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# Soybean row spacing and weed emergence time influence weed competitiveness and competitive indices

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Weed competitiveness can be quantified with the concept of competitive index (CI), a relative scale of weed competitiveness. Field studies were conducted in 2002 and 2003 in northeastern and southeastern Nebraska to evaluate the influence of soybean row spacing and relative weed emergence time on the competitiveness of major weed species in soybean. Ten weed species were seeded in soybean spaced 19 and 76 cm apart at the planting, emergence, and first trifoliate leaf stages of soybean. Total dry matter (TDM), weed plant volume, and percent soybean yield loss were arbitrarily selected as a base for determining the CI for each weed species. Soybean yield loss was the least variable parameter used to quantify weed competitiveness and rank their CIs. In general, weeds grown with soybean planted in 19-cm rows produced less TDM, plant volume, and reduced soybean yield less than weed species grown in 76-cm rows. Later-emerging weeds produced less TDM, plant volume, and reduced soybean yield less than the early-emerging ones. In general, broadleaf species were more competitive than grass weed species. Common sunflower was the most competitive weed species in this study.

**Nomenclature:** Common sunflower, *Helianthus annuus* L. HELAN; soybean, *Glycine max* (L.) Merr. 'Agripro 2502', 'Agripro 2703'.

**Key words:** Competitive index, integrated weed management, plant volume, weed competition.

Weed populations in agricultural systems often consist of a broad complex of species and densities making management decisions complicated. A producer faced with a single weed species in his crop can generally make an economically based decision fairly efficiently (Forcella et al. 1996). However, in most cases producers are faced with a multi-species complex of weeds, different relative emergence times, variable weed densities, and site-specific environmental conditions (Evans et al. 2003; Knezevic et al. 1997, 2002, 2003). All these factors complicate the decision-making process, thereby necessitating computerized systems to integrate system information.

A number of computer programs have been developed over the past two decades to assist practitioners in making weed management decisions (Martin et al. 1997). Decision support systems (DSSs) are designed to help growers make weed management decisions that are economically and biologically justified. For these reasons, some in the weed science discipline have conducted research to contribute information toward construction and calibration of various DSSs (Gunther et al. 1993; Medd and Pandey 1993; Schweizer et al. 1994; Stigliani and Resina 1993; Wilkerson et al. 1991).

Some DSSs use the concept of competitive indices (CIs) for ranking weed species competitiveness. Coble and Mortensen (1992) proposed the CI indexing system and suggested that it measured relative weed competitiveness, with larger CI values indicating more competitive weeds. Such a ranking system of weed competitiveness is used in WeedSOFT, a DSS developed in Nebraska (Neeser et al. 2004). WeedSOFT calculates crop yield loss using several input variables and a set of yield loss functions. Input variables are provided by the user and include information about the crop

species, crop growth stage, and density and growth stage of over 40 weed species. Crop yield loss due to each weed species is calculated by using its CI value. WeedSOFT uses a modifier to adjust the CI values to account for crop row spacing and weed and crop growth stages (Neeser et al. 2004). Many CI values in WeedSOFT are based on expert opinion or experimental data or both derived from single-species crop–weed competition studies. However, expert opinions can differ, while results of many single-weed crop–weed interference studies can be variable among years and locations (Bauer et al. 1991; Chikoye et al. 1995; Cousens et al. 1988; Knezevic et al. 1995, 1997; Lindquist et al. 1999; Lotz et al. 1996). Therefore a total of ten common midwestern U.S. weed species were seeded in soybean with the primary objective of describing their growth as influenced by crop row spacing and weed emergence timing. The secondary objective was to determine the CI for each of the weed species and rank them according to their competitiveness.

## Materials and Methods

Field experiments were conducted in 2002 and 2003 at the University of Nebraska Haskell Agricultural Laboratory in Concord, NE (lat 42.37°N, long 96.97°W) and in 2003 at the University of Nebraska Agricultural Research Farm in Lincoln, NE (lat 40.82°N, long 96.68°W) for a total of 3 site yr. Concord and Lincoln are located in northeastern and southeastern Nebraska, respectively, and are approximately 190 km apart. Soil types were Kennebec series silty clay loam (fine-silty mixed, mesic Cumulic Hapludolls) at Concord, and Sharpsburg series silty clay loam (fine, montmorillonitic mesic Typic Argiudolls) at Lincoln.

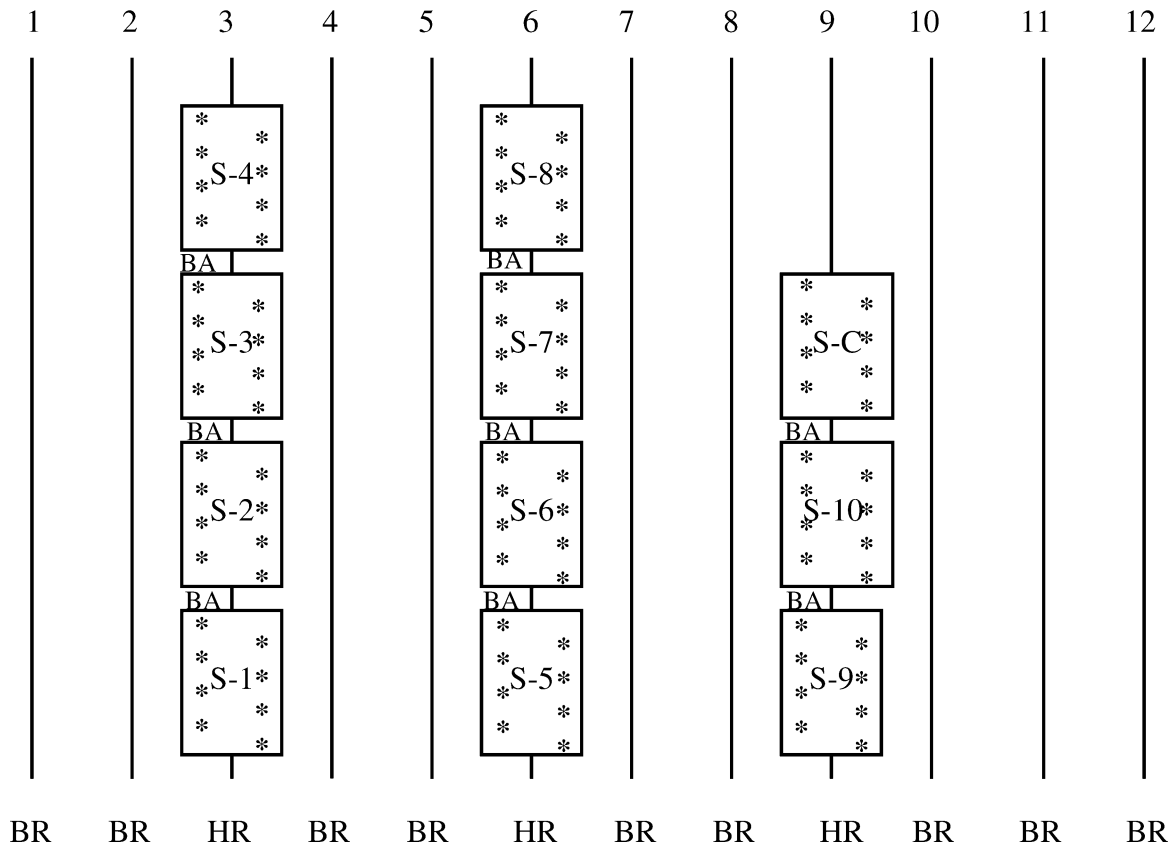


FIGURE 1. Layout of one subplot of a split-split plot design used in the study. Soybean row spacing (19 or 76 cm) was the main plot, the three relative weed emergence times were the subplots, and the 10 weed species were the sub-subplots. Each level was randomized. Subplot size was 21 m long by 9 m wide. Numbers 1–12 indicate crop row numbers in 76-cm wide rows; abbreviations BR, BA, and HR indicate buffer rows, buffer areas (1 m), and harvest rows, respectively. Individual weed species were grown in areas marked S1–S10, and SC was the weed-free area. An asterisk indicates a single weed plant that was positioned within 10 cm on either side of the soybean row, creating a 4-m-long single-species stand of eight plants for each weed species planted 1 m apart. The same layout was used in the 19-cm row spacing, but the subplot had a total of 48 rows to cover the same land area.

For each year and location, primary tillage consisted of spring disking followed by field cultivation before soybean planting. The previous crop was grain sorghum [*Sorghum bicolor* (L.) Moench] at Lincoln and corn (*Zea mays* L.) at Concord for each year. Glyphosate-tolerant soybean varieties, ‘Agripro 2502’ and ‘Agripro 2703’, were planted in Concord and Lincoln, respectively, at a density of 407,000 seeds ha<sup>-1</sup> in 19- and 76-cm rows using a John Deere drill. Soybean was planted on May 31, 2002, and June 5, 2003, at Concord and on May 29, 2003, at Lincoln.

Experiments were established in a factorial arrangement of treatments in a split-split plot design with four replicates. Soybean row spacing (19 or 76 cm) was the main plot completely randomized, the three relative weed emergence times were the subplots randomized within the main plots, and the 10 weed species were the sub-subplots randomized within the subplots (Figure 1). The main plot was 75 m long with twelve 76- and forty-eight 19-cm-wide rows running the length of the plot. The three subplots were established by seeding weeds at soybean planting, emergence (VE), and first trifoliolate leaf (V1) stages. The six broadleaf and four grass weed species included common cocklebur (*Xanthium strumarium* L. XANST), common sunflower (*Helianthus annuus* L. HELAN), common waterhemp (*Amaranthus rudis* Sauer AMATA), giant ragweed (*Ambrosia trifida* L. AMBTR), redroot pigweed (*Amaranthus retroflexus* L. AMARE), velvetleaf (*Abutilon theophrasti* Medic. ABUTH), barn-

yardgrass [*Echinochloa crus-galli* (L.) Beauv. ECHCG], fall panicum [*Panicum dichotomiflorum* (L.) Michx. PANDI], giant foxtail (*Setaria faberi* Herrm. SETFA), and yellow foxtail [*Setaria glauca* (L.) Beauv. SETLU]. The ten weed species were established at Concord in both years; however, giant ragweed had sporadic establishment and thus soybean yield loss data are not presented. At Lincoln, fall panicum was the only weed to have poor emergence; thus data are not presented. Seeds of a single weed species were hand planted, alternating 10 cm on either side of the soybean row spaced 0.5 m apart, creating a 4-m-long single-species stand of eight plants for each weed species (Figure 1). Soybean growth stages were determined as described by Ritchie et al. (1993). Weed emergence dates were recorded at the time of approximate 50% weed emergence (Table 1). For example, the weed emergence date was recorded when four out of eight weed plants had emerged in a sub-subplot. Weeds were thinned by hand to obtain desired density of 1 plant per 0.5 m of row weekly beginning at soybean V1 stage. Undesirable species were removed by hand or sprayed with glyphosate at a labeled rate as needed. Plastic jugs were temporarily placed over desired weeds to protect them from glyphosate drift.

Plant height was measured from the soil surface to the highest free-standing point of one randomly selected plant in each sub-subplot. Canopy diameter was measured at its widest point. Weed plant height and canopy diameter were

TABLE 1. Weed planting and emergence dates, and soybean leaf stages at the time of weed emergence for each weed cohort in 2002 and 2003.

Cohort	Planting date			Emergence date			Soybean leaf stage <sup>a</sup>		
	Concord		Lincoln	Concord		Lincoln	Concord		Lincoln
	2002	2003	2003	2002	2003	2003	2002	2003	2003
1	May 31	June 5	May 29	June 10	June 16	June 10	VE	VE	VE
2	June 10	June 13	June 7	June 19	June 25	June 17	V1	V1	V1

<sup>a</sup> Abbreviations: VE, emergence; V1, first trifoliate leaf.

measured biweekly until physiological maturity. Weed volume was defined and presented as the point of maximum cylindrical volume for each respective weed species and was calculated using Equation 1:

$$V = \pi \times r^2 \times h \quad [1]$$

where V is weed volume (cm<sup>3</sup>),  $\pi$  is the ratio between the circumference and the diameter of any given circle equaling 3.14159, *r* is the radius of the weed at its widest point, and *h* is weed height. Weed aboveground biomass (TDM) was harvested by hand over a week-long period as the weed species reached their respective physiological maturity. Samples were dried at 70 C to a constant mass and weighed.

Soybean plants were hand harvested in each sub-subplot at physiological maturity from a 4-m length of one row in 76-cm rows or four rows in 19-cm rows. There were two weed-free buffers, 2- and 1-m long, between each subplot and sub-subplots, respectively, and weed-free buffers of 1.5 m between sub-subplots (Figure 1). Weed-free buffers successfully prevented competition between plants of neighboring sub-subplots. Weed-free yield was harvested from a single soybean row in 76-cm rows and from four rows in 19-cm rows, each 4 m long. Soybean plants were counted and threshed to separate grain. Seeds were then dried at 70 C to a constant mass and weighed. Yield loss was calculated by relating the weed-free yield to the yield from each sub-subplot.

## Data Analysis

Analyses of variance was performed using PROC MIXED procedure in SAS (1999) to test significance ( $P < 0.05$ ) of year, location, soybean row spacing, weed emergence time, weed species, replications, and their interactions with weed TDM, weed volume, and soybean yield loss response variables.

Values of CI were calculated for each weed species based

on weed TDM, weed volume, or soybean yield loss using Equation 2:

$$CI_x = (A_x/B_y)K \quad [2]$$

where  $CI_x$  is the competitive index of the target weed species *X*,  $A_x$  is the measured variable (TDM, weed volume, or soybean yield loss) associated with target *X*,  $B_y$  is the measured variable of the most competitive weed, and *K* is a constant with a value of 10. The constant  $K = 10$  provides a common scale to calculate CI values that range from 0.01 to 10 and can be used to compare competitiveness among weed species. Common sunflower had the greatest TDM and volume, and reduced soybean yield loss the most when it emerged with soybean in 76-cm rows compared to all other weed species. Thus, common sunflower was considered the most competitive weed species (e.g.,  $B_y$ ) to calculate all other CI values in this study.

## Results and Discussion

### Weed Dry Matter Production

Weed dry matter production was influenced by location ( $P < 0.05$ ); therefore, Lincoln and Concord data were analyzed separately, but years were not different at Concord. Location differences can be attributed to rainfall amount and periodicity (Table 2). Lincoln received more timely rainfall during weed establishment and vegetative growth compared to Concord. In general, weed species produced higher TDM plant<sup>-1</sup> at Lincoln than at Concord. At both locations, weed species from the first and second planting dates emerged at soybean VE and V1 stages, respectively (Table 1). Weed species seeded at the third planting date did not emerge at any of the two locations and years as a result of dry weather conditions (e.g., low rainfall and high temperature).

At Concord, TDM production was not significantly dif-

TABLE 2. Monthly rainfall, mean daily temperature, and their 30-yr averages in Concord, NE, during the 2002 and 2003 growing seasons and in Lincoln, NE, during the 2003 growing season.

Month	Rainfall						Temperature				
	Concord			Lincoln			Concord			Lincoln	
	2002	2003	30-yr average	2003	30-yr average	2002	2003	30-yr average	2003	30-yr average	
	mm						C				
May	68	107	98	68	107	13	14	16	16	17	
June	66	162	106	166	99	24	20	22	21	23	
July	47	63	79	26	91	26	24	24	27	25	
August	148	22	74	32	76	22	24	22	26	23	
September	14	173	67	97	84	18	17	17	17	18	
Total	343	527	424	389	457						

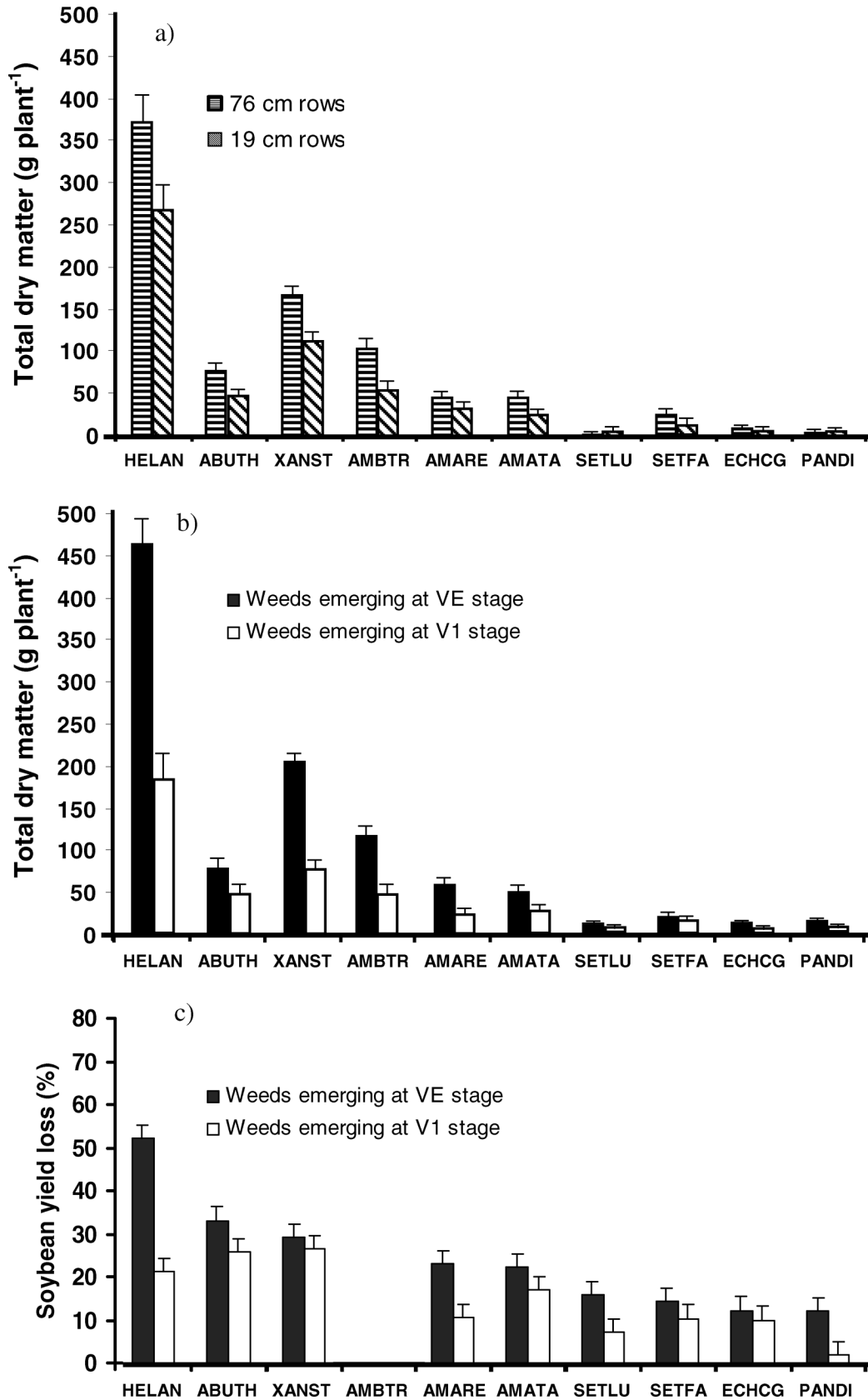


FIGURE 2. Weed species (WSSA-approved letter code for weed names) total dry matter (g plant<sup>-1</sup>) at Concord, NE (averaged over 2002 and 2003) as influenced by (a) soybean row spacing, (b) time of weed emergence, and soybean yield loss at Concord (averaged over 2002 and 2003) as influenced by time of weed emergence. Means and standard error bars based on least significant means (lsmeans) ( $P < 0.05$ ).

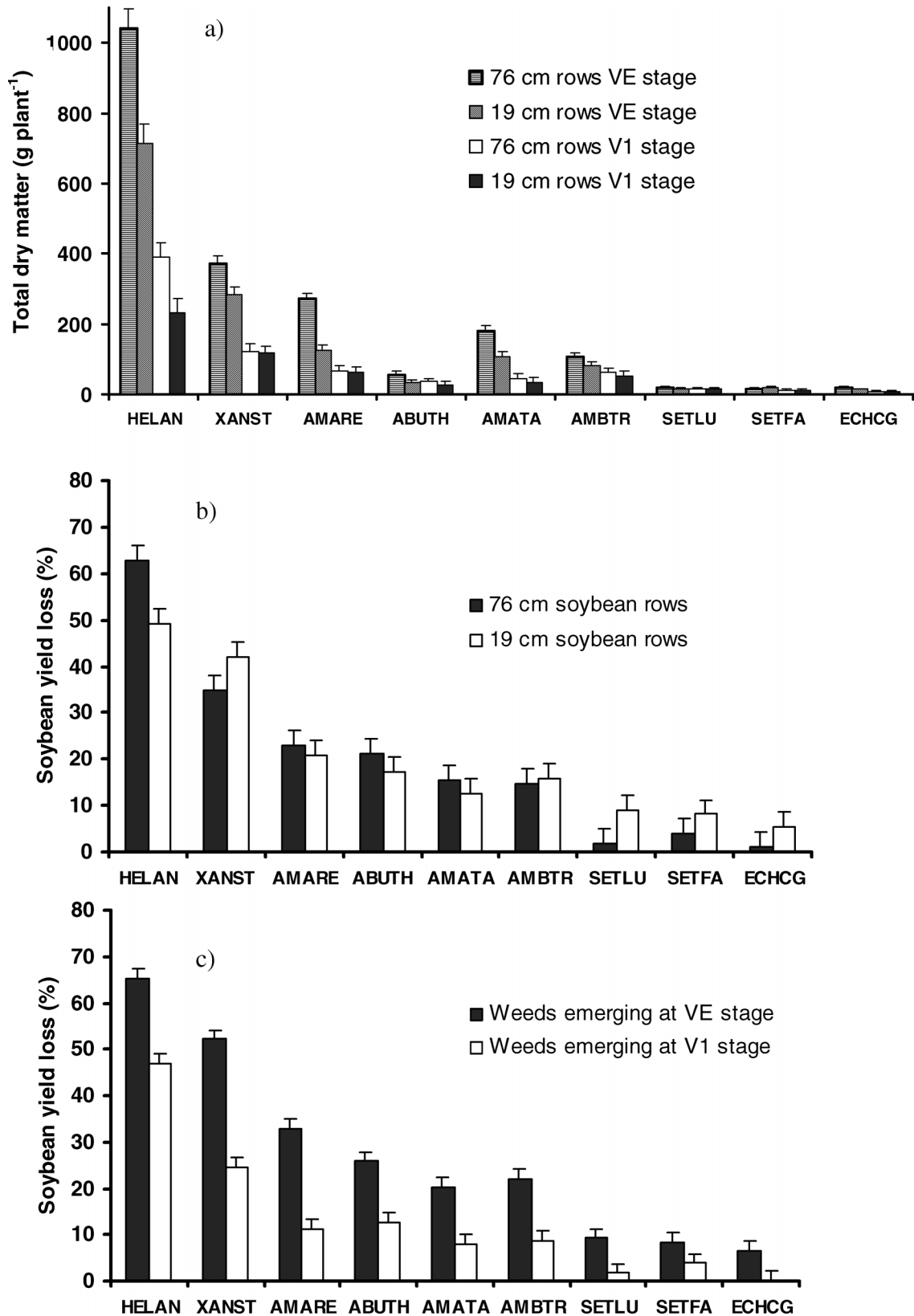


FIGURE 3. Weed species (WSSA-approved letter code for weed names): (a) total dry matter (g plant<sup>-1</sup>) as influenced by three-way interaction between soybean row spacing, time of weed emergence, and weed species; soybean yield loss (%) as influenced by (b) soybean row spacing and (c) time of weed emergence at Lincoln, NE, in 2003. Means and standard error bars based on least significant means (lsmeans) ( $P < 0.05$ ).

TABLE 3. Weed species plant volume as influenced by soybean row spacing (76- and 19-cm rows), time of weed emergence (emergence [VE] and first trifoliolate leaf [V1] crop stages), and weed species at Concord, NE (averaged over 2002 and 2003) and Lincoln, NE (2003).

Weed species <sup>a</sup>	76 cm				19 cm				SE <sup>b</sup>	
	VE		V1		VE		V1			
	Concord	Lincoln	Concord	Lincoln	Concord	Lincoln	Concord	Lincoln	Concord	Lincoln
	m <sup>3</sup> plant <sup>-1</sup>									
HELAN	1.296 a <sup>c</sup>	4.931 a	0.352 a	2.948 a	0.680 a	3.026 a	0.165 a	0.473 a	0.0810	0.7871
XANST	1.226 a	2.787 a	0.316 a	0.433 b	0.511 b	0.762 b	0.100 ab	0.363 a	0.1362	0.1519
AMATA	0.193 b	0.396 b	0.115 ab	0.188 bc	0.049 bc	0.361 bc	0.024 bc	0.074 b	0.0456	0.0824
AMBTR	0.154 b	0.508 b	0.049 abc	0.104 c	0.062 b	0.250 bc	0.034 bcd	0.038 b	0.0492	0.1505
AMARE	0.137 b	0.417 b	0.067 abc	0.323 b	0.055 bc	0.206 c	0.043 abc	0.063 b	0.0254	0.0571
ABUTH	0.119 bc	0.467 b	0.060 abc	0.118 bc	0.068 b	0.221 c	0.028 bcde	0.072 b	0.0195	0.0253
SETFA	0.056 bcd	0.029 c	0.014 bcd	0.019 d	0.013 bcd	0.031 d	0.009 def	0.004 c	0.0153	0.0053
SETLU	0.027 bcde	0.026 c	0.011 bcd	0.017 e	0.011 cd	0.010 e	0.004 ef	0.004 c	0.0033	0.0098
ECHCG	0.022 cde	0.027 c	0.008 e	0.005 d	0.007 d	0.008 e	0.002 f	0.001 c	0.0076	0.0160
PANDI	0.008 e		0.008 e		0.002 d		0.004 ef		0.0022	

<sup>a</sup> WSSA-approved letter code for weed names.

<sup>b</sup> Means and standard errors (SE) for each weed species, based on least squares means and  $P < 0.05$ .

<sup>c</sup> Within a column, the same letter indicates that the weed volume is not significantly different based on a multiple range  $t$  test at  $P < 0.05$ .

ferent among years; therefore, data were combined. There was a two-way interaction between soybean row spacing and weed species and between weed emergence time and weed species ( $P < 0.05$ ); therefore, weed species data were presented separately for each row spacing and emergence time. Most weed species grown in 19-cm rows produced less TDM than in 76-cm rows (Figure 2a). Common sunflower produced 375 and 275 g plant<sup>-1</sup> of TDM when grown in 76- and 19-cm soybean rows, respectively. Overall, grass weed species produced the least amount of TDM (Figure 2a).

Weed emergence time affected weed growth at Concord. Weeds produced less TDM when emerging at the V1 soybean stage than earlier-emerging ones at the VE stage. For example, common waterhemp produced 50 g plant<sup>-1</sup> when emerging early compared to 25 g plant<sup>-1</sup> emerging later (Figure 2b). In general, broadleaf weed species were impacted more by relative emergence time than were grass weed species.

At Lincoln, there was a three-way interaction between soybean row spacing, weed emergence time, and weed species ( $P < 0.05$ ); therefore, weed species data were presented separately for each row spacing and emergence time. Generally, weed species grown in 76-cm wide rows produced more TDM plant<sup>-1</sup> than in 19-cm rows (Figure 3a). Also, weed species that emerged with the crop produced more TDM plant<sup>-1</sup> than later-emerging weeds (Figure 3a).

## Weed Volume

In general, results based on weed volume followed the same trend as those of TDM production. Because weed volume varied among locations, data were analyzed separately for each site ( $P < 0.05$ ). Generally, weeds grown at Concord had lower volume than those from Lincoln (Table 3). Common sunflower produced greater plant volume at Lincoln than Concord. This difference has been observed in the past (A. R. Martin, unpublished data) and may be due to the higher temperatures in Lincoln than in Concord.

Because weed volume data at Concord were not significantly different between years, data were combined. There

was a three-way interaction between soybean row spacing, weed emergence time, and weed species ( $P < 0.05$ ); therefore, weed species data were presented separately for each row spacing and emergence time. Weeds grown in 76-cm soybean rows produced more volume than those in 19-cm rows for each emergence cohort (Table 3). However, soybean row spacing had more impact on earlier- than on later-emerging weeds. This is likely a result of soybean canopy closure timing. In general, soybean canopy closure occurred about 20 d later in 76-cm than in 19-cm rows, providing a longer shade-free environment. This provided a competitive advantage to weeds emerging at the first emergence date (VE). Broadleaf weeds generally produced greater plant volume than grass species (Table 3). However, that was not the case for all species. Velvetleaf and giant foxtail plant volumes did not differ in any treatment.

At Lincoln, plant volume data had a three-way interaction between soybean row spacing, weed emergence time, and weed species ( $P < 0.05$ ); therefore, weeds species data are presented separately for each row spacing and emergence time (Table 3). Common waterhemp, common sunflower, redroot pigweed, and giant foxtail produced more plant volume in 76-cm than in 19-cm soybean rows. Plant volume was affected similarly to weed emergence time as it did at Concord.

## Soybean Yield Loss

Soybean yield loss varied across locations; therefore, data were presented separately for each site ( $P < 0.05$ ). At Concord, there were no effects of year or row spacing, but there was an interaction between weed emergence time and weed species ( $P < 0.05$ ). Generally, weeds emerging with soybean caused greater yield reduction than those emerging at the V1 crop stage. For instance, soybean yield loss was 52 and 21% when common sunflower emerged at the VE and V1 crop stages, respectively (Figure 2c).

At Lincoln, soybean yield loss was dependent upon row spacing as well as each weed emergence time ( $P < 0.05$ ). Generally, weeds caused greater soybean yield losses when grown in 76- than in 19-cm soybean rows. The difference

between yield losses in 76- vs. 19-cm rows was 29 and 31% for common sunflower and velvetleaf, respectively (Figure 3b). However, common cocklebur, giant ragweed, and grass species affected soybean yield loss similarly in both row spacings. This may be explained by giant ragweed and common cocklebur apparent tolerance to reduced light (Regnier and Stoller 1989; Webster et al. 1994). Webster et al. (1994) reported that giant ragweed was able to compete for light by placing leaves both within and above the soybean canopy. Common cocklebur has been described as a species that does not grow taller than the soybean canopy until much later in the season (Regnier and Stoller 1989). They suggested that common cocklebur can branch extensively, shading lower soybean leaves during early- and mid-season. Contrary to common cocklebur that exploits both full light (above crop canopy) and shaded environment (within crop canopy), velvetleaf was described as a species that prefers to use light by placing most of its leaves above the soybean canopy (Regnier and Harrison 1993). This suggests that common cocklebur and giant ragweed can be as competitive in 19-cm as in 76-cm soybean rows compared to the other broadleaf weeds, such as velvetleaf, which alters its canopy upwards to shade the soybean crop. Additionally, weed emergence time affected soybean yield loss similar to that observed at Concord (Figure 3c).

At both locations, broadleaf weeds caused greater yield reduction than grasses. For instance, at Concord, common sunflower, velvetleaf, common cocklebur, redroot pigweed, and common waterhemp caused 52, 33, 29, 23, and 23% yield loss when they emerged with the crop, respectively, compared to yellow foxtail, giant foxtail, barnyardgrass, and fall panicum, which caused 16, 15, 13, and 13% yield loss, respectively (Figure 2c). We suggest that lower yield losses caused by grasses are likely a result of the low grass density used in this study. Although the yield losses presented in this paper provided a good indication of weed competitiveness when compared among species grown at the same density, it is important to note that under high grass pressure, crop yield loss can be as high as the losses caused by most competitive broadleaf weed (S. Z. Knezevic, unpublished data).

### Competitive Indices Based on Measured Variables

CI values were presented according to the significant effects of site, row spacing, or emergence time for each variable tested (TDM, weed volume, soybean yield loss). Generally, CI values were higher for most weeds grown in wider crop rows and for earlier weed emergence times (Tables 4–6). For example, CI values based on TDM for common sunflower, common cocklebur, and velvetleaf were 10, 4.53, and 2.08 in 76-cm wide rows compared to 7.33, 2.99, and 1.27 in 19-cm rows for each respective weed at Concord (Table 5). When the same species emerged at the VE stage in 76-cm rows, CI values were 10, 3.59, and 0.54 compared to 3.74, 1.17, and 0.34 for emergence at the V1 stage, respectively, based on TDM. A similar response was observed for CI values based on soybean yield loss (Table 4) and volume (Table 6).

Broadleaf weeds were more competitive than grass weeds, which resulted in much higher CI values for broadleaf species. For instance, common sunflower had CI = 10 based on TDM, volume, or yield loss; and common cocklebur had

TABLE 4. Weed species competitive indices (CI) and competitive ranking (Rank) for each weed species based on weed volume as influenced by soybean row spacing (76- and 19-cm rows) and relative time of weed removal (emergence [VE] and first trifoliate leaf [V1] crop stages) at Concord, NE (2002 and 2003) and Lincoln, NE (2003).

Weed species <sup>a</sup>	CI										Rank									
	76 cm					19 cm					76 cm					19 cm				
	VE		V1			VE		V1			VE		V1			VE		V1		
HELAN	10	10	2.83	5.98	0.96	1.34	0.96	1	1	1	1	1	1	1	1	1	1	1	1	1
XANST	9.92	5.65	1.67	0.88	0.74	0.81	0.74	2	2	2	2	2	2	2	2	2	2	2	2	2
AMATA	1.57	0.80	0.89	0.38	0.15	0.20	0.15	3	3	3	3	3	3	3	3	3	3	3	3	3
AMBTR	1.24	1.03	0.20	0.21	0.08	0.28	0.08	4	4	4	4	4	4	4	4	4	4	4	4	4
AMARE	1.11	0.85	0.55	0.66	0.13	0.35	0.13	5	5	5	5	5	5	5	5	5	5	5	5	5
ABUTH	0.97	0.95	0.49	0.24	0.15	0.23	0.15	6	6	6	6	6	6	6	6	6	6	6	6	6
SETFA	0.45	0.06	0.14	0.04	0.01	0.08	0.01	7	7	7	7	7	7	7	7	7	7	7	7	7
SETLU	0.22	0.05	0.10	0.04	0.01	0.04	0.01	8	8	8	8	8	8	8	8	8	8	8	8	8
ECHCG	0.18	0.06	0.12	0.01	0.002	0.02	0.002	9	9	9	9	9	9	9	9	9	9	9	9	9
PANDI	0.07		0.03		0.04	0.04	0.04	10	10	10	10	10	10	10	10	10	10	10	10	10

<sup>a</sup> WSSA-approved letter code for weed names.



TABLE 5. Weed species competitive index (CI) and competitive ranking (Rank) for each weed species based on total dry matter (g plant<sup>-1</sup>) as influenced by soybean row spacing (76- and 19-cm rows) and time of weed emergence (emergence [VE] and first trifoliolate leaf [V1] crop stages) at Concord, NE (averaged over 2002 and 2003) and Lincoln, NE (2003).

Weed species <sup>a</sup>	CI								Rank							
	Concord				Lincoln				Concord				Lincoln			
	VE		V1		76 cm		19 cm		VE		V1		76 cm		19 cm	
	VE	V1	76 cm	19 cm	VE	V1	76 cm	19 cm	VE	V1	76 cm	19 cm	VE	V1	76 cm	19 cm
HELAN	10	4.03	10	7.33	10	3.74	6.88	2.22	1	1	1	1	1	1	1	1
XANST	4.42	1.66	4.53	2.99	3.59	1.17	2.74	1.12	2	2	2	2	2	2	2	2
AMBTR	2.54	1.02	2.81	1.59	1.02	0.59	0.76	0.5	3	3	3	3	5	4	5	4
ABUTH	1.71	1	2.08	1.27	0.54	0.34	0.31	0.25	4	4	4	4	6	6	6	6
AMATA	1.09	0.54	1.3	0.72	1.74	0.44	1.04	0.33	6	6	5	6	4	5	4	5
AMARE	1.23	0.56	1.29	0.93	2.62	0.64	1.22	0.61	5	5	6	5	3	3	3	3
SETFA	0.41	0.37	0.61	0.36	0.16	0.11	0.18	0.1	7	7	7	7	9	8	7	8
PANDI	0.29	0.12	0.32	0.18					8	9	8	10				
ECHCG	0.29	0.16	0.32	0.23	0.17	0.07	0.13	0.07	9	8	9	8	7	9	9	9
SETLU	0.21	0.12	0.2	0.21	0.17	0.13	0.15	0.14	10	10	10	9	8	7	8	7

<sup>a</sup> WSSA-approved letter code for weed names.

CI = 3.6 based on TDM, CI = 5.7 based on volume, and CI = 5.5 based on yield loss in 76-cm rows and emerging with the crop at Lincoln compared to many grass species whose CI values ranged from 0.01 to 3.1 across all measured variables (Tables 4–6).

There were also inconsistent results in CI values depending on what variable CI calculations were based, which also resulted in differential weed ranking (Tables 4–6). For example, in some cases CI based on volume were larger for weeds grown in 19- than 76-cm rows, and for later-emerging weeds compared to early-emerging ones, which was contrary to the CIs based on TDM and yield loss. This indicated that the CI values based on plant volume were the most inconsistent and possibly the least reliable. For instance, using CI based on volume, redroot pigweed was more competitive in narrow than in wide rows, which contradicted the CI values based on TDM and yield loss. Also, early-emerging common cocklebur in 76-cm rows had a CI = 9.9 at Concord based on plant volume compared to CI = 4.4 based on TDM. The difference in CI values based on plant volume was likely a result of the method used to calculate plant volume for each weed species. Equation 1

assumes a cylindrical volume for every weed species; however, not all weed species have a cylindrical shape. Therefore, we suggest that future studies of plant volumes should use equations that are designed to account for respective plant shapes. For example, some species have a canopy in the shape of a cylinder, while others are “cone”- or “inverted cone”-shaped. Further studies are needed to test such a hypothesis.

Of the three plant variables tested, our data also suggested that the CI values based on soybean yield loss were the least variable. Therefore, we suggest that the yield loss parameter would be the most suitable parameter for quantifying weed species competitiveness in soybean. Preventing crop yield loss is of most significance to practitioners and a main reason for making weed management decisions.

Because of the variability in CI values between the two sites, we suggest that there is a need for further refinement of the CI concept for use with DSSs. A multi-state experiment may provide additional information about the potential magnitude of the site-specific variability that can influence CI values. Also, the CI values presented in this paper must be tested with current (or future) DSS computer pack-

TABLE 6. Weed species competitive index (CI) and competitive ranking (Rank) for each weed species based on soybean yield loss (%) as influenced by relative time of weed emergence (emergence [VE] and first trifoliolate leaf [V1] crop stages) at Concord, NE (averaged over 2002 and 2003) and at Lincoln, NE (2003), and soybean row spacing (76- and 19-cm rows) at Lincoln.

Weed species <sup>a</sup>	CI						Rank					
	VE		V1		Lincoln		VE		V1		Lincoln	
	Concord		Lincoln		76 cm		Concord		Lincoln		76 cm	
	Concord	Lincoln	Concord	Lincoln	76 cm	19 cm	Concord	Lincoln	Concord	Lincoln	76 cm	19 cm
HELAN	10	10	4.10	7.20	10	7.82	1	1	3	1	1	1
ABUTH	6.36	3.96	4.93	1.94	3.36	2.74	2	4	2	3	4	4
XANST	5.60	7.99	5.08	3.78	5.52	6.68	3	2	1	2	2	2
AMARE	4.45	5.02	2.06	1.71	3.65	3.32	4	3	5	4	3	3
AMATA	4.33	3.09	3.32	1.21	2.44	2.02	5	6	4	6	5	6
AMBTR		3.38		1.32	2.35	2.52		5		5	6	5
SETLU	3.11	1.42	1.42	0.26	0.30	1.44	6	7	8	8	8	7
SETFA	2.82	1.26	2.05	0.59	0.63	1.29	7	8	6	7	7	8
ECHCG	2.41	1.00	1.97	0.01	0.17	0.87	8	9	7	9	9	9
PANDI	2.40		0.45				9		9			

<sup>a</sup> WSSA-approved letter code for weed names.

ages. For example, the CI values presented in this paper may improve performance of the WeedSOFT program by replacing current CIs, which are primarily based on expert opinion, with the “new” CIs from this multi-species study. Further evaluation of WeedSOFT is needed to test such a hypothesis.

Despite the variability in CI values between the two sites, the CI values and weed rankings presented in this paper can be useful to both practitioners and academics. Practitioners can use our CI data as a general rule of thumb for comparing competitive ability of weed species as part of their decision-making process for weed management. For example, knowing that there is a fivefold difference in competitive ability between a weed with CI = 10 and a weed with CI = 2 can be very useful in making plans for weed control options. This can result in less extensive management options for less competitive weeds, which usually results in economic savings. Academics can use such information as a teaching tool for comparing weed species, both in a regular academic setting or extension activities. Perhaps students would like to know if five plants of a weed with CI = 2 would have a similar competitive ability as one plant with CI = 10. This provides a simple visual tool for comparison among weed species as part of an effective learning process.

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