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Interference of large crabgrass (*Digitaria sanguinalis*) with snap beans

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Field experiments were conducted to determine the effect of large crabgrass densities of 0.5 to 8 plants m^{-1} of row and emergence time on snap bean yield. Large crabgrass was planted either along with snap beans (early) or when the first trifoliate leaf of snap beans was opening (late). Observed yield loss ranged from 46 to 50%, and predicted yield loss ranged from 53 ± 29.3% to 63 ± 18.3%. Relative leaf area was correlated to snap bean yield (r^2 = 0.88 to 0.92). The relative damage coefficient (q), an indication of the competitiveness of large crabgrass with snap bean, was 1.65 ± 1.03 and 1.26 ± 0.72 for early- and late-emerging large crabgrass, respectively. Early-emerging large crabgrass reduced snap bean biomass 10 to 28% and snap bean pod numbers 44 to 60%, depending on the density. Because of intraspecies competition, leaf area index and number of seed for large crabgrass were reduced with increasing density. Emergence of > 2 plants m^{-1} of large crabgrass with snap beans should be controlled to avoid significant yield loss.

Nomenclature: Large crabgrass, *Digitaria sanguinalis* (L.) Scop. DIGSA; snap bean, *Phaseolus vulgaris* L. 'Matador'.

Key words: Relative leaf area, weed density, competition, critical weed-free period, threshold density.

Large crabgrass, an annual weed, is distributed throughout the world's tropical and temperate regions (Simpson 1990) and is mainly propagated by seed (Holm et al. 1979, 1991). Large crabgrass is a serious problem weed in peppers (*Capiscum annum* L.) (Fu and Ashley 1999), watermelon (*Citrullus lanatus* L.) (Monks and Schultheis 1998), sorghum [*Sorghum bicolor* (L.) Moench.] (Smith et al. 1990), and cotton (*Gossypium hirsutum* L.) (Buchanan and Burns 1971). Large crabgrass is one of the most common weeds found among vegetable crops in the United States (Bridges and Baumann 1992). It is a prolific seed producer (Johnson and Coble 1986) that emerges from May through September, when the main season crop of snap bean is produced (King and Oliver 1994).

Although management of large crabgrass in snap beans at an early growth stage can be achieved through cultivation or through application of herbicides such as trifluralin, metolachlor, or sethoxydim (Hartzler and Foy 1983), the weed becomes difficult to control as the cropping season progresses. Monks and Schultheis (1998) reported difficulties in controlling large crabgrass when it was over 8 to 10 cm tall or when it formed adventitious roots at the stem nodes. Furthermore, large crabgrass can easily reestablish itself by nodal roots after cultivation.

In Wisconsin, large crabgrass is reported to be resistant to acetyl-coenzyme A carboxylase inhibitors such as fluazifop-P butyl ester and sethoxydim (Wielderholt and Stollenberg 1995, 1996). Because of the limited choice of herbicides available to snap bean growers, the development of herbicide resistance in common weeds will likely continue to pose a serious weed management problem. Therefore, it is necessary to develop alternative weed management approaches to complement the few registered herbicides.

Although weeds emerging with and competing all season with snap beans result in decreased yields, it is unclear how specific time of emergence and density of weeds are involved in this response. In a study involving large crabgrass and smooth pigweed (*Amaranthus hybridus* L.), Lugo and Talbert (1989) observed a reduction in snap bean yield when large crabgrass was allowed to compete for the full season. They observed a snap bean yield loss of 72%, a dry weight reduction of 46%, and a leaf area reduction of 48% caused by large crabgrass interference. Evanylo and Zehnder (1989) reported a 75% reduction of snap bean pod yield when ragweed (*Ambrosia* sp.) was allowed to compete for the full season. The severe effect of weeds on snap bean yield and pod quality might be the result of the sensitivity of the shallow roots of snap bean to water stress (Bananno and Mack 1983). The objective of our study was to determine the effect of emergence time and density of large crabgrass on snap bean growth and yield.

Materials and Methods

Field experiments were conducted in 1998 and 1999 at the University of Illinois, Cruise Tract Vegetable Research Farm. The soil type was a Flanagan silt loam (fine montmorillonitic, mesic, Aquic Argiudoll; pH 6.5 and 3.2% organic matter). Site preparation included fall chisel plowing followed by spring disking, and harrowing. Snap bean seeds were planted at 80 kg ha^{-1} in 90-cm rows to give a plant population of 116,000 plants ha^{-1}. Because time of emergence affects weed thresholds, one set of the plots was seeded with large crabgrass at planting on June 1, 1998 and May 28, 1999 (early), and the second set of plots was seeded when the first trifoliate was just opening on June 17, 1998 and June 12, 1999 (late).

The experiment was a split-plot design with four replications. Whole-plot treatments included a combination of large crabgrass densities and planting dates (no weeds, early large crabgrass, and late large crabgrass). The four weed densities were 0.5, 1, 2, or 8 large crabgrass plants m^{-1} of row. The subplots were each 9 by 6 m. Twelve rows of snap beans were seeded in each subplot. Large crabgrass seed was purchased from a commercial supplier[1] and hand seeded in clumps adjacent to the crop row. Early-planted large crabgrass emerged with snap beans within 5 to 6 d of planting. Late-planted large crabgrass emerged 4 d after planting or when snap beans were at the second or third trifoliate. To obtain the desired weed densities, the crabgrass seedlings were thinned when they had two to four leaves.

Weeds other than large crabgrass were removed by cultivation, hand hoeing, and a POST application of bentazon, which is registered for the control of broadleaf weeds in snap beans. The herbicide was broadcast on all plots at 1.1 kg ai ha^{-1} on June 14, 1998 and June 11, 1999. No crop injury occurred from the bentazon application.

Every 2 wk, the shoots of 8 snap bean plants and 4 large crabgrass plants in the third and seventh rows of the plots were cut at the soil surface and their biomass determined. Leaf area for large crabgrass and for snap beans was recorded only in 1999 because of wet weather and insufficient labor in 1998. Leaf area of both crabgrass and snap beans was determined by removing all the leaves from each plant and passing them individually through a leaf area meter.[2] Leaf area index (LAI) was calculated by dividing leaf area per plot (m^2) by plot area (m^2). Both biomass and LAI are important variables influencing competition (Ngouajio et al. 1999). After leaf area was measured, the shoots were dried to a constant weight at 70 C and dry mass determined.

Weed seed production was estimated by the procedure of Knezevic et al. (1994). Five consecutive large crabgrass plants per plot were harvested at the end of the experiment. To collect crabgrass seeds, the inflorescences were cut, bagged, and dried in a greenhouse. Seed heads were threshed and the collected seed counted. Total seed number per crabgrass plant was estimated by counting seed in a subsample and correlating the seed number with the total dry mass of the inflorescence. Because of consistent rains and irrigation in the period leading to and at harvesting, no attempt was made to estimate the crabgrass seed loss due to shattering. Thus, our seed number is a conservative estimate of seed production.

Crop yield was determined by harvesting snap beans at three different times. Each time only snap beans that were marketable (more than 5.5 cm long) were picked. A 2-m section from each of the two center rows was harvested and total pod weight determined by summing the three harvests. At each harvest, 10 snap bean pods were randomly selected and their length and diameter determined as a measure of quality.

Analysis of variance was performed using the general linear model procedure (SAS 1995) to test the significance of large crabgrass emergence date, large crabgrass density, and the interaction between emergence date and density. Emergence time and density of large crabgrass were significant for most variables. Because multiple comparison tests are inappropriate for our additive design (Cousens 1988) and because previous studies have shown that crop yield response to weed density is asymptotic, a nonlinear hyperbolic regression model (Cousens 1985a, 1985b) was used to analyze the relationship between snap bean yield loss and weed density. The relationships between snap bean yield and density of large crabgrass were described separately for each of the 2 yr and for each time of emergence using the Cousens (1985b) equation. The yield losses were plotted to a hyperbolic yield curve (Cousens 1985a). The relationship of snap bean yield loss to relative leaf area (L_w) of large crabgrass was fitted to the empirical model used by Kropff and Spitters (1991). The Kropff and Spitters model also provided an estimate of the relative damage coefficient (q). The relative damage coefficient for large crabgrass allowed the competitiveness of large crabgrass against snap beans to be determined.

TABLE 1. Weekly rainfall and mean temperatures in the growing season of 1998 and 1999.

Weeks after planting	Temperature		Rainfall or irrigation	
	1998	1999	1998	1999
	C		cm	
1	16[a]	21	0.3	0.5
2	19	26	1.6	0.3
3	22	20	0.7	1.1
4	19	21	0.8[b]	0.7[b]
5	24	23	0.5	0.3
6	24	26	0.6	0.4[b]
7	23	22	0	0
8	26	27	0.4	0.6
9	21	27	0.2	0.7

[a] Temperature and rainfall data were averaged over 7 d from the date of snap bean planting.
[b] During this week, 0.4 cm of irrigation was applied.

Results and Discussion

Precipitation within 6 wk of snap bean planting was greater in 1998 than in 1999 (4.1 and 2.6 cm, respectively) (Table 1). Temperatures were 5 to 7 C cooler in the first 2 wk after planting in 1998 than in 1999. The cooler temperatures caused a 2-d delay (5 d compared with 7 d) in the emergence of snap bean in 1998 as compared with 1999. The cool early-season temperatures did not continue, and the temperatures substantially increased as the season progressed in both years (Table 1). The variability in early-season growing conditions between years affected the response of snap bean to large crabgrass density and emergence time.

Number of seeds per crabgrass plant varied with density and time of emergence. Number of seeds per plant was significantly lower for late-emerging crabgrass than for early-emerging crabgrass at all densities except at 8 plants m^{-1} (data not shown). Late-emerging crabgrass had fewer inflorescences compared with early-emerging crabgrass. The number of heads probably depended on the number of tillers. We observed more tillers per plant in early-emerging as opposed to late-emerging crabgrass.

Seed number and density of early-emerging crabgrass were negatively correlated (Figure 1A). The lowest crabgrass density (0.5 plants m^{-1}) produced 3,160 seed $plant^{-1}$ compared with 909 seed $plant^{-1}$ at 8 plants m^{-1}. Density of late-emerging crabgrass did not affect the number of seed per plant. The effect of density on seed number of early-emerging crabgrass was likely due to greater intra- and interspecific competition allowing fewer resources for seed

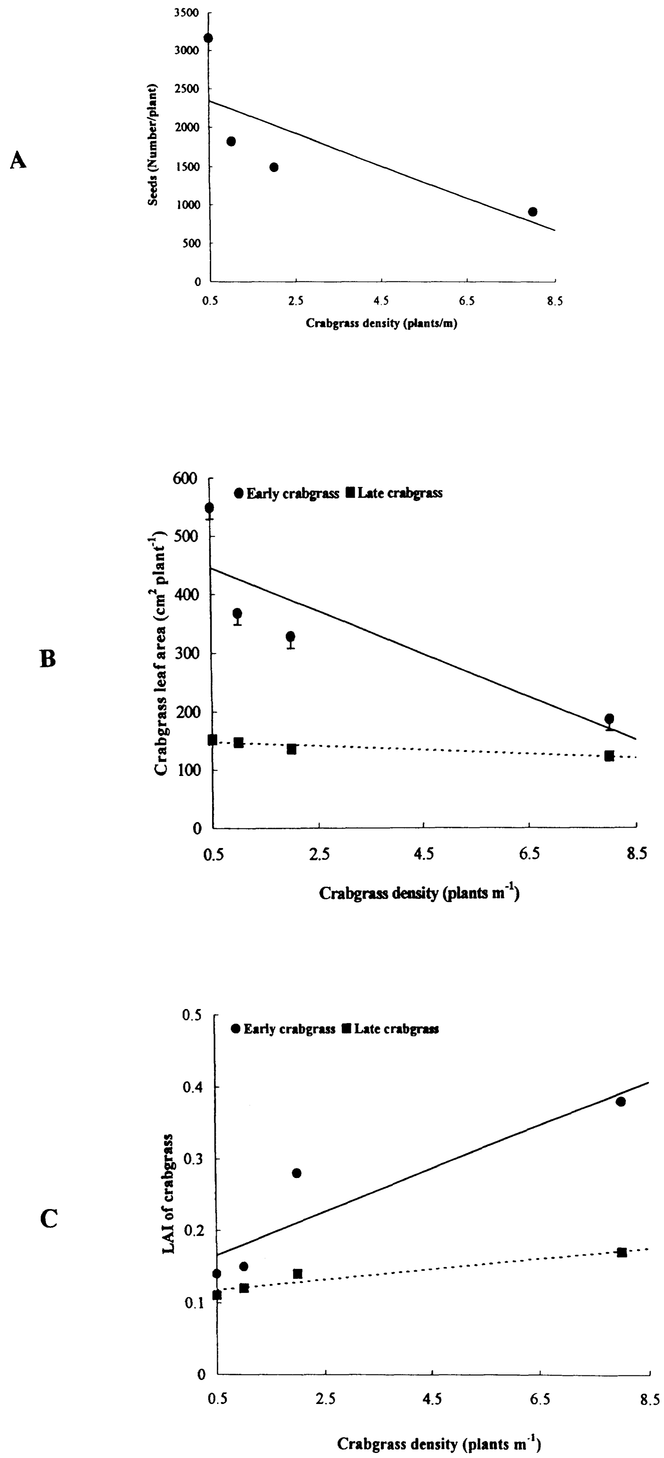

FIGURE 1. In 1999, large crabgrass [*Digitaria sanguinalis* (L.) Scop.] seed production per plant for early-emerging weeds (A), leaf area per plant (B), and leaf area index (LAI) (C), as influenced by density (x) and emergence time. Seed production of late-emerging crabgrass could not be predicted by weed density. The fitted regression lines were number of seed per plant = 3,620 − 709x (r^2 = 0.92); leaf area per plant for early large crabgrass = 591 − 83.2x (r^2 = 0.85); leaf area per plant for late crabgrass = 164 − 9.8x (r^2 = 0.97); LAI for early large crabgrass = 0.25 − 0.085x (r^2 = 0.92); and LAI for late large crabgrass = 0.2 − 0.087x (r^2 = 0.95).

production at higher densities. Other studies have also shown that seed number decreases as competition increases (King and Oliver 1994; Knezevic et al. 1994).

There was a greater loss in leaf area for early-emerging crabgrass than for late-emerging crabgrass as density increased (greater slope). The smallest leaf area of crabgrass at both emergence times was at the highest density of 8 plants m^{-1} (Figure 1B). In our experiment it is likely that the plants were competing for light and, possibly, moisture. The smaller leaf areas at the highest density could dramatically reduce the ability of individual large crabgrass plants to compete for light. The greater leaf area of early-emerging large crabgrass at low density indicates that these plants are the most competitive and should be controlled.

Early-emerging crabgrass with a density of 0.5 to 2 plants m^{-1} had a significantly lower LAI than did crabgrass emerging at the higher density of 8 plants m^{-1} (0.16 to 0.21 compared with 0.39, respectively) (Figure 1C). The LAI of late-emerging crabgrass ranged from 0.12 to 0.14 and was not affected by crabgrass density. Even at the highest density for early-emerging crabgrass, the leaf area of the weed only accounted for 39% of the total leaf area.

Early-emerging crabgrass reduced snap bean leaf area by 12 to 37% at densities of 0.5 to 8 plants m^{-1} and reduced LAI of snap beans (Figure 2A). Late-emerging crabgrass did not affect leaf area or LAI of snap beans. Crabgrass that emerged 2 wk after planting was probably not able to compete for light because of shading from the snap bean canopy. The changes in crabgrass LAI as density increased were much greater for early-emerging than for late-emerging weeds (Figure 1C).

Late-emerging crabgrass did not develop a substantial canopy and was not able to overtop or shade the snap bean. The lack of a closed crabgrass canopy makes these late-emerging weeds poor competitors. Snap bean that emerged and established earlier than the weed had a competitive advantage over late-emerging crabgrass and was able to place its canopy over the large crabgrass canopy; this might have allowed the crop to compete better for light. Berti and Sattin (1996) reported that the relative canopy heights for weed and crop might be the key competitive factor in summer annuals.

Snap bean biomass was different each year and depended on density and emergence time of crabgrass. In both years, late-emerging crabgrass did not affect biomass accumulation in snap beans (Figure 2B). The smaller snap bean plants in the higher density of early-emerging crabgrass were less competitive and were not able to support high yields.

Yield of snap bean is dependent on pod size and number of pods per plant. The number of snap bean pods per plant was dependent on the year and on the density and emergence time of crabgrass. Although crabgrass reduced snap bean yield in both years, in 1998 it did not affect the number of snap bean pods. Adequate precipitation in June resulted in fast vegetative growth of snap beans and an ability to set pods. In 1999 there was a linear decrease in the number of snap bean pods as crabgrass density increased from 0.5 to 8 plants m^{-1} (Figure 2C). The decrease was more rapid for snap bean with early- rather than late-emerging crabgrass. The reduction in the number of snap bean pods per plant ranged from 0 to 53% and from 0 to 34% in early- and late-emerging crabgrass, respectively.

Snap bean yield and percent yield loss were dependent on the year and on crabgrass density and time of emergence. Snap bean pod yields in weed-free plots were 2.4 to 3.0 metric tons ha^{-1} in 1998 and 1999, respectively (Table 2). The estimated yields in weed-free plots were not different

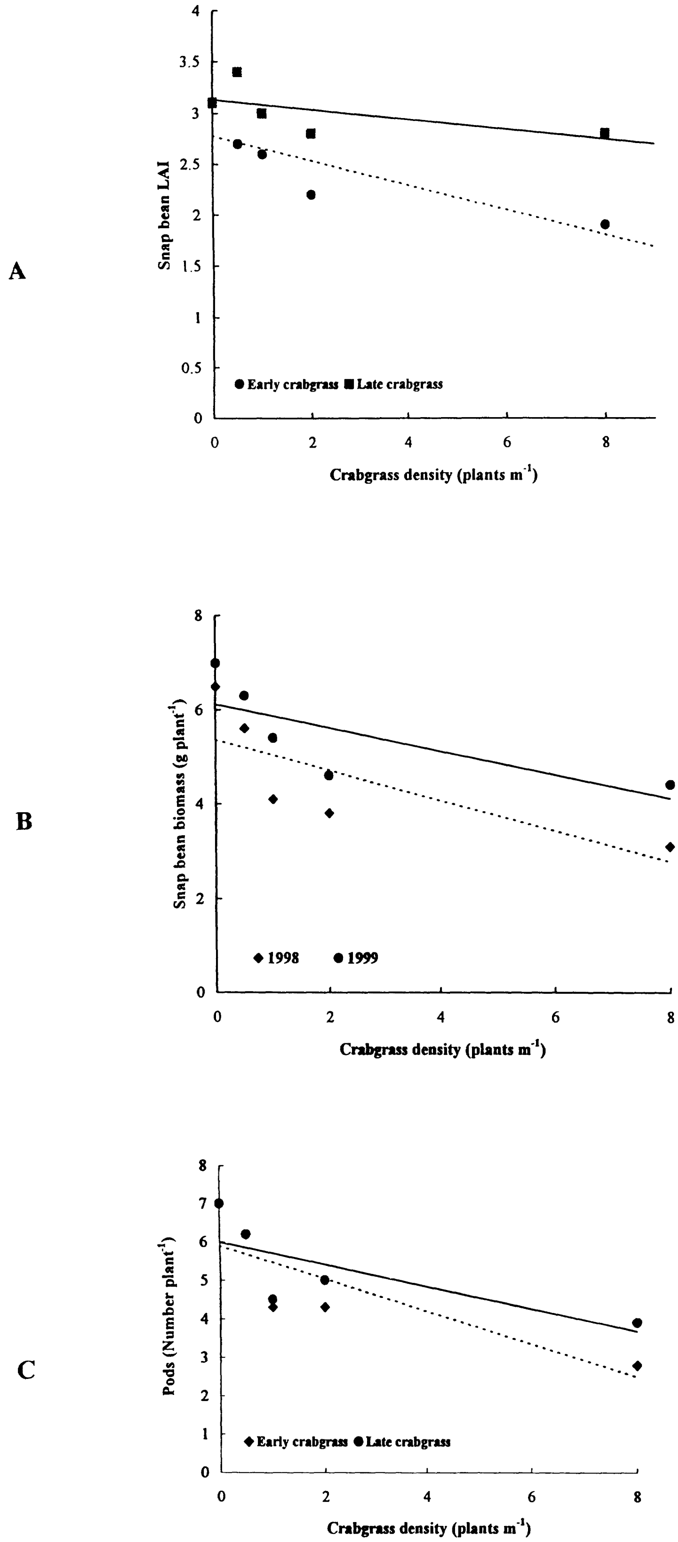

FIGURE 2. Snap bean (*Phaseolus vulgaris* L.) leaf area index (in 1999) (A), dry biomass per plant (in both years) (B), and number of pods per plant (in 1999) (C), as influenced by density (x) and emergence time of large crabgrass [*Digitaria sanguinalis* (L.) Scop.]. In both years, late-emerging large crabgrass did not affect biomass in snap beans. The fitted regression lines were leaf area index for snap bean in early large crabgrass (dotted line) = $2.59 - 0.25x$ ($r^2 = 0.96$); leaf area index for snap bean in late large crabgrass (solid line) = $3.42 - 0.14x$ ($r^2 = 0.65$); snap bean biomass per plant in 1998 (dotted line) = $5.6 - 0.86x$ ($r^2 = 0.96$); snap bean biomass per plant in 1999 (solid line) = $6.2 - 0.69x$ ($r^2 = 0.97$); number of pods per plant for snap bean in early large crabgrass (dotted line) = $6.01 - 1.03x$ ($r^2 = 0.86$); and number of pods per plant for snap bean in late large crabgrass (solid line) = $6.05 - 0.75x$ ($r^2 = 0.95$).

TABLE 2. Observed weed-free snap bean (*Phaseolus vulgaris* L.) yields and parameter estimates (± SE.) for the damage function based on the hyperbolic model.

Emergence		Yield		Parameter estimates[a]	
Year	Time	Observed	Estimated	I	A
		– metric tons ha^{-1} –		%	
1998	Early[b]	3.0 (0.8)	3.0 (0.9)	26.7 (8.8)[c] b	60.3 (6.1) a
	Late	3.0 (0.8)	2.9 (1.1)	9.3 (6.9) a	53.9 (2.1) a
1999	Early	2.4 (0.7)	2.3 (0.5)	38.7 (21.1) b	62.8 (7.3) b
	Late	2.4 (0.7)	3.5 (1.2)	29.5 (3.4) a	58.4 (5.3) a

[a] I (slope) is the percentage yield loss as density approaches 0, and A (asymptote) is the percentage yield loss as density approaches infinity.

[b] Early-emerging large crabgrass [*Digitaria sanguinalis* (L.) Scop.] was planted with snap beans, late-emerging large crabgrass was planted 2 wk after snap bean emergence.

[c] Within a column and a year, the same letter indicates that the parameter values did not differ significantly between emergence time to a t test LSD ($P > 0.05$).

from the observed yields in both years. Percent snap bean yield reduction as crabgrass density increased was similar for the 2 yr. For example, at a density of 8 crabgrass plants m^{-1}, snap bean pod yield was reduced by 47 and 50% for early-emerging crabgrass in 1998 and 1999, respectively, and by 46% for late-emerging crabgrass (in both years) (Figure 3).

The hyperbolic model using early- or late-emerging crabgrass density successfully ($r^2 > 0.95$) predicted snap bean yield in both years (Figure 3). In the hyperbolic model the relative competitiveness of crabgrass can be described by the percentage yield loss as the weed density approaches 0 (I) and the percentage yield loss as the weed density approaches infinity (A) (Cousens 1985b). The I values were 9 and 27% in 1998, but in 1999 the I values were 30 and 39%, for late- and early-emerging crabgrass, respectively (Table 2). In both years, early-emerging crabgrass was more competitive, causing a greater yield loss at low crabgrass densities than did late-emerging crabgrass. The I values were influenced by environmental conditions. For example, late-emerging crabgrass was less competitive in 1998 (a lower I value), when there was more rainfall during the first 7 wk of the season than in 1999 (Figure 3; Table 1). Each I estimate had a large standard error associated with it, which might be due to the variability associated with yield losses in crops at low weed densities.

The asymptotes (A) were not significantly different in 1998, but in 1999 the snap bean yield reduction at high crabgrass densities for early-emerging crabgrass was greater than for late-emerging crabgrass. Even though the hyperbolic model fit our data well ($r^2 > 0.95$), the highest density recorded was 8 crabgrass plants m^{-1}, making it likely that the asymptote estimates were not accurate.

Precipitation and irrigation in June and July during snap bean vegetative growth (Weeks 1–7) were 4.5 and 3.3 cm in 1998 and 1999, respectively. The lower moisture could favor the growth of large crabgrass, a C-4 plant with a low CO_2 compensation point and high transpiration efficiency (King and Oliver 1994), over the growth of snap beans, a C-3 plant. The dependence of the I and A coefficients on crop growth environment and time of emergence was previously reported by Chikoye et al. (1995).

Relative leaf area might be an easier parameter for snap

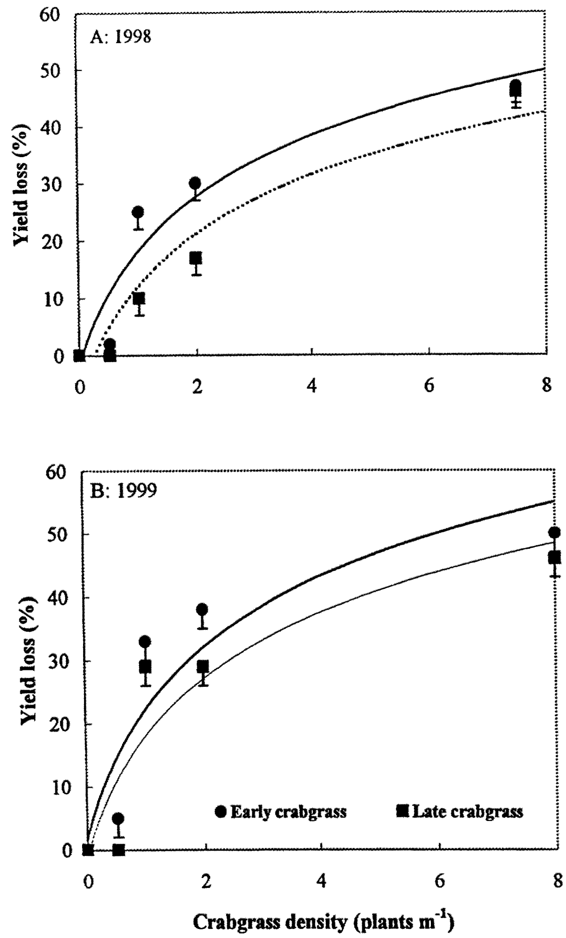

FIGURE 3. A hyperbolic rectangular relationship (Equation 2) between snap bean (*Phaseolus vulgaris* L.) yield loss and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] density in 1998 (A) and 1999 (B) for early- and late-emerging weeds. The lines are the fitted equations, and the symbols are observed yield loss with their standard errors. The slope (*I*), the percentage yield loss as density approaches 0, and the asymptote (*A*), the percentage yield loss as density approaches infinity, are presented in Table 2. All regression coefficients are greater than 0.95.

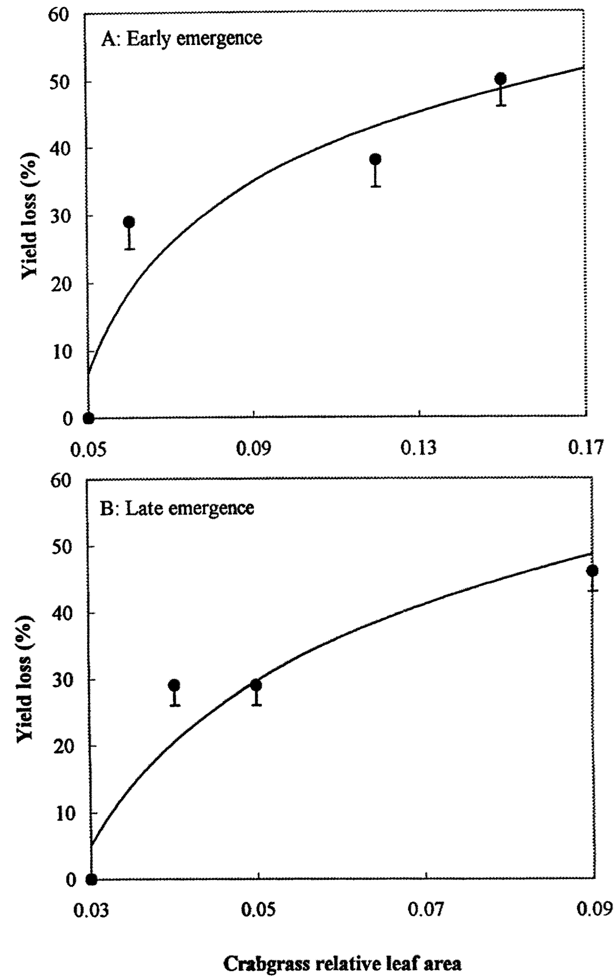

FIGURE 4. In 1999, the percentage snap bean yield loss as affected by relative leaf area at snap bean (*Phaseolus vulgaris* L.) maturity (x) of early (A) and late (B) large crabgrass [*Digitaria sanguinalis* (L.) Scop.]. The relationship of snap bean yield loss to relative leaf area of large crabgrass is fitted to the empirical model of Kropff and Spitters (1991). The model parameters are the relative damage coefficient (q) = 1.65 (± 1.03) and the maximum yield loss (m) = 0.46 (± 0.09) for early-emerging large crabgrass and q = 1.26 (± 0.72) and m = 0.41 (± 0.07) for late-emerging large crabgrass. The coefficient of determination (r^2) was 0.92 for early-emerging large crabgrass and 0.88 for late-emerging large crabgrass.

bean growers to estimate than is weed density. The effect of crabgrass relative leaf area on snap bean yield loss was dependent on crabgrass emergence time. Early-emerging large crabgrass produced a greater relative leaf area and a slightly greater yield loss than did later-emerging crabgrass. The maximum relative leaf area was 0.15 and 0.09 for early- and late-emerging crabgrass, respectively. As the relative leaf area of crabgrass increased, the percent snap bean yield loss also increased (Figure 4).

The data fit the empirical model of Kropff and Spitters (1991) (Figure 4). The damage coefficient (q) was 1.65 and 1.26 for early- and late-emerging large crabgrass, respectively. The greater q for early-emerging crabgrass again indicates that it is more competitive against snap bean than is late-emerging crabgrass. The maximum yield loss (m) was 0.46 and 0.41 for early- and late-emerging large crabgrass, respectively. This is similar to the A estimates using crabgrass density, and the estimates of m, like those of A, are likely imprecise because of the narrow range of relative leaf areas.

The regression curves were convex, indicating that large crabgrass was a better competitor than was snap bean (Kropff and Spitters 1991). Ngouajio et al. (1999) observed both concave and convex regression curves for corn (*Zea mays* L.), common lambsquarters (*Chenopodium album* L.), and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.]. A change in the functional form of the regression curves was attributed to weather conditions (Ngoujio et al. 1999).

Although part of the snap bean yield loss was probably caused by competition for light, the snap bean canopy was above the canopy of large crabgrass for most of the growing season. The greater competitiveness of large crabgrass in the drier year suggests that part of the yield loss was caused by competition for moisture. This suggests that it is important to provide adequate irrigation to ensure maximum snap bean yield when large crabgrass is present.

Our study determined that time of emergence and large crabgrass density both affected snap bean yield. Large crabgrass is more competitive than snap bean. Either large crabgrass density or relative leaf areas can be used to predict snap bean yield loss. Early-emerging large crabgrass at densities as low as 1 plant m^{-1} of row or with relative leaf areas as low as 0.06 can reduce snap bean yield. At low large crabgrass density, time of emergence is a critical factor for snap bean growers to consider when formulating POST management decisions. POST control should target large crabgrass emerging with snap beans.

Sources of Materials

[1] Large crabgrass seed, Valley Seed Service, P.O. Box 9335, Fresno, CA 93791.

[2] LI-COR LI-300 leaf area meter, LI-COR Inc., 4421 Superior St., Lincoln, NE 68504.

Acknowledgments

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