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Interference between shatter cane (*Sorghum bicolor*) and soybean (*Glycine max*)

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Abstract A field study was conducted to evaluate the effects of shatter cane (*Sorghum bicolor*) and soybean (*Glycine max*) densities on soybean seed yield and to quantify interspecific and intraspecific interference coefficients. The relations between soybean seed yield per plant and shatter cane density at different densities of soybean and also with soybean density at different densities of shatter cane are well described by the reciprocal equations. Soybean seed yield per unit area decreased with increasing shatter cane density. The highest yield loss (57%) was relative to 50 and 12 plants/m^2 of soybean and shatter cane densities, respectively. Optimum soybean densities on the basis of maximum soybean seed yield per unit area at 0, 4, 8, and 12 plants/m^2 of shatter cane were achieved at 50, 34, 32, and 36 plants/m^2, as estimated by the asymptotic or parabolic relations between soybean seed yield per unit area and soybean densities at different shatter cane densities. Shatter cane was a stronger competitor than soybean, as a shatter cane plant was equal to 2.5 soybean plants, based on soybean seed yield. In contrast, a soybean plant was equal to 0.18 of a shatter cane plant, on the basis of shatter cane biomass. It was, therefore, concluded that the superior competitor was mostly affected by intraspecific interference, but the weaker competitor was mostly affected by interspecific interference.

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INTRODUCTION

The weed species, relative weed density, and the length of time a weed coexists with the crop during the growing season are important factors that reduce soybean (*Glycine max*) seed yield (Harrison 1990). Shatter cane (*Sorghum bicolor*) is a weedy forage-type sorghum that infests many crop fields (Prather & Callahan 1991). It can grow to a height of 1–3 m and produce over 1000 seeds per panicle. Seeds on mature panicles may shatter before the crop is harvested and can remain viable for up to 13 years when buried in soil (Burnside et al. 1997). Shatter cane can vigorously compete with all crops for light, nutrients, and water (Burnside 1990; Fellows & Roeth 1992).

Fellows & Roeth (1992) reported that shatter cane interference reduced soybean yield by up to 25% before the height differential reached 30 cm. Vesecky et al. (1973) observed that both forage sorghum and shatter cane could reduce grain sorghum yields by over 50%. Becket et al. (1988) found that corn (*Zea mays*) yields were reduced 22% by shatter cane at 6.6 clumps per m of row. Cannel (1986) reported soybean yield reductions of 6%–62% at shatter cane densities ranging from 0.2 to 6.6 clumps per m of row. Therefore, the extent of crop yield reductions resulting from interference by shatter cane depends on shatter cane density.

Prather & Callihan (1991) used reciprocal yield models to quantify the effects of yellow star thistle and pubescent wheat grass interactions. They concluded that yellow star thistle aggressivity, judged by yellow star thistle biomass, was greater than pubescent wheat grass aggressivity at all densities.

Roush et al. (1998) compared three approaches to describe competitive interactions between wheat and Italian ryegrass. These comprised conventional analysis of replacement series experiments, development of synthetic no-interaction responses from monoculture experiments for comparison with results from mixed-culture, and responses of the reciprocal yield of individual plants to variation in densities of the two species. The three approaches varied in ability to quantify this competitive relationship. However, the reciprocal yield approach provided the simplest and the most sensitive analysis of the joint influences of density and proportion of species. This method also provided the most quantitative analysis of the influence of density on the species. Rejmanek et al. (1989) reviewed standard designs for two species competitive experiments and demonstrated the advantages of a reciprocal yield model applied to the data from an additive series experiment. Park & Watkinson (2002) indicated that the reciprocal model accounted for 94% and 90% of the variation in the mean dry weight of maize and bean, respectively, grown in intercropping stands.

Spiters (1983) used a series of experiments to examine how the reciprocal yield law was followed in a mixture of two or more species. Interference between two species was examined, using multiple regression models as:

$$1/W_1 = b_{1,0} + b_{1,1}\, N_1 + b_{1,2}\, N_2 \quad (1)$$

$$1/W_2 = b_{2,0} + b_{2,2}\, N_2 + b_{2,1}\, N_1 \quad (2)$$

where W_1 and W_2 are the weights of plants of species 1 and 2, $b_{1,0}$ and $b_{2,0}$ are the maximum yield of species 1 and 2 free from competition, $b_{1,1}$ and $b_{2,2}$ are the regression coefficients for intraspecific interference, $b_{1,2}$ and $b_{2,1}$ are the regression coefficients for intraspecific interference, and N_1 and N_2 are the density of plants of species 1 and 2, respectively.

Soybean is one of the major oil crops in Iran, where climatic conditions are favourable for its production. However, its yield is generally very low because of high levels of infestations by weeds such as shatter cane. Despite being recognised as a troublesome weed in soybean, the effect of shatter cane infestations on the yield of soybean is not well documented. Therefore, the objectives of this study are to: (1) test the reciprocal equations to describe the relationship between soybean seed yield and shatter cane density; (2) estimate optimum densities of soybean at different densities of shatter cane; and (3) evaluate the effect of shatter cane density on soybean yield, when grown simultaneously in competition with soybean.

MATERIALS AND METHODS

The field experiment was conducted during 2002 at the research farm of Tabriz University (38°5′N, 46°17′E, elevation of 1362 m) in a sandy-loam soil, using shatter cane and soybean (Williams), obtained from the Agricultural Research Center of Karaj, Iran. Speed-fed forage sorghum was planted to simulate shatter cane. Shatter cane is a heterogeneous species that has been shown to vary in its physical characteristics and phenological responses (Fellows & Roeth 1992). Therefore, interference work with shatter cane has an inherent variability that limits precision in crop and weed response. Use of speed-fed forage sorghum removed variation in germination and emergence, which occurs with shatter cane seeds because of dormancy. Culture pattern was an additive series. Treatments comprised soybean densities of 20, 30, 40, and 50 plants/m^2 and shatter cane densities of 0, 4, 8, and 12 plants/m^2. The factorial set of treatments was arranged within a randomised complete block design with three replications. The desired plant populations were obtained by oversowing and hand thinning. Control of weeds was supplemented by hand weeding. Individual plots were 5 m long with six rows 60 cm wide. Rows were numbered 1–6 from left to right. Rows 1 and 6 were border rows. Yield data were collected from rows 2, 3, 4, and 5. The harvesting of both soybean and shatter cane were conducted at soybean physiological maturity (R8). The soybean and shatter cane were hand harvested from the centre 4-m section within each yield row. As soon as plants were harvested, the seeds of soybean were detached from the pods by hand. Later, the seeds were dried by normal air circulation for a 3-week period to a constant weight. Shatter cane plants were dried in an oven at 80°C for 48 h. Then, shatter cane biomass and soybean seed yield were determined.

Statistical analysis

Biomass and seed yield data were analysed via multiple linear regression to select an appropriate model, using the density as an independent variable and shatter cane biological and soybean seed yield as dependent variables. The model of multiple regression of the reciprocal yield according to F test and adjusted R^2 was the best of all models tested. Aggressivity was calculated by dividing the coefficient of intraspecific interference relative to the coefficient of interspecific interference (Rejmanek et al. 1989).

$$\text{Aggressivity of species 1 } (a_1) = b_{1,1}/b_{1,2} \quad (3)$$

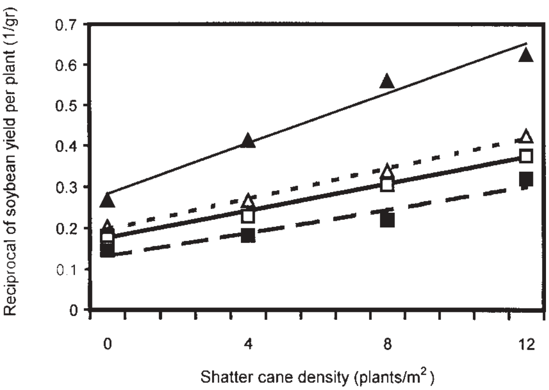

Fig. 1 Relations between the reciprocal of soybean (*Glycine max*) seed yield per plant and shattercane (*Sorghum bicolor*) density at soybean densities of 20 (–■–), 30 (–□–), 40 (–▲–), and 50 (–△–) plants/m^2.

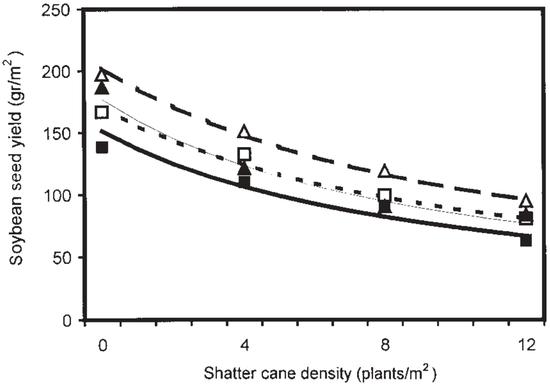

Fig. 2 Relations between soybean (*Glycine max*) seed yield per unit area and shatter cane density (*Sorghum bicolor*) at soybean densities of 20 (–■–), 30 (–□–), 40 (–▲–), and 50 (–△–) plants/m^2.

Table 1 Equations for the reciprocal of soybean (*Glycine max*) seed yield per plant (1/w), at different densities of shatter cane (*Sorghum bicolor*) (d_{sh}).

Soybean density (plants/m^2)	Reciprocal equations	*P* value	R^2
20	$1/w = 0.13222 + 0.013962 \times d_{sh}$	0.0000	0.88
30	$1/w = 0.17678 + 0.016268 \times d_{sh}$	0.0000	0.89
40	$1/w = 0.19788 + 0.018306 \times d_{sh}$	0.0000	0.92
50	$1/w = 0.2825 + 0.030826 \times d_{sh}$	0.0001	0.76

Table 2 Equations for soybean (*Glycine max*) seed yield per unit area (*Y*) at different shatter cane (*Sorghum bicolor*) densities (d_{sh}).

Soybean density (plants/m^2)	Yield/density equations	*P* value	R^2
20	$Y = 20 / (0.13222 + 0.013962d_{sh})$	0.0000	0.88
30	$Y = 30 / (0.17678 + 0.016268d_{sh})$	0.0000	0.89
40	$Y = 40 / (0.19788 + 0.018306d_{sh})$	0.0000	0.92
50	$Y = 50 / (0.2825 + 0.030826d_{sh})$	0.0001	0.76

Aggressivity of species 2 (a_2) = $b_{2,2}/b_{2,1}$ (4)

When two species were competing for the same resources, the niche differential index (NDI) was calculated (Dunan & Zimdahl 1991).

$$NDI = (b_{1,1}/b_{1,2})(b_{2,2}/b_{2,1}) \quad (5)$$

For estimating seed yield, yield data were expressed as the percentage of yield loss, compared to control plots (Mamolos & Kalburtji 2001):

% yield loss = (control yield-actual yield)/(control yield) (6)

RESULTS

Influence of shatter cane density on soybean seed yield and yield loss

Reciprocal of soybean seed yield per plant at all densities was linearly increased with increasing shatter cane density (Fig. 1). The values calculated for the intercept and slope of each regression line (Table1) was used to estimate soybean seed yield per unit area (g/m^2) at different densities of shatter cane

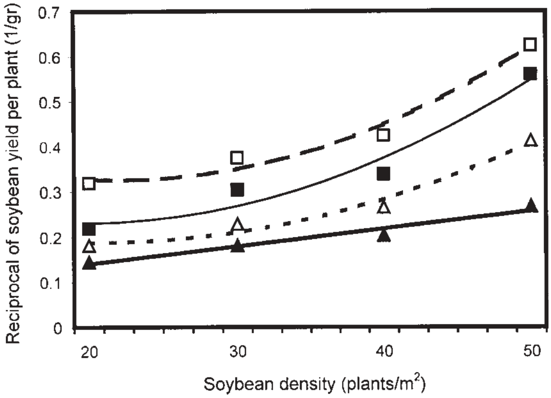

Fig. 3 Relations between the reciprocal of soybean (*Glycine max*) seed yield per plant and soybean density at shatter cane (*Sorghum bicolor*) densities of 0 (–▲–), 4 (–△–), 8 (–■–), and 12 (–□–) plants/m².

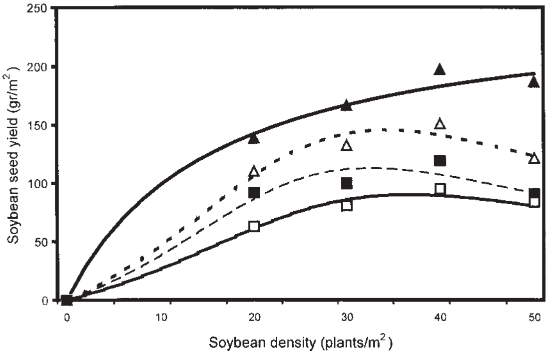

Fig. 4 Relations between the reciprocal of soybean (*Glycine max*) seed yield per unit area and soybean density at shatter cane (*Sorghum bicolor*) densities of 0 (–▲–), 4 (–△–), 8 (–■–), and 12 (–□–) plants/m².

in accordance with the equations presented in Table 2. The results indicated that soybean seed yield was decreased with increasing shatter cane density (Fig. 2). Soybean seed yield at low densities of shatter cane was more than that of high densities. The highest yield loss (57%) was observed at 50 plants/m² of soybean and 12 plants/m² of shatter cane (Fig. 2).

Reciprocal yield/density equations were improved (Table 3, Fig. 3) to describe relations between soybean density and soybean seed yield per unit area at different densities of shatter cane (Table 4, Fig. 4). The relationship between soybean seed yield and soybean density at different densities of shatter cane were parabolic, but this relationship for shatter cane-free treatments was almost asymptotic (Fig. 4). Although soybean seed yield (g/m²) at shatter cane-free treatments increased with increasing soybean density up to 50 plants/m² (maximum density tested in this experiment), but at 4, 8, and 12 shatter cane plants/m², soybean seed yield increased with increasing soybean density up to 34, 32, and 36 plants/m², respectively. Further increases in soybean density resulted in decreasing soybean seed yield at different shatter cane densities (Fig. 4).

The highest soybean seed yield at all densities of soybean was achieved in control, and that was decreased with increasing shatter cane density (Fig. 4). Differences in soybean seed yield of control and all three shatter cane densities were greater at soybean densities higher than 40 plants/m² (Fig. 4).

Quantitive determination of intraspecific and interspecific interference coefficients

Multipe linear regression analysis of soybean seed yield data showed significant effect of shatter cane density on soybean seed yield. Soybean seed yield was predicted, using the equation:

$$W_1=1/(-0.079942 + 0.0079N_1 + 0.01987N_2) \quad (7)$$

where W_1, N_1, and N_2 are soybean seed yield per plant, soybean density, and shatter cane density, respectively. The regression coefficient for intraspecific interference was 0.0079 and the regression coefficient for interspecific interference was 0.01987 (Table 5). Reciprocal of soybean seed yield per plant under non-competition conditions was 0.07999, the inverse of which shows the maximum yield of soybean per plant. Aggressivity of soybean was 0.4 (Table 5).

The inverse of shatter cane biomass was described by:

$$W_2 = 1/(-0.003174 + 0.000764N_2 + 0.0001425N_1) \quad (8)$$

where W_2, N_2 and N_1 are biomass of shatter cane per plant, shatter cane and soybean densities, respectively. Coefficients for intraspecific interference, interspecific interference, and shatter cane aggressivity judged by Shatter cane biomass, are presented in Table 5. Maximum biomass of shatter cane per plant was 315.46, predicted via inverse of Equation 8. The niche differentiation index (NDI) was 2.09. NDI >1 suggests that niche differentiation has occurred.

Ratios of regression coefficient indicated that one shatter cane plant was approximately equivalent to 2.5 soybean plants ($b_{1,2}/b_{1,1}$), as measured by effects on soybean seed yield. Conversely, one soybean plant was approximately equivalent to 0.18 of a shatter cane plant ($b_{2,1}/b_{2,2}$), as measured by effects on shatter cane biomass.

DISCUSSION

The relationship between soybean seed yield per unit area and shatter cane density at different densities of soybean, and the relations between soybean seed yield per plant and soybean density at different densities of shatter cane are well described by reciprocal equations (Tables 1 and 3, Fig. 1 and 3). Subsequent use of the values calculated for the parameters of reciprocal equations, to estimate changes in soybean seed yield per unit area at different densities of shatter cane and soybean according to the equations presented in Tables 2 and 4, was also very successful (Fig. 2 and 4). Increasing shatter cane density decreased soybean seed yield per unit area at different densities of soybean, and the highest yield loss (57%) was observed at the highest tested density of soybean (Fig. 2). This was because of increasing intraspecific interference among soybean plants.

Optimum soybean densities on the basis of maximum soybean seed yield per unit area at 0, 4, 8, and 12 plants/m^2 of shatter cane were achieved at 50, 34, 32, and 36 plants/m^2, which shows that the greatest effect of two species on each other was

Table 3 Equations for the reciprocal of soybean (*Glycine max*) seed yield per plant (1/w) at different densities of soybean (d_{sy}).

Shatter cane density (plants/m^2)	Equation reciprocals	*P* value	R^2
0	$1/w = 0.06219 + 0.00391d_{sy}$	0.0000	0.9
4	$1/w = 0.29215–0.01022d_{sy} + 0.00025d_{sy}^2$	0.0000	0.94
8	$1/w = 0.36085–0.0133d_{sy} + 0.00034\ d_{sy}^2$	0.0000	0.86
12	$1/w = 0.50604–0.0165d_{sy} + 0.00038\ d_{sy}^2$	0.0002	0.76

Table 4 Equations for soybean (*Glycine max*) seed yield per unit area (*Y*) at different soybean densities (d_{sy}).

Shatter cane density (plants/m^2)	Yield/density equations	*P* value	R^2
0	$Y = d_{sy} / (0.06219 + 0.00391d_{sy})$	0.0000	0.9
4	$Y = d_{sy} / (0.2922–0.01022d_{sy} + 0.00025d_{sy}^2)$	0.0000	0.94
8	$Y = d_{sy} / (0.36085–0.0133d_{sy} + 0.00034d_{sy}^2)$	0.0000	0.86
12	$Y = d_{sy} / (0.50604–0.0165d_{sy} + 0.00038d_{sy}^2)$	0.0000	0.76

Table 5 Coefficients for intraspecific and interspecific interferences of soybean (*Glycine max*) and shatter cane (*Sorghum bicolor*).

Response variable 1/w (1/g)	Intraspecific interference coefficient (1/g m^2)	Interspecific interference coefficient (1/g m^2)	Aggressivity	*P* value	R^2
Reciprocal of soybean seed yield per plant	0.0079	0.01987	0.4	0.0000	0.81
Reciprocal of shatter cane biomass per plant	0.00076	0.00014	5.23	0.0000	0.78

attributed to shatter cane density. Such effects were greater at soybean densities higher than 40 plants/ m^2 (Fig. 4). These results were confirmed by low aggressivity of soybean (0.4), compared with that of shatter cane (5.23).

Lower intraspecific interference in comparison to interspecific interference on the basis of soybean seed yield per plant (Table 5), also suggested that the effect of a shatter cane plant was more than that of a soybean plant, as a shatter cane plant was equal to 2.5 soybean plants ($b_{1,2}/b_{1,1}$). In contrast, on the basis of shatter cane biomass, intraspecific interference was greater than interspecific interference, as a soybean plant was equal to 0.18 of a shatter cane plant ($b_{2,1}/b_{2,2}$). Therefore, the superior competitor was mostly affected by intraspecific interference. Rejmanek et al. (1989) reported that one Japanese millet plant was equivalent to 3.67 tomato plants, as measured by effects on tomato biomass. Conversely, one tomato plant was equivalent to 0.14 Japanese millet plants, as measured by effects on millet biomass. Dunan & Zimdahl (1991) reported that NDI for wild oats and barley was greater than 1. Our results, also, suggested that the NDI for soybean and shatter cane was greater than 1 (2.09), indicating that the species could yield more when mixed than when grown separately.

Therefore, the proposed models could be used to quantify interspecific and intraspecific interfernce of shatter cane and soybean, and also enable us to predict optimum plant population densities for soybean at different densities of shatter cane. Since, soybean seed yield was considerably decreased with increasing shatter cane density, it would be nesessary to control shatter cane populations in soybean fields. Further research on similar bases at different locations and years may be needed to test the validity of applying these equations for many plants in a wide range of environmental conditions.

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