Weed Science, 45:31–37. 1997

Field evaluation of soybean (*Glycine max*) genotypes for weed competitiveness

Alvin J. Bussan
Corresponding author. Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN 55108. Corresponding address: Department of Agronomy, University of Wisconsin, 1575 Linden Drive, Madison, WI 53706

Orvin C. Burnside, James H. Orf, Eric A. Ristau
Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN 55108

Klaus J. Puettmann
Department of Forest Resources, University of Minnesota, St. Paul, MN 55108

In the first of 2 field studies, weed biomass and soybean seed yield were used to evaluate 16 soybean genotypes for competitive ability against 12 weed species at Rosemount, MN, in 1992 and 1993. The yield and ranking of soybean genotypes often varied with the weed species. Grass weed species reduced yields the most, and small-seeded broadleaf weeds reduced yields the least across years. 'Parker' was highly competitive, as it suppressed weed biomass and produced high soybean yield. 'Kato,' 'Kasota,' 'Dawson,' and 'Glenwood' minimized weed biomass and maintained soybean yield while in competition with grass weeds but yielded poorly relative to other soybean genotypes in weed-free conditions. 'Lambert' produced high soybean yield in weed-free conditions, but yield dropped markedly when in competition with grass weeds. 'Grande,' 'Heifeng 25,' and 'Norman' soybeans were poor competitive genotypes in weedy situations and low yielding in weed-free conditions. A 2nd field study conducted at Rosemount and St. Paul, MN, during 1993 evaluated 16 soybean genotypes under 4 levels and durations of weed pressure for weed competitiveness. Parker, 'Sturdy,' and M89-794 were most competitive in suppressing weed biomass and producing high yields. Lambert yielded fairly well but allowed high weed biomass. M89-1743, M89-1006, 'Archer,' and 'Ozzie' yielded poorly and did not suppress weed biomass production. No relationship was found between weed competitiveness and soybean canopy area, height, and volume measured 30–45 d after planting (DAP).

Key words: Aggresivity, competition, crop interference, genotype response to weeds, weed suppression, weed tolerance, ABUTH, AMARE, AMBEL, CHEAL, ECHCG, POLAV, SETFA, SETLU, SETVI, SINAR, SOLPT, XANST.

Many farmers are moving toward sustainable farming practices because of environmental and economic concerns. As a result, herbicide use is reduced. As herbicides are reduced, new biological, cultural, and physical management will be required to control weeds. An objective of these new crop production systems will be to incorporate biological and ecological strategies that maximize crop interference with weeds (Wyse 1994).

A potential method for reducing herbicide use is development of competitive crop genotypes. The competitive ability of crops can be expressed 2 ways. First is the ability of the crop to compete with weeds, reducing weed seed and biomass production. The 2nd possibility is having crops tolerate competition from weeds while maintaining high yields. Numerous crops exhibited genotype differences in competitive ability (Callaway 1992). Several studies document differences among soybean genotypes in their competitiveness with weeds (Burnside 1972, 1979; Callaway 1992; Monks and Oliver 1988; Rose et al. 1984). There have been up to 45% differences in weed biomass production when in competition with various soybean genotypes (Rose et al. 1984).

Most research evaluating competitive ability of soybean has screened genotypes against a narrow range of weed species or under a single level of multiple species competition. Little research has been done to show the effect of various weed species or levels of weed pressure on competitive ranking of soybean genotypes. 'Forrest' and 'Centennial' soybeans were evaluated against 4 different weed species, but no differences in relative competitive ability of these 2 soybean genotypes were observed (Monks and Oliver 1988). If weed species or pressure has little effect on the competitive rank of soybean genotypes, then the highest yielding genotypes under weed-free conditions will be the highest yielding and best competitors when interacting with weeds (Grime 1979). An alternative hypothesis is that soybean genotypes vary in competitive ability against different weed species. Thus, high yielding genotypes in weed-free conditions may be poor competitors, and competitive genotypes may yield less under weed-free conditions. This hypothesis is supported by the tradeoff theory of competition (Tilman 1990).

The tradeoff theory of competition (Tilman 1990) has been developed to describe differences in competitive ability among species, and it may apply to differences in competitive ability among crop genotypes as well. The tradeoff theory is based on different species (genotypes) varying in their allocation of resources, causing tradeoffs in competition. For example, soybeans allocate energy towards nodule development. As a result, soybeans require a low nitrogen and high potassium supply to survive. Soybeans are strong competitors under low nitrogen soils and poor competitors in low-potassium soils. An experiment that investigated grass species competition across a nitrogen gradient documented the tradeoff theory and found that little bluestem [*Schizachyrium scoparium* (Michx.) Nash-Gould] was a stronger competitor than quackgrass (*Elytrigia repens* L. Nevski AGRRE) at low nitrogen levels (Tilman and Wedin 1991). Little bluestem was a stronger competitor for nitrogen than quackgrass, but quackgrass was a superior competitor under high nitrogen conditions because it produced more seeds and rhizomes than little bluestem (Tilman and Wedin 1991).

Plant breeders need quick, accurate measures of weed competitiveness to select competitive genotypes. Rates of soybean seed germination, emergence, and early growth are important in relation to weed competitiveness (Rose et al. 1984). Determining crop leaf area development combines these factors into 1 measurement that correlates strongly with yield loss (Kropff and Spitters 1991). Crop canopy area and volume also predicted crop yield loss (Harvey and Wagner 1994). Leaf expansion rate of soybeans has selected for weed competitive genotypes (Callaway and Forcella 1993). Canopy area, height, and volume have potential use in plant breeding programs as selection criteria for competitiveness because they are nondestructive and can be measured rapidly.

Objectives of this research were to evaluate weed competitiveness of soybean genotypes across a wide range of weed species and density; to determine if early soybean canopy area, height, and volume could be used as selection criteria in developing weed competitive crops; and to determine if a weed species by soybean genotype interaction will be important in the selection and development of competitive soybean genotypes.

Materials and Methods

There were 2 types of field studies conducted to assess genotype differences in soybean competitive ability. The first assessed the competitive ability of 16 soybean genotypes against 12 weed species. The second evaluated competitiveness of 16 soybean genotypes to different levels and durations of mixed weed stands. Soybean genotypes refer to publicly released soybean lines planted across Minnesota and breeding lines from the University of Minnesota soybean breeding project.

Weed Species

This study evaluated the weed competitiveness of 16 soybean genotypes with 12 weed species. The study was repeated in 1992 and 1993 at the weed nursery at the Minnesota Agricultural Experiment Station at Rosemount. The experimental area was moldboard plowed in the fall and tandem disked and harrowed in the spring to prepare the seedbed. Soil type was a Waukegan silt loam (fine-silty, mixed, mesic Typic Hapludoll) with 59% silt, 22% clay, 19% sand, pH 6.6, and 4.5% organic matter. Weeds have been maintained in monoculture on these field plots for more than a decade to build up the seed bank of individual weed species. The experimental area was not fertilized, but no visible phosphorous or potassium deficiency symptoms appeared in any of the plots.

Experimental design was a randomized complete block with a split-plot treatment arrangement and 3 replications (Johnson 1990; Lentner and Bishop 1986). Whole plots were weed treatments and subplots were soybean genotypes. Weed treatments included weed-free, natural mixture of weeds, and pure stands of barnyardgrass [*Echinochloa crus-galli* (L.) Beauv. ECHCG], common cocklebur (*Xanthium strumarium* L. XANST), common ragweed (*Ambrosia artemisiifolia* L. AMBEL), eastern black nightshade (*Solanum ptycanthum* Dun. SOLPT), giant foxtail (*Setaria faberi* Herrm. SETFA), green foxtail [*Setaria viridis* (L.) Beauv. SETVI], common lambsquarters (*Chenopodium album* L. CHEAL), pigweed (*Amaranthus* spp. AMARE), smartweed (*Polygonum* spp. POLAV), velvetleaf (*Abutilon theophrasti* Medikus ABUTH), wild mustard [*Brassica kaber* (DC.) L. C. Wheeler SINAR], and yellow foxtail [*Setaria glauca* (L.) Beauv. SETLU]. Natural densities of weeds were allowed to establish from enhanced seed banks. Weed stands were dense across whole plots. Grass weeds were controlled in broadleaf weed plots with sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) at 0.21 kg ai ha^{-1} plus 2.34 L ha^{-1} Dash[1] in 140 L ha^{-1} water applied POST. Whole plots were hand-weeded throughout the growing season to maintain desired species. Whole plots were 6 × 42 m in 1992 and 6 × 89 m in 1993. Soybean genotypes included 'Dassel,' Dawson, 'Evans,' Glenwood, Grande, Heifeng 25, 'Hendricks,' 'Hodgson 78,' Kato, Kasota, Lambert, Norman, Ozzie, Parker, 'Simpson,' and 'Swift.' Soybean subplots were planted at 645,000 seeds ha^{-1} in 4 25-cm-wide rows, 3 m long in 1992 and 6 m long in 1993, with a 75-cm spacing between subplots. Plot size was increased in 1993 to reduce standard error. Soybeans were planted May 24, 1992, and June 3, 1993.

Soybean canopy area and height was measured 30–45 d after planting (DAP). Canopy area constituted soybean leaf area viewed from directly above the plants. Canopy area was determined by videotaping a representative 0.125-m^2 section of the middle 2 rows of each soybean subplot with a video camcorder from 2 m above the soybean plants. Agvision pseudo-color system leaf area analysis[2] was used to compute canopy area of soybean from the videotapes. One frame of each replicate was digitized and displayed as gray-shaded pixels on a computer monitor, where the image was highlighted so soybean leaves were shaded. A known length was included in video images for accurate calibration. Pixels in the same range of gray as soybean leaves were removed by editing so they would not be included in calculation of soybean canopy area.

Weeds were harvested at physiological maturity from between the middle 2 rows of each subplot, and oven-dry biomass was weighed. The numbers of broadleaf plants were counted when harvested, and grass weed populations were estimated by counting plants in 3 randomly placed 100-cm^2 sections per whole plot. Soybeans were harvested from the entire subplot with a plot combine, and seed yields and 100-seed weights were determined.

Weed Mixtures and Duration of Competition

The 2nd of 2 field studies evaluated weed competitiveness of 16 soybean genotypes in different levels and durations of mixed-weed stands. Soybean genotypes were selected from breeding nurseries based on soybean canopy area 30–45 DAP. The study was repeated in 1993 at Minnesota agricultural experiment stations at Rosemount and St. Paul. Soil at both locations was a Waukegan silt loam. Fertilizer was applied at both locations according to soil test recommendations. The St. Paul experiment was planted June 1, 1993, and the Rosemount experiment June 3, 1993, in fields with moderate to heavy levels of natural weed seed banks. The experimental design was a randomized complete block with treatments arranged in a 4 × 16 factorial (4 weed levels and 16 soybean genotypes) and 4 replications. The 4 weed treatments were weed-free, selective POST herbicide treatments 2 and 4 wk after planting (WAP), and a weedy check. POST herbicide treatments were applied at 2 and 4 WAP to generate different levels and durations of weed pressure. POST herbicide treatment was bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] at 1.1 kg ai ha^{-1}, sethoxydim at 0.21 kg ai ha^{-1}, plus 2.34 L ha^{-1} Dash in 140 L ha^{-1} water. Plots consisted of soybeans planted at 625,000 seeds ha^{-1} in four 25-cm spaced rows 4.5 m long with a 75-cm spacing between plots.

The St. Paul experiment received a POST application of fluazifop-P [(R)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy] phenoxy]propanoic acid] at 0.21 kg ai ha^{-1} 1 WAP to control quackgrass. Foxtail millet [*Setaria italica* (L.) Beauv. SETIT] was spread on the site 3 d after herbicide application with a cyclone seeder at 1.7 kg ha^{-1} to replace annual grass weeds controlled by fluazifop-P. Canada thistle [*Cirsium arvense* (L.) Scop. CIRAR] and other perennial broadleaf weeds were hand weeded every 2 wk during the growing season at St. Paul. Perennial weeds were removed because they were highly aggregated within the experimental area.

Soybean canopy area and height were measured as previously described, weekly from 2 to 10 wk after soybean emergence in weed-free plots. Seven weeks after emergence, all plots were videotaped, and canopy area was determined as described earlier. Weeds were harvested and counted at physiological maturity from between the middle 2 rows for the entire length of each plot and oven-dry biomass was weighed. Soybeans were harvested with a plot combine from the entire plot, and seed yields and 100 seed weights were determined.

Statistical Analysis

Soybean genotypes were analyzed for differences in their ability to suppress weed biomass and maintain soybean yield by analysis of variance (ANOVA). Weed treatments were evaluated for their effect on soybean yield and weed growth. Year and replication effects were considered random, while all other treatment effects were fixed in the ANOVA for both experiments. Means were separated by the least significant difference at the 0.05% level where appropriate. Correlation analyses were conducted to determine the relationship among soybean canopy area, height, and volume vs. soybean yield, soybean yield loss, and weed biomass.

Results and Discussion

Weed Species

This study investigated weed competitiveness of 16 soybean genotypes with 12 weed species. Broadleaf weeds were successfully established and maintained. Grass weed plots consisted of a mixture of grass species. Giant foxtail plots were dominated by giant foxtail. Yellow foxtail, barnyardgrass, and green foxtail plots had relatively uniform mixtures of all 4 grass species. Natural weed mixture plots were 95% grass species and 5% broadleaf. All weed species had relatively high densities during 1992 with respect to previous research on interference in soybeans (Coble and Ritter 1978; Coble et al. 1981; Harrison 1990; Harrison et al. 1985; Henry and Bauman 1989; Orwick and Schrieber 1979; Quakenbush and Andersen 1984; Stoller and Woolley 1985) (Table 1). In 1993, eastern black nightshade, common lambsquarters, smartweed spp., and pigweed spp. had low weed densities, while the remainder of the species had high densities. Every species except common cocklebur had higher density in 1992 than 1993. This may have been due to a later planting date in 1993 than 1992 (Gunsolus 1990) or because the spring was cool and wet in 1993 and was hot and dry in 1992 (Egley 1990).

Table 1. Weed biomass with and without soybean competition, weed density, and soybean seed yield of 13 weed species in the weed nursery at Rosemount, MN, in 1992 and 1993.

Weed species	Weed biomass with soybean[a]		Weed biomass no soybean	Weed density[a]		Soybean seed yield[a]	
	1992	1993	1993	1992	1993	1992	1993
	kg ha^{-1}			plants m^{-2}		kg ha^{-1}	
Mixture	10,000	4,920	6,630	—	—	470	560
SETFA	8,860	5,160	7,360	10,000	7,300	620	970
SETLU	7,650	3,680	6,080	8,000	5,500	660	1,170
ECHCG	7,140	2,550	4,930	6,500	3,000	960	1,570
SETVI	6,540	2,860	5,090	5,500	1,500	1,190	1,440
XANST	1,870	6,720	9,350	3	34	2,670	200
AMBEL	4,580	2,780	4,960	37	20	2,040	810
AMARE	3,880	300	1,780	21	9	2,330	1,980
POLAV	2,320	1,150	3,800	11	7	2,430	1,740
SINAR	2,110	820	2,040	26	23	2,330	1,510
CHEAL	720	260	2,710	28	2	3,110	2,240
ABUTH	420	70	880	37	3	3,330	2,340
SOLPT	170	140	1,800	22	2	3,190	2,420
Weed free	0	0	0	0	0	3,410	2,500
LSD (0.05)	700	830	1,190			240	210

[a] Averaged across 16 soybean genotypes.

Differences in weed biomass occurred across species while in competition with soybeans (Table 1). Weed biomass had a significant year by weed species interaction so data are presented for both years. Limited inferences can be made about the competitiveness of weed species because of varying density among them. In general, broadleaf weed species produced less biomass than grass weed species when competing with soybean. Exceptions to this were common cocklebur and common ragweed in 1993. Common cocklebur, common ragweed, and grass species biomass production were reduced 25–48% by soybean competition in 1993 as compared to 60–92% for other species. Velvetleaf was noticeably stunted across the entire experimental area, resulting in low biomass. This was due to a natural infection of *Verticilium wilt* (*Verticilium* spp.) that built up in these plots after decades of monoculture velvetleaf growth.

The 16 soybean genotypes differed in ability to suppress weeds (Table 2). Weed biomass is presented from 1992 and 1993 because there was a soybean genotype by year interaction. This interaction occurred because Swift, Simpson, Evans, and Lambert greatly reduced weed biomass production in 1993 but not in 1992, whereas Hodgson 78 and Hendricks reduced weed biomass in 1992 but not in 1993. The yearly interaction may have been due to differences in soybean growth caused by different environments between years. The rank in weed biomass production for the soybean genotypes across all 13 weed species was relatively constant within years. Kato, Kasota, Dawson, Parker, Glenwood, and Dassel were strong competitors and suppressed weed biomass growth the most. Heifeng 25, Grande, and Norman

TABLE 2. Weed biomass production in 16 soybean genotypes in the weed nursery at Rosemount, MN, during 1992 and 1993.

Soybean genotype	Weed biomass[a] 1992	1993
	kg ha^{-1}	
Heifeng 25	5,450	2,710
Grande	5,070	2,810
Norman	5,040	2,360
Swift	4,600	1,970
Simpson	4,510	2,090
Evans	4,480	2,180
Lambert	4,480	2,220
Ozzie	4,380	2,460
Hodgson 78	4,220	2,480
Dassel	4,110	2,240
Glenwood	4,010	2,200
Hendricks	3,920	2,390
Parker	3,890	2,240
Dawson	3,870	2,150
Kasota	3,830	2,060
Kato	3,620	2,150
LSD (0.05)	630	330

[a] Average weed biomass across 12 weed species.

TABLE 3. Yield of soybean genotypes grown with highly competitive weeds, less competitive weeds, and in weed-free areas at Rosemount, MN, for 1992 and 1993.

Soybean genotype	Highly competitive[a] weeds 1992	Highly competitive[a] weeds 1993	Less competitive[a] weeds 1992	Less competitive[a] weeds 1993	Weed free 1992	Weed free 1993
	kg ha^{-1}					
Parker	1,340	1,350	3,410	2,600	3,920	2,810
Lambert	1,050	1,250	3,230	2,590	4,410	2,900
Dawson	1,270	1,290	3,140	2,320	3,710	2,690
Hendricks	1,210	1,290	3,060	2,400	3,600	2,610
Kato	1,310	1,280	2,920	2,330	3,390	2,820
Evans	830	1,370	2,740	2,540	3,490	2,940
Kasota	960	1,310	2,530	2,600	3,070	3,070
Simpson	910	1,130	2,740	2,390	3,620	2,680
Glenwood	1,040	1,280	2,800	1,990	3,190	2,710
Dassel	910	1,040	3,000	2,110	3,600	2,640
Swift	850	1,300	2,560	2,340	3,010	2,970
Hodgson 78	1,020	1,060	2,830	1,980	3,470	2,400
Ozzie	950	1,000	2,890	1,940	3,850	2,060
Heifeng 25	750	880	2,410	1,540	2,950	1,670
Grande	640	940	1,870	1,770	2,280	1,800
Norman	800	720	2,470	1,190	2,920	1,200
LSD (0.05)	130	130	200	160	490	490

[a] Highly competitive weed means are the average of natural mixture, giant foxtail, yellow foxtail, green foxtail, barnyardgrass, and common ragweed. Less competitive weed means are the average of smartweed, pigweed, eastern black nightshade, common lambsquarters, and velvetleaf.

were poorer competitors and suppressed weed biomass least in 1992. Heifeng 25 and Grande suppressed weed biomass least in 1993. Further research needs to be done to assess why genotypes differ in their ability to compete with weeds.

Soybean yield was analyzed across weed species over years. There were year by weed species and weed species by soybean genotype interactions for soybean yield. Therefore, soybean yield within each weed species is reported separately for 1992 and 1993 (Table 1). Soybean yields were generally higher in grass weed plots and lower in broadleaf weed plots in 1993 compared to 1992. Natural weed mixture, giant foxtail, and yellow foxtail competition reduced average soybean yields most in 1992, and common cocklebur reduced soybean yield more than 90% in 1993. Highest soybean yields occurred in weed-free, eastern black nightshade, velvetleaf, and common lambsquarters conditions. Regression of average soybean yield on average weed biomass for all weed species (R^2 = 0.96 and 0.86 in 1992 and 1993, respectively) showed that for every 100 kg ha^{-1} of weed biomass, there was a 30 kg ha^{-1} reduction in soybean seed yield (data not shown).

Yield for each soybean genotype was averaged over less competitive weeds and more competitive weeds and presented for 1992 and 1993 (Table 3). A weed species by soybean genotype, soybean genotype by year, and soybean genotype by weed species by year interaction occurred when describing soybean seed yield. To describe weed species by soybean genotype interaction, weed species were grouped into more competitive weeds and less competitive weeds, and soybeans were compared for their ability to produce soybean yield within each group. Groupings were based on weed biomass data for each species (Table 1) and configured so that ANOVA interaction terms were no longer significant. Natural weed mixture, yellow foxtail, green foxtail, giant foxtail, barnyardgrass, and common ragweed were combined in the more competitive weed category (Tables 1 and 3). Velvetleaf, eastern black nightshade, common lambsquarters, smartweed spp., pigweed spp., and wild mustard were combined in the less competitive weed category. Common cocklebur was not included in these analyses because of highly variable soybean yields over years.

Dawson, Kato, Glenwood, and Kasota were strong competitors against weeds as they suppressed weed biomass most across years (Table 2) and produced high yield when competing with weeds (Table 3). However, these genotypes yielded less than Lambert and Parker under weed-free or low competitive situations in 1992, and Dawson, Kato, and Glenwood yielded less than Lambert, Parker, and Kasota under low competitive situations in 1993 (Table 3). Lambert soybean yielded high in weed-free and less competitive conditions, but had lower yields when competing with weeds, particularly in 1992. Lambert also allowed high weed biomass yields during 1992 (Table 2). Hendricks produced high yields under high weed biomass production relative to other genotypes during 1993, indicating it was more tolerant to weed competition (Tables 2 and 3). The competitive results of these genotypes may be explained by a tradeoff between yield potential and competitive ability (Tilman 1990). If a tradeoff does exist, selecting for high soybean yield under weed-free conditions would not select for weed competitiveness.

Parker soybean yielded high in weed-free and competitive situations and suppressed weed biomass across years (Tables 2 and 3). During 1993, Kasota yielded high under all competitive situations and suppressed weed biomass. Grande, Norman, Ozzie, and Heifeng 25 were the poorest competitors with little suppression of weed biomass, and had poor yields when competing with weeds across years. The com-

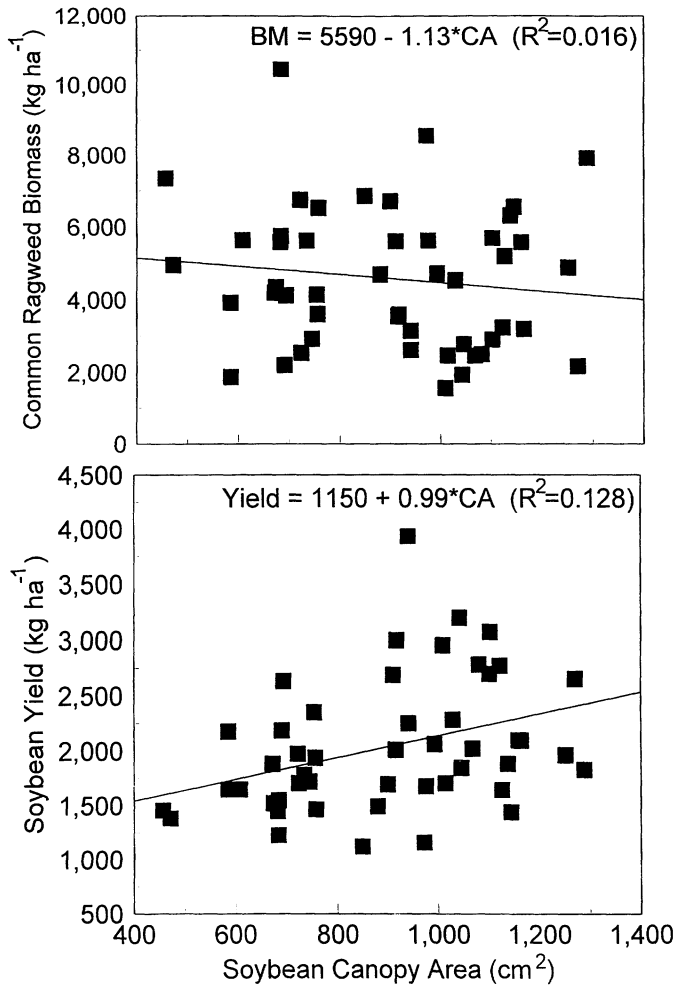

FIGURE 1. Scatter plots of soybean canopy area (CA) vs. ragweed biomass (BM) and soybean yield from Rosemount, MN, during 1992 and 1993.

petitive results of these genotypes suggest no tradeoff between yield potential and competitiveness. This indicates that selection for high seed yield under weed-free conditions would select for weed competitiveness.

No consistent relationship was found among soybean canopy area, height, volume, or 100 seed weight, and weed biomass per plant, weed biomass, soybean yield, or percent soybean yield loss. Therefore, the ability of soybean genotypes to compete with weeds could not be attributed to early growth. For example, the relation of soybean canopy area to weed biomass or soybean yield had correlation coefficients of 0.25 ($P > 0.05$) or less (Figure 1). The poor relationships were due to the large variation in weed density from plot to plot. Natural populations of weed species were utilized in this study, and their sometimes erratic growth patterns may have contributed to large errors in correlation analysis. Measuring soybean canopy area with only a single 0.125-m^2 sample from each plot may have resulted in a large sampling error, adding to variation in regression analysis. It still may be possible to utilize aboveground growth characteristics to select for competitive soybean. Early crop leaf area, crop canopy area, and plant volume have been used to develop crop yield loss equations (Harvey and Wagner 1994; Kropff and Spitters 1991). If genotypes can be developed with more rapid early growth, yield loss from weed competition may be reduced. It has been shown that soybean

TABLE 4. Weed biomass when grown with 16 soybean genotypes under 3 different weed levels in Rosemount and St. Paul, MN, during 1993.

	Weed biomass					
	Herbicide[a] application time				No weed control	
	2 WAP[b]		4 WAP			
Soybean genotypes	Rosemount	St. Paul	Rosemount	St. Paul	Rosemount	St. Paul
	kg ha^{-1}					
Parker	750	1,440	1,630	890	3,590	740
Lambert	870	550	3,430	2,520	6,850	1,620
M89-792	1,090	130	2,930	570	3,710	3,600
Sturdy	1,110	400	1,310	2,060	2,680	1,510
Ozzie	1,150	370	1,730	2,420	4,870	1,700
M89-1743	1,210	430	6,070	2,790	4,480	5,070
M89-794	1,330	190	1,700	1,370	3,740	610
M90-1682	1,630	200	2,000	880	3,330	3,030
M89-1946	1,660	230	2,290	2,210	3,180	2,640
Archer	2,210	1,110	3,070	2,120	6,980	2,210
M89-642	2,290	220	1,530	390	3,750	2,590
M90-317	2,320	330	1,760	680	2,320	2,700
M90-610	2,480	350	1,360	1,680	5,240	1,510
M88-250	2,480	350	1,810	1,020	6,230	2,420
M89-1006	2,430	280	2,420	2,350	5,990	1,590
M89-1926	3,120	260	1,360	1,840	5,980	1,560
No soybean	20,310	17,550	14,030	23,290	20,460	18,060
LSD (0.05)	530	170	590	740	850	900

[a] POST herbicide treatment was sethoxydim at 1.1 kg ha^{-1} and bentazon at 1.1 kg ha^{-1}.

[b] WAP = weeks after planting.

canopy area relates to weed competitiveness under tightly controlled conditions in a greenhouse, whereas in the field, conditions were more variable and similar relationships were not detected or may not have existed (Bussan 1995).

Weed Mixtures and Duration of Competition

The study at Rosemount and St. Paul investigated competitive ability of 16 soybean genotypes with 4 weed levels and durations. Herbicide applications varied the weed pressure that competed with soybean. At St. Paul, grass weeds were < 5% of the weed biomass. Weed species present were pigweed spp., common lambsquarters, and Canada thistle (data not presented). The mean weed biomass was 1,300, 2,700, and 2,900 kg ha^{-1} for 2 WAP herbicide applications, 4 WAP herbicide applications, and no control, respectively. At Rosemount, weed species included giant foxtail, yellow foxtail, barnyardgrass, large crabgrass [*Digitaria sanguinalis* (L.) Scop. DIGSA], pigweed spp., common lambsquarters, and velvetleaf. Mean weed biomass was 2,600, 2,700, and 5,000 kg ha^{-1} for 2 WAP herbicide applications, 4 WAP herbicide applications, and no control, respectively. Higher weed biomass at Rosemount compared to St. Paul resulted from more competitive weeds, based on the weed species results presented earlier.

Significant location by soybean genotype and weed treatment by soybean genotype interactions occurred in weed biomass and soybean yield (Tables 4 and 5). This indicates that soybean genotypes varied in their relative competitive

TABLE 5. Seed yields of 16 soybean genotypes as affected by 4 weed-control treatments at Rosemount, MN, during 1993.

Soybean genotypes	Soybean seed yields			
	Weed free	Herbicide[a] 2 WAP[b]	Herbicide[a] 4 WAP	No-weed control
	kg ha^{-1}			
Parker	2,650	2,350	1,770	1,800
M88-250	2,500	1,620	2,050	1,420
M90-317	2,460	2,200	2,060	1,660
M90-610	2,440	2,110	2,180	1,340
M89-794	2,430	2,250	1,940	1,480
Sturdy	2,410	1,910	2,010	1,620
M89-642	2,330	2,030	1,830	1,410
M89-1946	2,230	2,160	1,800	1,250
M89-792	2,220	2,270	1,940	1,510
Archer	2,170	1,720	1,540	1,100
Lambert	2,150	1,530	1,820	1,340
M89-1926	2,120	1,520	1,750	1,200
M90-1682	2,010	2,220	2,140	1,620
Ozzie	1,900	1,550	1,540	840
M89-1743	1,750	1,610	1,350	1,050
M89-1006	1,610	1,400	1,410	990
LSD (0.05)	400	420	340	420

[a] POST herbicide treatment was sethoxydim at 1.1 kg ha^{-1} and bentazon at 1.1 kg ha^{-1}.

[b] WAP = weeks after planting.

TABLE 6. Seed yields of 16 soybean genotypes as affected by 4 weed-control treatments at St. Paul, MN, during 1993.

Soybean genotypes	Soybean seed yields			
	Weed free	Herbicide[a] 2 WAP[b]	Herbicide[a] 4 WAP	No-weed control
	kg ha^{-1}			
M90-317	4,330	3,790	3,490	3,350
M89-1926	4,220	4,010	2,810	3,580
Lambert	4,180	3,920	3,220	3,600
M90-610	4,150	3,910	3,640	3,020
M90-1682	4,130	4,200	3,330	2,970
M88-250	4,080	3,790	3,660	3,540
M89-794	3,960	3,560	3,010	3,190
M89-792	3,960	3,700	3,180	2,930
Parker	3,960	3,640	3,320	3,570
Archer	3,770	2,500	2,770	3,150
Sturdy	3,740	3,300	3,160	3,440
M89-642	3,530	3,260	3,510	2,620
M89-1006	3,400	2,960	2,420	2,740
Ozzie	3,300	3,250	2,840	3,170
M89-1946	3,160	3,640	2,600	2,360
M89-1743	3,100	3,040	2,500	1,830
LSD (0.05)	570	510	920	800

[a] POST herbicide treatment was sethoxydim at 1.1 kg ha^{-1} and bentazon at 1.1 kg ha^{-1}.

[b] WAP = weeks after planting.

ability when grown under 4 weed treatments. However, soybean yield at St. Paul showed no soybean genotype by weed-treatment interaction (Table 6). There was lower weed pressure at St. Paul than at Rosemount, resulting in less yield reduction. As a result, yield ranking of soybean genotypes did not differ across weed treatments.

Parker, Sturdy, and M89-794 were highly competitive, high-yielding genotypes that suppressed weed biomass most at both locations (Table 4). M89-794 had high soybean yield at St. Paul and under all 4 weed treatments at Rosemount (Tables 5 and 6). Parker and Sturdy yielded with the best genotypes at St. Paul and in the weed-free and no-weed control treatments at Rosemount. Genotypes M88-250 and M90-1682 were somewhat tolerant to weed competition, as they yielded well with high weed biomass (Tables 4, 5, and 6). Lambert produced high yields at St. Paul (Table 6), but it also allowed high weed biomass production at both locations in the four WAP applications and no-weed control treatments (Table 4). Archer, Ozzie, M89-1743, and M89-1006 yielded poorly under all weed treatments (Tables 5 and 6) and were poor competitors that did not suppress weed biomass production in the 4 WAP herbicide applications and no-weed control treatments at both locations (Table 4).

No consistent relationship existed between soybean canopy area and weed competitiveness. The poor relationship could be due to the large variation described earlier. The parameters measured do not easily relate to weed competitiveness and should not be used to select for weed competitive soybean varieties in the field.

Soybean genotype by weed-treatment interactions in weed competitiveness occurred in both field studies. The interactions indicate that some soybean genotypes are more competitive under different weed conditions. Parker, Sturdy, and M89-794 had high yields in all weedy and weed-free situations and were highly effective at limiting weed growth. Archer, Grande, Heifeng 25, Norman, Ozzie, M89-1006, and M89-1743 were low yielding, poorly competitive genotypes. Results with these genotypes suggest that breeding for high yield in weed-free conditions selects for competitive ability. However, Lambert was high yielding under weed-free conditions and was a poor competitor. Dawson, Glenwood, and Kato were highly competitive genotypes that yielded lower than other genotypes when weed free. In addition, Hendricks, M88-250, and M90-1682 appeared to tolerate competition but were low yielding when weed free. Therefore, it is evident that selection for weed competitiveness in soybean needs to be done under multiple weedy conditions and environments. Further research is needed to determine if the tradeoff between soybean yield and weed competitiveness exists.

Single traits, such as weed-free soybean yield or soybean canopy area, may be indicative of competitiveness based on previous research (Bussan 1995; Callaway and Forcella 1993; Rose et al. 1984). However, no relationship between competitiveness and soybean canopy area, height, or volume was consistently found in this research. If breeding crop competitive genotypes is going to be a future weed management option, nondestructively measured traits that correlate to weed competitiveness must be determined. Research is needed to establish a generic nondestructive method of assessing weed competitiveness.

Sources of Materials

[1] Dash is a proprietary blend of 99% functioning agents (petroleum hydrocarbons, alkyl esters and acids, and anionic surfactant) from BASF Corp., 100 Cherry Road, Parsippany, NJ 07054.

[2] Agvision Pseudo-Color System, Root and Leaf Analysis. Decagon Devices Inc., P.O. Box 835, Pullman, WA 99163.

Acknowledgment

We appreciate the partial financial support of this research from the Minnesota Soybean Research and Promotion Council. This is Contribution No. 22,073 from the Minnesota Agricultural Experiment Station, St. Paul, MN.

Literature Cited

Burnside, O. C. 1972. Tolerance of soybean cultivars to weed competition and herbicides. Weed Sci. 20:294–297.

Burnside, O. C. 1979. Soybean (*Glycine max*) growth as affected by weed removal, cultivar, and row spacing. Weed Sci. 27:562–565.

Bussan, A. J. 1995. Selection for weed competitiveness among soybean genotypes. M.S. thesis. University of Minnesota, St. Paul, MN. 108 p.

Callaway, M. B. 1992. A compendium of crop varietal tolerance to weeds. Am. J. Alt. Agric. 7:169–180.

Callaway, M. B. and F. Forcella. 1993. Crop tolerance to weeds. *In* M. B. Callaway and C. A. Francis, eds. Crop Improvement for Sustainable Agriculture. Lincoln, NE: University of Nebraska Press, pp. 100–131.

Coble, H. D. and R. L. Ritter. 1978. Pennsylvania smartweed (*Polygonum pennsylvanicum*) interference in soybeans (*Glycine max*). Weed Sci. 26: 556–559.

Coble, H. D., F. M. Williams, and R. L. Ritter. 1981. Common ragweed (*Ambrosia artemisiifolia*) interference in soybeans (*Glycine max*). Weed Sci. 29:339–342.

Egley, G. H. 1990. High temperature effects on germination and survival of weed seeds in soil. Weed Sci. 38:429–435.

Grime, J. P. 1979. Primary strategies in the established phase. *In* J. P. Grime, ed. Plant Strategies and Vegetation Processes. New York: J. Wiley, pp. 7–25.

Gunsolus, J. L. 1990. Mechanical and cultural weed control in corn and soybeans. Am. J. Alt. Agric. 5:114–119.

Harrison, J. K. 1990. Interference and seed production by common lambsquarters (*Chenopodium album*) in soybeans (*Glycine max*). Weed Sci. 38:113–118.

Harrison, S. K., C. S. Williams, and L. M. Wax. 1985. Interference and control of giant foxtail (*Setaria faberi*)in soybeans (*Glycine max*). Weed Sci. 33:203–208.

Harvey, R. G. and C. R. Wagner. 1994. Using estimates of weed pressure to establish crop yield loss equations. Weed Technol. 8:114–118.

Henry, W. T. and T. T. Bauman. 1989. Interference between soybeans (*Glycine max*) and common cocklebur (*Xanthium strumarium*) under Indiana field conditions. Weed Sci. 37:753–760.

Johnson, B. J. 1990. Herbicide × annual fertility programs influence on creeping bentgrass performance. Agron. J. 82:27–33.

Kropff, M. J. and C.J.T. Spitters. 1991. A simple model of crop loss by weed competition from early observations on relative leaf area of the weeds. Weed Res. 31:97–105.

Lentner, M. M. and T. Bishop. 1986. *In* M. M. Lentner and T. Bishop, eds. Experimental Design and Analysis. Blacksburg, VA: Valley Book, pp. 365–371.

Monks, D. W. and L. R. Oliver. 1988. Interactions between soybean (*Glycine max*) cultivars and selected weeds. Weed Sci. 36:770–776.

Orwick, P. L. and M. M. Schrieber. 1979. Interference of redroot pigweed (*Amaranthus retroflexus*) and robust foxtail (*Setaria viridis* var. *robusta alba* or var. *robusta puprurea*) in soybeans (*Glycine max*). Weed Sci. 27:665–674.

Quakenbush, L. S. and R. N. Andersen. 1984. Effect of soybean (*Glycine max*) interference on eastern black nightshade (*Solanum ptycanthum*). Weed Sci. 32:638–645.

Rose, S. J., O. C. Burnside, J. E. Specht, and B. A. Swisher. 1984. Competition and allelopathy between soybeans and weeds. Agron. J. 76: 523–528.

Stoller, E. W. and J. T. Woolley. 1985. Competition for light by broadleaf weeds in soybean (*Glycine max*). Weed Sci. 33:199–202.

Tilman, D. 1990. Constraints and tradeoffs: toward a predictive theory of competition and succession. Acta Oecol. Scand. 58:3–15.

Tilman, D. and D. Wedin. 1991. Dynamics of nitrogen competition between successional grasses. Ecology 72:1038–1049.

Wyse, D. L. 1994. New technologies and approaches for weed management in sustainable agriculture systems. Weed Technol. 8:403–407.

Nomenclature: Soybean, *Glycine max* (L.) Merr.

Received October 30, 1995, and approved May 31, 1996.