2005

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Weed Science, 53:160–165. 2005

Influence of soybean row width and velvetleaf emergence time on velvetleaf (*Abutilon theophrasti*)

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Row spacing and the relative time of velvetleaf emergence affects the time of soybean canopy closure relative to velvetleaf, influencing the growth and development of velvetleaf. Field studies were conducted in northeastern Nebraska in 2002 and 2003 to describe velvetleaf growth as influenced by soybean presence or absence (velvetleaf grown with soybean or in monoculture), soybean row spacing (19 and 76 cm), and relative time of velvetleaf emergence. Velvetleaf seed production, leaf area (LA), and total dry matter (TDM) were greater in 76-cm- than in 19-cm-wide soybean rows. LA, TDM, and seed production of velvetleaf were reduced with later emergence times in both monoculture and with soybean. Velvetleaf LA, TDM, and seed production decreased when grown with soybean compared with when grown in monoculture. Practical implications of this study suggest that narrowing crop row spacing and controlling early-emerging velvetleaf in soybean can be an effective part of an integrated weed management strategy.

Nomenclature: Velvetleaf, *Abutilon theophrasti* ABUTH; soybean, *Glycine max* (L.) Merr.

Key words: Integrated weed management, plant architecture, velvetleaf growth, weed emergence, weed seed production.

One method of reducing our reliance on chemical weed control is through the development and use of integrated weed management (IWM) (Knezevic and Horak 1998). IWM suggests managing weed populations through mortality and fitness-reducing events (Williams et al. 1998). The basic premise of an IWM program is to use a combination of preventive, cultural, mechanical, and chemical practices that reduce weed interference with the crop (Swanton and Weise 1991). Cultural practices that improve crop competitiveness can be a useful part of an IWM program (Pyon et al. 1997). Examples of cultural practices that improve crop competitiveness may include: timing and placement of fertilizer, modifying seeding rate, and reducing crop row spacing (Walker and Buchanan 1982). Several studies indicated that soybean planted in narrow vs. wide rows was more competitive against weeds (Knezevic et al. 2003a, 2003b; Mulugeta and Boerboom 2000). Knezevic et al. (2003a, 2003b) also suggested that planting soybean in narrow rows improved early season crop tolerance to weeds, delayed the critical time for weed removal, and required less intensive weed management programs than in wide rows.

To establish effective IWM in soybean, an understanding of the biology of major weed species is necessary. Velvetleaf has been reported as a problem weed in corn (*Zea mays* L.) and soybean (Warwick and Black 1988). Most velvetleaf emerge during the early part of the season, whereas some can emerge during the midgrowing season (Egley and Williams 1991). Velvetleaf can complete its life cycle even when grown under a crop canopy (Mitich 1991) and can produce up to 17,000 seeds per plant seed (Warwick and Black 1988). Velvetleaf competitive effects have been studied in many crops, including soybean (Dekker and Meggitt 1983; Lindquist et al. 1995; Patterson 1992; Regnier and Stoller 1989), corn (Lindquist and Mortensen 1998, 1999; McDonald and Riha 1999), tomato (*Lycopersicon esculentum*) (Ngouajio et al. 2001), and cotton (*Gossypium hirsutum*) (Smith et al. 1990). Although velvetleaf has been evaluated under varying shade and water regimes under controlled environments (Sailsbury and Chandler 1993), no studies reported any evaluation of velvetleaf growth under field conditions in soybean with soybean row width and the relative emergence time of velvetleaf taken under consideration. Therefore, objectives of this study were to describe velvetleaf growth as influenced by soybean presence or absence (velvetleaf grown with soybean or in monoculture), soybean row spacing (19 and 76 cm), and time of velvetleaf emergence relative to the crop's growth stage.

Materials and Methods

Site Description

Field experiments were conducted in 2002 and 2003 at the Haskell Agricultural Laboratory in Concord, NE. The soil type was Kennebec series silty clay loam 0 to 2% slopes (fine-silty mixed, mesic Cumulic Haplusolls). Soil organic matter was 4.3% with a pH of 6.7.

Experimental Design

The experiment was conducted as a strip-plot design (A. K. Gomez and A. A. Gomez 1984), with one strip (two soybean row spacings) perpendicular to the second strip (three growing scenarios consisting of velvetleaf monoculture, soybean monoculture, or velvetleaf with soybean) and a random complete block for three relative emergence times (velvetleaf planted at soybean planting, emergence, or first trifoliate leaf stage) within the first strip. The interaction between the two strips is designated as the intersection area. A total of 12 treatments with four replications had two in-

Table 1. Velvetleaf planting and emergence date and soybean leaf stage at the time of weed emergence in mixture and monoculture plots for 2002 and 2003.

Year	Planting date[a]	Emergence date[b]	Soybean leaf stage
2002	May 31	June 10	VE
	June 10	June 19	V1
	June 18	July 9	V4
2003	June 5	June 16	VE
	June 13	June 25	V1
	June 30	July 10	V4

[a] Three planting dates of velvetleaf in each year. Planting dates were the same in both weed–soybean and monoculture plots.

[b] Three emergence dates of velvetleaf in each year in monoculture plots. In 2002, only the first emergence dates occurred in velvetleaf–soybean plots.

tersection areas: (1) intersection area of soybean row spacing vs. velvetleaf (hereafter referred to as the velvetleaf–soybean area) and (2) intersection area of soybean row spacing vs. soybean monoculture. Experimental units were 9 m long and 10 m wide with twelve 76-cm rows or forty-eight 19-cm rows of soybean.

Observations were taken from the center 6 m of each intersection area, leaving a 2-m border at the front and back. Within each plot area, there were six designated harvest areas (1-m length) that were taken at soybean first trifoliate (V1), third trifoliate (V3), fifth trifoliate (V5), seventh trifoliate (V7), full flower (R2), and full pod (R4) (Ritchie et al. 1993) stages and from a designated final harvest area (4-m length) that was harvested at physiological maturity. Knezevic and Horak (1998) used a similar experimental design while studying effects of sorghum (*Sorghum bicolor* L.) on redroot pigweed (*Amaranthus retroflexus* L.) growth and development.

Experimental Procedures

Fields were disked and then cultivated in the spring before the experiment was planted. A 24-row, 19-cm-spaced drill was used to plant 'Agripro 2502' at a density of 410,000 seeds ha^{-1} for both 19- and 76-cm row widths. The 76-cm rows were planted by restricting seed passage of 18 out of the total 24 rows. Velvetleaf was manually planted at a density of 2 plants m^{-1} at soybean planting, soybean emergence, and soybean first trifoliate leaf stage within a band of 10 cm on either side of the row. Planting and emergence dates are reported in Table 1. Velvetleaf emergence dates were based on visual estimates of 50% emerged plants. Undesirable weeds were controlled by hand-hoeing. To obtain the desired density of velvetleaf, seedlings were thinned by hand, starting at the third trifoliate leaf stage of soybean. Developmental stages were based on the number of fully expanded primary leaves per plant.

Harvests

Because of overlapping vegetative and reproductive stages in 2003, the V7 and R2 harvests were combined. Velvetleaf plants were clipped at the soil surface and divided into leaf, stem, and inflorescence. During the R4 harvest, velvetleaf plants were clipped at the soil surface, cross-sectioned into 30-cm height increments and divided into leaf, stem, and inflorescence. The leaf area (LA) of velvetleaf was measured with a LI-COR[1] 3100 leaf area meter. Plant components were dried at 70 C until dry matter achieved constant mass.

Velvetleaf plants were harvested on September 27, 2002, and October 1, 2003. Plants were harvested from a 4-m length of the middle row in each plot. Seed capsules were collected from the designated harvest areas as they matured before final harvest. Seeds that had shattered onto the ground before or at the final harvest were not collected, and seed loss was not estimated. Seed quality was not evaluated in this study but is assumed to be equal among treatments. Plants were clipped at the soil surface, dried, and weighed. Subsamples of 200 seeds were counted from each treatment and weighed. Seed number was then estimated using the total seed weight and the subsample seed weight. Seeds in 2003 were collected weekly after seed capsules ripened. This methodology ensured more accurate seed production numbers in 2003 than 2002 when seed collection occurred only once during final harvest.

Statistical Analyses

Analyses of variance were performed using PROC MIXED (SAS 1999) to test data normality and significance ($P < 0.05$) of growing scenario, soybean row spacing, velvetleaf relative emergence date, and interactions between relative emergence date and soybean row for each measured growth parameter. The effects of inter–intraspecific competition, soybean row width, and relative emergence date were significant in most cases ($P < 0.05$). Years were analyzed and presented separately because of significant year interactions ($P < 0.05$).

The Gompertz model (Knezevic et al. 2002) was used to relate dry matter as a function of thermal time as influenced by growing scenario soybean row spacing and relative emergence date:

$$Y = a \exp(-b \exp(-kT)) \qquad [1]$$

where Y is the total dry matter (TDM) of velvetleaf, a is the asymptote, b and k are constants, and T is thermal time (x-axis expressed in growing degree days). The parameter estimates were calculated as outlined in Knezevic et al. (2002) using PROC NLIN (SAS 1999) and are presented in Table 2.

Results and Discussion

Velvetleaf LA in Monoculture

Vertical distribution of velvetleaf LA grown in monoculture was influenced by emergence date (VE and V1) and year (2002 and 2003) (Figure 1). Monoculture-grown velvetleaf that emerged early accumulated 91 and 247% more LA than plants from the second emergence date (Figures 1a and 1b) in 2002 and 2003, respectively.

Plant LA distribution and overall plant height were affected by emergence date in 2002 but not in 2003. Plants from the first emergence date produced more LA (2,694 cm^2 $plant^{-1}$) in the lower strata (bottom 30 cm) of the plant and were at least 30 cm taller than later emerging velvetleaf (940 cm^2 $plant^{-1}$) in 2002. There was a similar response for vertical distribution of TDM (data not shown). Similarly, Knezevic and Horak (1998) observed that redroot pig-

Table 2. Parameter estimates (±SE) of Gompertz equation (see text) used to relate velvetleaf total dry matter (TDM) at the beginning pod stage of soybean.

Growth parameter	Growing scenario	Year	EDV[a]	LSS[b]	Parameter estimates of Gompertz equation[c]			r^2
					a	*b*	*k*	
TDM at soybean final harvest	Weed grown in monoculture							
		2002	1	VE	356 (13) a[d]	197 (125) a	0.00352 (0.0004) b	0.97
		2002	2	V1	300 (10) b	80.4 (23) a	0.00238 (0.000156) c	0.98
		2003	1	VE	179 (9) c	132 (113) a	0.0040 (0.0007) a	0.94
		2003	2	V1	138 (6) d	83 (66) a	0.0030 (0.0006) b	0.98
		2003	3	V4				
	Weed grown with soybean							
	19-cm row spacing	2002	1	VE	120 (9) e	101 (36) a	0.0020 (0.0001) d	0.97
		2002	2	V1	70 (8) g	122 (49) a	0.0024 (0.0002) c	0.97
		2003	1	VE	40 (2) f	528 (765) a	0.00534 (0.0012) a	0.93
		2003	2	V1	16 (2) h	106 (354) a	0.00334 (0.002) b	0.81
	76-cm row spacing							
		2002	1	VE	130 (8) d	402 (268) a	0.00334 (0.000384) b	0.98
		2002	2	V1	90 (5) f	81 (25) a	0.00241 (0.00017) c	0.98
		2003	1	VE	83 (2) h	47 (17) a	0.0030 (0.000321) b	0.98
		2003	2	V1	35 (9) l	31 (44) a	0.0020 (0.0012) d	0.94

[a] EDV, emergence date of velvetleaf.
[b] LSS, leaf stage of soybean at the time of weed emergence.
[c] *a*, *b*, *k* are parameter estimates.
[d] Within a column, the same letter indicates that the parameter values did not differ significantly between years and velvetleaf emergence dates according to SE.

weed had reduced height and lateral growth in the second emergence date compared with pigweed emerging 9 d earlier.

Velvetleaf LA in Mixed Stands (Harvested at Soybean Full Pod Stage)

Velvetleaf in mixed stands accumulated less LA than velvetleaf grown in monoculture ($P < 0.01$) for 2002 and 2003. Velvetleaf grown in monoculture had 40% of its LA in the upper three strata compared with 67% for velvetleaf grown in 76-cm-row soybean and 78% for velvetleaf grown in 19-cm-row soybean in 2002 (Figure 1a). Similarly, velvetleaf grown in 2003 had more LA in its upper two strata for velvetleaf in mixed stands than when it was grown in monoculture (Figure 1b). This indicates that velvetleaf was able to distribute its LA to the upper portions of the plant canopy to compete more efficiently with soybean for sunlight. Others observed similar responses with soybean grown alone (Heindl and Brun 1983, 1984) and with redroot pigweed grown in soybean (Legere and Schreiber 1989). Legere and Schreiber (1989) reported that redroot pigweed produced less lateral leaf growth on the lower strata of the plant in 25-cm-wide soybean rows than in 76-cm-wide rows.

Velvetleaf LA was affected by soybean row spacing ($P < 0.05$) and velvetleaf relative emergence date ($P < 0.05$) in 2002 and 2003 (Figure 1). Velvetleaf LA was reduced more by narrow rows when emerging during soybean V1 than VE stage in 2002. Soybean planted in 19-cm rows reduced velvetleaf LA by 62% (1,759 cm^2 $plant^{-1}$) compared with 76-cm rows (2,860 cm^2 $plant^{-1}$) when emerging with the soybean in 2003 and 137% compared with 76-cm rows when emerging at soybean first trifoliate leaf stage in 2002 (Figure 1a). However, row spacing affected velvetleaf LA similarly for both emergence dates in 2003. Soybean planted in 19-cm rows reduced velvetleaf LA by 45% compared with 76-cm rows for both emergence dates (Figure 1b). The reduction of LA when planted in 19-cm rows compared with 76-cm rows suggests that there was greater competition for light between velvetleaf and soybean canopies in narrow row soybean.

Velvetleaf Dry Matter Accumulation in Monoculture

Velvetleaf emerging at the same time as the soybean produced greater TDM than velvetleaf emerging at the second and third emergence date ($P < 0.05$) in 2002 and 2003 (Figure 2; Table 3). Velvetleaf emerging with the soybean (324 g $plant^{-1}$) produced 25 and 362% more TDM than velvetleaf emerging at V1 (259 g $plant^{-1}$) and V4 (70 g $plant^{-1}$) soybean stage in 2002, respectively (Figure 2a). Similar trends were observed in 2003, but less TDM was produced in 2003 than 2002 (Figure 2).

Velvetleaf Dry Matter Accumulation in Mixed Stands (with Time)

In mixture with soybean, velvetleaf dry matter accumulation was affected by soybean row spacing and relative emergence date in most cases (Figure 3; Table 2). In general, velvetleaf produced more TDM in 76- than 19-cm rows in both years (Figure 3). Early-emerging velvetleaf grown in 76-cm-wide soybean rows produced almost 25% more TDM (123 g $plant^{-1}$) than velvetleaf grown in 19-cm rows (98 g $plant^{-1}$) in 2002 (Figure 3a). Similarly, velvetleaf

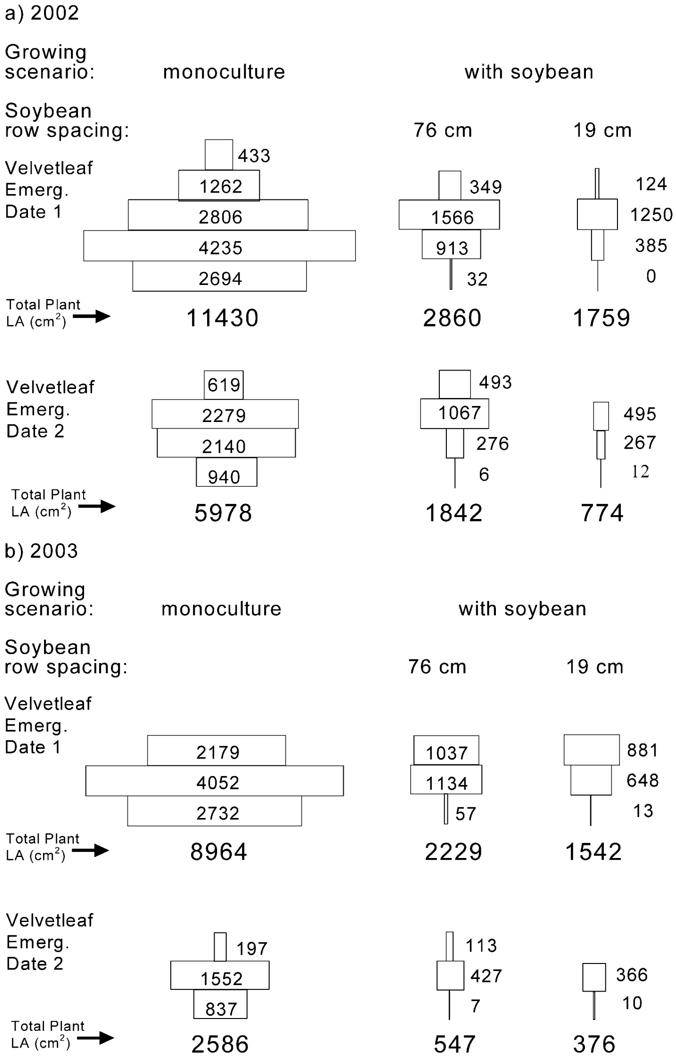

FIGURE 1. Velvetleaf leaf area (LA) distribution at soybean flowering for years 2002 (a) and 2003 (b) as influenced by crop row spacing and time of velvetleaf emergence in velvetleaf monoculture and velvetleaf–soybean plots. Each rectangle represents a 30-cm height increment. Total LA is shown at the bottom of each symbolic plant.

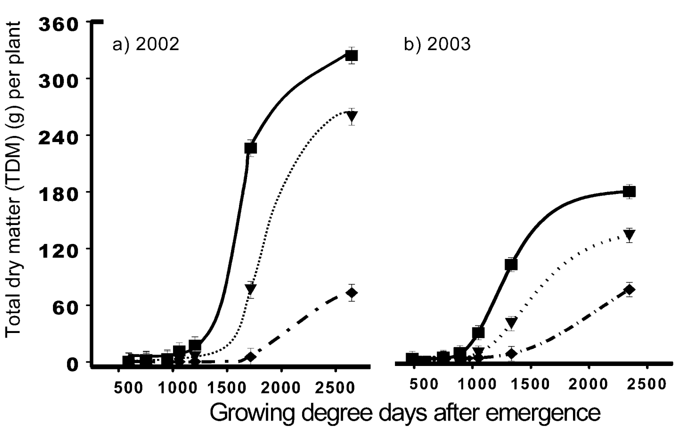

FIGURE 2. Monoculture-grown velvetleaf accumulation of total dry matter (g) during the growing season for years 2002 (a) and 2003 (b) as influenced by the relative emergence of velvetleaf to soybean at crop planting (■), emergence (▼), and first trifoliate leaf stage (●).

TABLE 3. Velvetleaf seed production in monoculture and in mixture with soybean.

Growing scenario	Year	EDV[a]	LSS[b]	Seeds plant^{-1} [c]	SE[d]
Weeds grown in Monoculture					
	2002	1	VE	14,066	1,021
	2002	2	V1	10,324	1,021
	2002	3	V4	553	1,021
	2003	1	VE	8,078	341
	2003	2	V1	4,452	341
	2003	3	V4	1,954	341
Weeds grown in soybean					
19 cm row spacing	2002	1	VE	1,600	109
	2002	2	V1	1,672	109
	2003	1	VE	842	179
	2003	2	V1	524	179
	2003	3	V4	0	179
76 cm row spacing					
	2002	1	VE	2,007	109
	2002	2	V1	1,398	109
	2003	1	VE	3,594	179
	2003	2	V1	960	179
	2003	3	V4	0	179

[a] EDV, emergence date of velvetleaf.
[b] LSS, leaf stage of soybean at the time of velvetleaf emergence.
[c] Seeds plant^{-1}, based on least square means (P = 0.05).
[d] Standard error based on least square means (P = 0.05).

grown in wide rows emerging at the second emergence date produced 32% more dry matter than velvetleaf grown in narrow row soybean.

Overall, early-emerging velvetleaf produced more TDM than those emerging later. For example, in 19-cm rows, velvetleaf emerging with the soybean produced 70% more TDM (120 g plant^{-1}) than velvetleaf emerging at soybean first trifoliate stage (70 g plant^{-1}) in 2002 (Table 2). Gen-

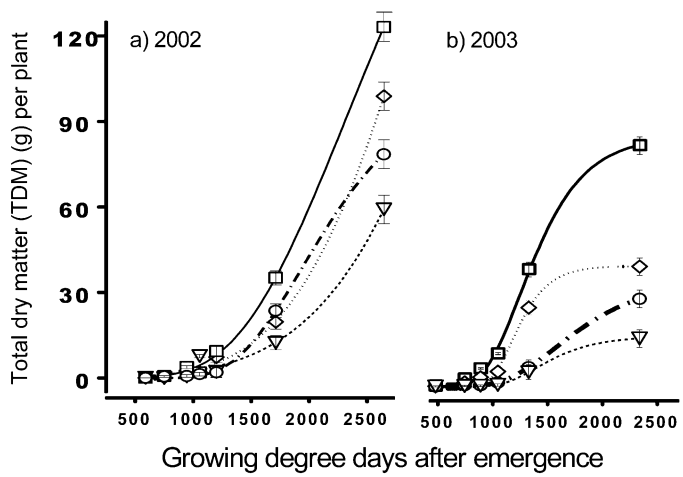

FIGURE 3. Mixture-grown velvetleaf accumulation of total dry matter (g) during the growing season for years 2002 (a) and 2003 (b) as influenced by soybean row spacing (76 and 19 cm) and the relative emergence of velvetleaf to soybean (soybean emergence and soybean first trifoliate leaf stage). The 76-cm soybean row spacing at soybean emergence (□) and first trifoliate leaf stage (○). The 19-cm soybean row spacing at soybean emergence (◇) and first trifoliate leaf stage (▽).

erally, velvetleaf in 2003 responded similarly to row spacing and emergence time as in 2002 (Figure 3b).

Velvetleaf Seed Production in Monoculture (Final Harvest)

A single velvetleaf plant produced approximately 25 times more seed at the first (36,800 seeds m^{-2}) and second (27,100 seeds m^{-2}) emergence dates than in the third (1,400 seeds m^{-2}) emergence date in 2002 ($P < 0.01$). Similarly, velvetleaf emerging at the first emergence date produced 21,000 seeds m^{-2} compared with 11,800 and 5,300 seeds m^{-2} for the second and third emergence date, respectively, in 2003 ($P < 0.05$). Sato et al. (1994) also reported decreasing seed production for velvetleaf grown in monoculture with later velvetleaf emergence dates (Table 3).

Velvetleaf Seed Production in Mixed Stands (Final Harvest)

As with dry matter accumulation, velvetleaf seed production differed between years, and generally, velvetleaf seed production decreased in narrow rows and with later emergence dates (Table 3). An interaction effect of soybean row spacing and emergence date on velvetleaf seed production ($P < 0.05$) was observed in both 2002 and 2003. Velvetleaf emerging with the soybean in 76-cm rows produced 25% more seed (5,300 seeds m^{-2}) than in 19-cm rows (4,200 seeds m^{-2}) in 2002. However, there was no difference in the effects of soybean row spacing on velvetleaf seed production when they emerged at the V1 stage of soybean development. Velvetleaf seed production differed among emergence dates in the 76-cm row spacing treatment ($P < 0.05$) but not for 19-cm row spacing in 2002. In 76-cm rows, velvetleaf produced 43% more seed when emerging at soybean stage VE than at V1 stage (Table 3).

Velvetleaf grown in 76-cm rows (9,500 seeds m^{-2}) and emerging with the soybean produced 327% more seed than velvetleaf grown in 19-cm rows (2,200 seeds m^{-2}) in 2003, but no differences were observed among row spacing treatments ($P = 0.10$) for velvetleaf emerging at the V1 soybean stage (Table 3). As in 2002, velvetleaf in 76-cm rows produced more seed when emerging with the soybean (9,500 seeds m^{-2}) than at the V1 stage (2,500 seeds m^{-2}), but no difference in seed production was observed between emergence dates in 19-cm row spacing. Velvetleaf grown in 19-cm rows produced approximately the same number of seed as velvetleaf that emerged at V1 in 76-cm rows. Velvetleaf emerging at the fourth trifoliate leaf stage did not produce seed in either row spacing in 2003 (Table 3); indicating that regardless of row spacing, velvetleaf emerging at soybean V4 stage will not contribute to velvetleaf infestations in the next cropping season.

In summary, velvetleaf LA, TDM, and seed production were reduced with later emergence times in both monoculture and with soybean. The same growth parameters also were greater in 76-cm-wide soybean rows compared with 19-cm-wide rows and when velvetleaf was grown in monoculture. Vertical distribution of LA presented in this article can further aid in the understanding of velvetleaf response to various competitive scenarios. Some reported that a plant species can be at an advantage if its leaves were placed in the upper portion of the canopy (Haizel 1972; Lindquist et al. 1998). Such positioning of LA has been described as being as important as total LA in determining species competitive ability (Akey et al. 1990; Cudney et al. 1991). The data of this study showed that vertical distribution of LA was altered in interspecific competition with soybean compared with monoculture-grown velvetleaf. In essence, velvetleaf was able to reallocate its LA to the upper portion of the canopy when grown with the crop, likely as a result of increased competition for light. This resulted in "pyramidal" shaped velvetleaf plants when grown in monoculture, with most LA in the bottom and middle strata of the plant, compared with the "inverted pyramidal" shape of velvetleaf plants, with most of its LA in the upper and middle portions of the plant, when grown with the crop. This may not be surprising because others reported that velvetleaf can adjust petiole length, leaf angle, and produce new leaves only on the upper portion of the plant under low-light conditions (Regnier and Harrison 1993).

The difference in the shape of the velvetleaf plants grown with the crop, as influenced by the emergence time and crop row spacing also, was noteworthy. Early-emerging velvetleaf positioned most of its LA in the upper strata of the plant in narrow rows compared with the LA positioned in the lower strata in wide rows. However, that was not the case for the late-emerging weeds. Late-emerging velvetleaf allocated most LA to its upper portion to reach the light regardless of the row spacing. This was probably because of the crop's ability to provide similar level of shading at the later velvetleaf emergence time in both row spacings.

Amount and timing of rainfall may have contributed to the year-related differences in the velvetleaf canopy development in this study. Velvetleaf did not produce as much LA and TDM in 2003 as compared with 2002. The 2003 year had sufficient moisture during early part of the growing season, whereas the rest of the season was dry (Table 4). Such water stress may have contributed to why velvetleaf did not respond as much to the lower light conditions in narrow row soybean and relative emergence times in 2003 as in 2002. These results are similar to those of Sailsbury and Chandler (1993), who reported that under dry conditions, velvetleaf was less competitive with cotton as long as the plants were under cotton canopy.

From a practical standpoint, this study reaffirms the importance of IWM practices such as adjusting weed control tactics depending on the relative time of weed emergence and crop row spacing. Furthermore, the data on LA, TDM, and seed production also suggested the greater need for con-

TABLE 4. Monthly rainfall and the mean daily temperature for Concord, NE, during the 2002 and 2003 growing seasons and the 30-yr averages.

Month	Rainfall		Temperature		30-yr average	
	2002	2003	2002	2003	Rainfall	Temperature
	mm		C		mm	C
May	68	107	13	14	98	16
June	66	162	24	20	106	22
July	47	63	26	24	79	24
August	148	22	22	24	74	22
September	14	173	18	17	67	17
Total	343	527			424	

trol of early- rather than late-emerging velvetleaf. Furthermore, the growth parameters and the plant architecture data presented in this article may aid those interested in developing mechanistic models to simulate plant growth or crop–weed interactions (or both).

Sources of Materials

[1] LI-3100 leaf area meter, LI-COR Inc., P.O. Box 4425, 4421 Superior Street, Lincoln, NE 68501.

Acknowledgments

Published as University of Nebraska Agricultural Research Division Journal Series No. 14646. Many thanks to Jon Scott, Ray Brentlinger, fellow graduate students, and many summer helpers for assisting with plot maintenance and treatment implementation.

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Received June 23, 2004, and approved October 18, 2004.