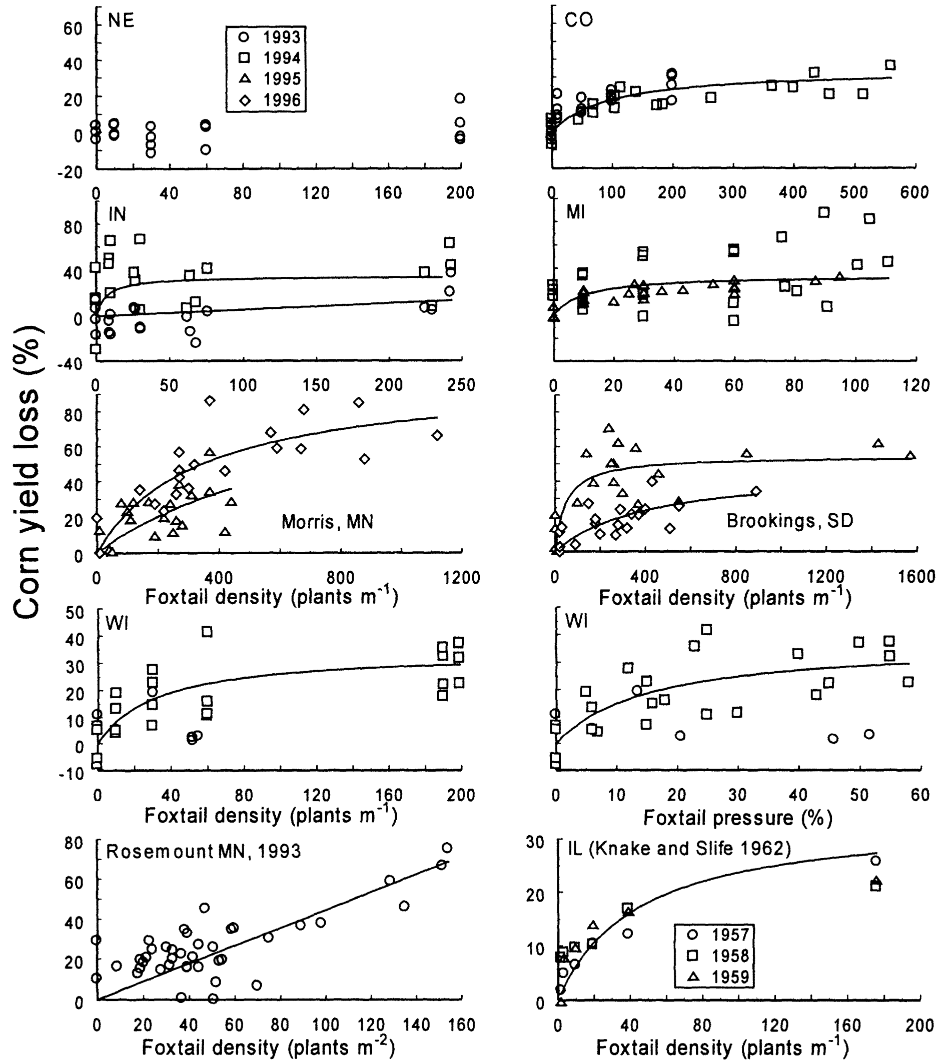

FIGURE 1. Relationship between percent corn yield loss and foxtail density or pressure for 17 data sets from nine locations. Density of the Rosemount, MN, data is reported in plants m^{-2}; all other densities were measured in plants m^{-1} crop row.

TABLE 3. Stability of corn–foxtail interference relationships between years.

Location	Null hypothesis	df$_1$[a]	df$_2$[b]	Variance ratio[c]
Fort Collins, CO	*I* and/or *A* does not vary	2	36	3.08 NS
(1993/1994)	*I* does not vary	2	36	2.05 NS
	A does not vary	2	36	0.58 NS
West Lafayette, IN	*I* and/or *A* does not vary	2	46	26.22 ***
(1993/1994)	*I* does not vary	2	46	6.28 ***
	A does not vary	2	46	0.35 NS
East Lansing, MI	*I* and/or *A* does not vary	2	44	1.53 NS
(1994/1995)	*I* does not vary	2	44	0.24 NS
	A does not vary	2	44	0.34 NS
Morris, MN	*I* and/or *A* does not vary	2	36	9.00 ***
(1995/1996)	*I* does not vary	2	36	3.73 *
	A does not vary	2	36	1.01 NS
Brookings, SD	*I* and/or *A* does not vary	2	36	22.41 ***
(1995/1996)	*I* does not vary	2	36	3.74 *
	A does not vary	2	36	1.20 NS

[a] df$_1$, degrees of freedom for the sum of squares of the regression.

[b] df$_2$, degrees of freedom for the residual sum of squares.

[c] NS, not significant at $P < 0.05$; * significant at $P < 0.05$; ** significant at $P < 0.01$; *** significant at $P < 0.001$.

TABLE 4. Stability of corn–foxtail interference relationships among the IN, SD, and Morris, MN, locations.

Null hypothesis	df_1[a]	df_2[b]	Variance ratio[c]
I and A do not vary	10	116	13.85 ***
I does not vary	6	116	3.52 ***
A does not vary	6	116	6.48 ***

[a] df_1, numerator degrees of freedom.

[b] df_2, denominator degrees of freedom.

[c] NS, not significant; *** significant at $P < 0.005$.

foxtail competition for light was likely the primary cause for yield reduction. Foxtails are generally much shorter than corn, suggesting that yield reduction would be minimized under such conditions. Competition for water and nitrogen may play a greater role in reducing corn yield in normal years or in soils prone to nitrogen deficiency or loss.

The number of data sets used for the comparison of yield loss–foxtail density relationships among locations was restricted because there was considerable nonhomogeneity of variance (residuals). Only data obtained from the IN, SD, and Morris, MN, locations could be included in this analysis. Yield loss as foxtail density approaches zero (I) varied among years within a location (Table 3) and among locations (Table 4). Although A did not vary among years within a location, it did vary among locations (Table 4). Lindquist et al. (1996) also found that I was less stable among years and locations than A. This is unfortunate because yield loss resulting from low weed density is more important in determining T_e than maximum yield loss. The relatively small values of I and A at CO and Morris, MN, may be attributed to the use of green and yellow foxtail at those locations, respectively. Both species are generally smaller in stature and likely less competitive than giant foxtail.

Variation in T_e

Estimated single-year economic threshold (T_e) varied from 3.2 to 94.1 plants m^{-1} row at IN (Table 2) or from 4.8 to an infinite number of foxtail plants m^{-1} row at WI. This result suggests that management decisions based upon T_e are risky. For example, if T_e for weed management decisions is too large, growers may not manage weeds when they should. However, if T_e is too small, the grower may waste time and money by applying a management tactic when it is not needed. Given the range in T_e shown in Table 2, most decision makers will choose a conservative approach and use a T_e of 3 to 4 foxtail plants m^{-1} row. Unfortunately, this means that growers will frequently apply a herbicide when it's not needed. An important question is: how frequent is this expected to occur? Estimates of T_e clearly vary among environments, but knowledge of how much they vary may be valuable for answering this question or for evaluating the risk involved in any weed management decision.

Estimating the potential variation in T_e requires greater knowledge of the causes of variation in crop–weed interference relationships among environments. Unfortunately, few papers published in weed science journals report research that contributes to this knowledge. Research is needed to understand the mechanisms of interspecific competition for at least two reasons. First, variation in yield loss relationships among years and locations can be quantified. If we know the probability of observing a particular set of I and A values we could better define what T_e value should be used, depending upon the level of risk the grower wishes to take. Second, the competitive effects of weeds can be minimized. If we knew why foxtails did not cause loss at NE and WI in 1993, we could recommend management practices that more closely approximate this situation in other years. Regional research projects such as NC202 can contribute toward a more mechanistic understanding of crop–weed interference, but improvements are needed in data collection. For example, actual date of weed and crop emergence and density counts of both crop and weed may explain some of the variation in yield loss relationships among years and locations. Measurement of crop and weed biomass accumulation, height, and leaf area index may reveal situations where crop growth is favored over weed growth. Accurate weather (daily estimates of maximum and minimum temperature, precipitation, solar irradiance, wind speed, and relative humidity) and soil (temperature, type, texture, water holding capacity, etc.) data are necessary to evaluate their effects on interference relationships among years and locations. All of these data are necessary for evaluating the performance of various crop–weed competition models. Our challenge for the future is to design and conduct experiments that will increase our understanding of the response of both crop and weed growth and competitive ability to their environment. Only when these responses are understood and incorporated into crop–weed competition models can we accurately predict the potential influence of weeds on crop yield and make more informed weed management decisions.

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Literature Cited

Bauer, T. A., D. A. Mortensen, G. A. Wicks, T. A. Hayden, and A. R. Martin. 1991. Environmental variability associated with economic thresholds for soybeans. Weed Sci. 39:564–569.

Bridges, D. C. 1992. Crop Losses Due to Weeds in the United States, 1992. Champaign, IL: Weed Science Society of America. 403 p.

Bussler, B. H., B. D. Maxwell, and K. J. Puettman. 1995. Using plant volume to quantify interference in corn (*Zea mays*) neighborhoods. Weed Sci. 43:586–594.

Cardina, J., E. Regnier, D. Sparrow. 1995. Velvetleaf (*Abutilon theophrasti*) competition and economic thresholds in conventional and no-tillage corn (*Zea mays*). Weed Sci. 43:81–87.

Chikoye, D., S. F. Weise, and C. J. Swanton. 1995. Influence of common ragweed (*Ambrosia artemisifolia*) time of emergence and density on white bean (*Phaseolus vulgaris*). Weed Sci. 43:375–380.

Coble, H. D. and D. A. Mortensen. 1992. The threshold concept and its application to weed science. Weed Technol. 6:191–195.

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

Cousens, R. 1987. Theory and reality of weed control thresholds. Plant Prot. Q. 2:13–20.

Cousens, R., L. G. Firbank, A. M. Mortimer, and R.G.R. Smith. 1988.

Variability in the relationship between crop yield and weed density for winter wheat and *Bromus sterilis.* J. Appl. Ecol. 25:1033–1044.

Fausey, J. C., J. J. Kells, S. M. Swinton, and K. A. Renner. 1997. Giant foxtail (*Setaria faberi*) interference in nonirrigated corn (*Zea mays*). Weed Sci. 45:256–260.

King, R. P., D. W. Lybecker, E. E. Schweizer, and R. L. Zimdahl. 1986. Bioeconomic modeling to simulate weed control strategies for continuous corn (*Zea mays*). Weed Sci. 34:972–979.

Knake, E. L. and F. W. Slife. 1962. Competition of *Setaria faberii* with corn and soybeans. Weeds 10:26–29.

Knezevic, S. Z., S. F. Weise, and C. J. Swanton. 1994. Interference of redroot pigweed (*Amaranthus retroflexus* L.) in corn (*Zea mays* L.). Weed Sci. 42:568–573.

Knezevic, S. Z., S. F. Weise, and C. J. Swanton. 1995. Comparison of empirical models depicting density of *Amaranthus retroflexus* L. and relative leaf area as predictors of yield loss in maize (*Zea mays* L.). Weed Res. 35:207–214.

Langton, S. J. and R. G. Harvey. 1994. Using alachlor impregnated on dry fertilizer to create varying giant foxtail populations for corn competition studies. Proc. North Cent. Weed Sci. Soc. 49:18.

Lindquist, J. L., B. D. Maxwell, D. D. Buhler, and J. L. Gunsolus. 1995. Velvetleaf (*Abutilon theophrasti*) recruitment, survival, seed production and interference in soybean (*Glycine max*). Weed Sci. 43:226–232.

Lindquist, J. L., D. A. Mortensen, S. A. Clay, R. Schmenk, J. J. Kells, K. Howatt, and P. Westra. 1996. Stability of corn (*Zea mays*)–velvetleaf (*Abutilon theophrasti*) interference relationships. Weed Sci. 44:309–313.

Lotz, L.A.P., S. Christensen, D. Cloutier, C. Fernandez-Quintanilla, A. Legere, C. Lemieux, P.J.W. Lutman, A. Pardo Iglesias, J. Salonen, M. Sattin, L. Stigliani, and F. Tei. 1996. Prediction of the competitive effects of weeds on crop yields based on the relative leaf area of weeds. Weed Res. 36:93–101.

Lybecker, D. W., E. E. Schweizer, and R. P. King. 1991. Weed management decisions in corn based on bioeconomic modeling. Weed Sci. 39:124–129.

Lybecker, D. W., E. E. Schweizer, and P. Westra. 1994. WEEDCAM Manual. Progress Report. EPA Contract DW12934950-01-1 Transfer Weed Management Expert System Technology for Reduced Corn Herbicide Use to Farmers, Extension Agents, and Crop Consultants. Ft. Collins, CO: Department of Agricultural Economics, Colorado State University. 49 p.

Marra, M. C. and G. A. Carlson. 1983. An economic threshold model for weeds in soybeans (*Glycine max*). Weed Sci. 31:604–609.

Martin, A. R., D. A. Mortensen, and J. L. Lindquist. 1997. Decision support models for weed management: in-field management tools. Pages 363–369 *in* J. L. Hatfield, D. D. Buhler, and B. A. Stewart, eds. Integrated Weed and Soil Management. Chelsea, MI: Ann Arbor Press.

Ratkowsky, D. A. 1983. Nonlinear Regression Modeling: A Unified Practical Approach. New York: Marcel Dekker. 276 p.

Swinton, S. M. and R. P. King. 1994. A bioeconomic model for weed management in corn and soybean. Agric. Sys. 44:313–335.

Wilkerson, G. G, S. A. Modena, and H. D. Coble. 1991. HERB: decision model for postemergence weed control in soybean. Agron. J. 83:413–417.

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