Yield and Yield Components Response of Corn/Soybean Intercrop to Simultaneous Competition of Redroot Pigweed and Jimson weed

F. Zaefarian¹, M. Aghaalikhani¹, H. Rahimian Mashhadi², E. Zand³, M. Rezvani⁴

¹Department of Agronomy, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran, ²Department of Agronomy, Faculty of Agriculture, University of Tehran, Tehran, Iran, ³Department of Weed Research, Plant Pest and Diseases Research Institute, Tehran, Iran, ⁴Department of Agronomy and Plant Breeding, Faculty of Agriculture, Islamic Azad University, Ghaemshahr Branch, Iran.

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ABSTRACT

In order to investigate the role of intercropping of corn/soybean on the resource use efficiency and suppression of weeds, a field experiment was carried out at the Faculty of Agriculture Research Farm, University of Tehran in 2006. Treatments were arranged in a factorial experiment based on a randomized complete block design with three replications. Treatments were five different mixing ratios of corn (Zea mays) and soybean (Glycine max) consisting of 100% : 0% (P₁), 75% : 25% (P₂), 50% : 50% (P₃), 25% : 75% (P₄) and 0% : 100% (P₅). The weed infestation consisted of one weed free (W₁), and three levels of weed infestation of redroot pigweed (Amaranthus retroflexus) (W₂), jimson weed (Datura stramonium) (W₃) and a simultaneous presence of redroot pigweed and jimson weed (W₄). Weed density for both species was 15 plant m⁻¹ of crop row in weed infested treatments. The Correspondence to: M. Aghaalikhani, E-mail: maghaalikhani@modares.ac.ir
results showed the highest yield of corn (9627.8 kg ha\(^{-1}\)) was obtained in the P\(_2\)W\(_1\) treatment, and the lowest (3916.7 kg ha\(^{-1}\)) was in P\(_2\)W\(_4\). But the highest yield of soybean (5050.00 kg ha\(^{-1}\)) was seen in P\(_5\)W\(_1\) and the lowest (365.67 kg ha\(^{-1}\)) in P\(_2\)W\(_4\). Some yield components of corn such as the kernel row number per ear, kernel number per row, and 1000 kernel weight were highest for P\(_4\)W\(_1\), but the harvest Index was highest (0.45) for P\(_2\)W\(_1\) and lowest (0.20) for P\(_4\)W\(_4\). Some yield components of soybean such as pod number per plant, grain number per pod and 1000 grain weight were highest in the monoculture of soybean and the weed free treatment (P\(_3\)W\(_1\)). This treatment had the highest soybean harvest index. It could be concluded that decreasing the corn/soybean ratio in the cropping rows will increase the corn and soybean yield components. The highest weed biomass (376.73 g m\(^{-2}\)) was obtained in the monoculture of soybean infested with jimson weed and redroot pigweed. Therefore, it could be stated that corn/soybean intercropping significantly reduced the weed biomass comparing to both monocultures.

**Key words:** intercropping, grain corn, soybean, redroot pigweed, jimson weed, weed competition.
INTRODUCTION

Increase in agricultural products during the 20th century was a result of high levels of external inputs (Evans, 1998). Intense agriculture, however, caused some side effects, such as soil erosion, environmental pollution by agrochemicals and fertilizers misuse, and emergence of agrochemical resistant populations of weeds and pests (Vandermeer et al., 1998; Poggio, 2005).

Diversification of cropping systems by increasing the number of crop species grown in the land was known to be a solution to some problems of modern agriculture (Vandermeer, 1995; Brummer, 1998; Vandermeer et al., 1998; Altieri, 1999). Intercropping (IC) known as the simultaneous growing of two or more species or cultivars on the same piece of land, is known to increase yield stability compared to sole cropping (SC), especially in low input conditions (Vandermeer, 1989; Hauggaard-Nielsen, 2006) and was presented as an option to diversify cropping systems (Brummer, 1998; Altieri, 1999). The most common reason for the adoption of...
Intercropping is yield advantage, which is explained by the greater resource depletion by different crops than monocultures, particularly when cereal and legume crops are grown together (Vandermeer, 1989; Fukai and Trenbath, 1993; Poggio, 2006). Cereal/legume intercropping is most frequently used and productive (Carruthers et al., 2000). Corn/soybean intercrops have been shown to be more productive than corn monocropping (Marchiol et al., 1992). The soybean partner adds valuable nitrogen to the soil (Singh et al., 1986), and improves overall protein content of the resulting silage (Martin et al., 1990).

Intercropping systems are reported to use resources higher and more efficient than monocultures. These systems could suppress weed growth due to lack of nutrients, water and solar radiation (Zimdahl, 1993; Carruthers et al., 1998). Therefore, intercropping can reduce reliance of weed management on herbicide use (Liebman and Dyck, 1993; Liebman and Davis, 2000; Poggio, 2005).

Redroot pigweed is one of the most common weeds in corn, soybean, sugar beet and sunflower fields with a C₄ photosynthetic pathway. It is one of the first weeds whose herbicide resistant biotypes have been observed in the fields (Holm et al., 1996). In the past two decades jimson weed has been increasingly troublesome for solanaceous crops such as potato, pepper, tobacco and tomato, also causing severe reduction in the yield of soybean and corn. It prefers rich soils and plentiful rainfall but can survive in sandy pastures and many severe conditions. Jimson weed is almost dispersed by seed. It is, however, a very strong (heavy) seed producer, and well-nourished which is capable of producing up to 25,000 seeds. It mainly appears in corn, soybean and sunflowers fields (Holm et al., 1996).

Wheat/chickpea intercropping significantly reduced yield of chickpea. However, total productivity and land use efficiency were higher in intercropping systems comparing to monocultures of either species. There was a significant reduction in weed density and biomass for the intercropping system over both monocultures. These
findings suggest wheat/chickpea intercropping increases total productivity per unit area improves land use efficiency and suppresses weeds (Banik et al., 2006). Carruthers et al., (2000) investigated the effects of soybean or lupin seeding alone and in combination with one of three forages (annual ryegrass, *Lolium multiflorum* Lam.; perennial ryegrass, *Lolium perenne* L.; red clover, *Trifolium pratense* L.) with corn on the yield components of corn, soybean and lupin. They also examined the effects of seeding date (simultaneously with corn or with 3 weeks delay) and number of rows of large seeded legumes (one or two) between the corn rows. Results showed that the corn kernel yield was generally not affected by any intercrop treatments, although in the first experiment some simultaneously seeded treatments resulted in decreased yields. Soybean grain yield was decreased by most treatments, although some simultaneous seeding produced yields similar to soybean monocultures. The corn harvest index was not affected by any intercrop treatments.

The main objective of the research was to determine the role of corn/soybean intercropping in the resources use efficiency and suppression of weeds as compared to their monocultures.

**MATERIALS AND METHODS**

The experiment was conducted during the growing season of 2006 at the research field of the Agricultural Faculty, University of Tehran (35° 59′ N, 50° 75′ E; 1313 m above sea level). Treatments were arranged in a factorial experiment based on a randomized complete block design with three replications. The climate of the region is cold and semi-arid, with a mean annual rainfall of 240 mm mainly occurring in the spring and fall. The soil texture was clay loam with: EC= 0.68 (dS/m), pH= 7.4, O.C= 0.61 %, total N= 0.08%, P= 22.8 ppm and K= 140 ppm.

In spring, after seedbed preparation, according to conventional practices, corn (*Zea mays* L.) (K.SC. 500 cultivar) and soybean (*Glycine max* L.) (Williams cultivar)
seeds were sown. The treatments consisted of 5 different mixing ratios of corn and soybean including: 100% corn: 0% soybean (P1), 75% corn: 25% soybean (P2), 50% corn: 50% soybean (P3), 25% corn: 75% soybean (P4) and 0% corn: 100% soybean (P5). The weed infestation treatment consisted of: weed free (W1), redroot pigweed (W2), jimson weed (W3) and simultaneous presence of redroot pigweed and jimson weed (W4).

The redroot pigweed and jimson weed seeds were collected the past year from the surrounding research site and were kept at 4°C. Each plot had 6 rows with 60 cm inter row space. Plant arrangements of corn and soybean were 20 x 60 cm and 25 x 60 cm, respectively. They were sown on the same date. The weeds were sown 15 cm apart from crops on both sides of the rows, at high density on the crop sowing date. They were thinned to 15 plants per meter of the row at the two leaf-stage of each species. The field was irrigated with 7 days intervals. At the end of the growing season, all plants in the 4 rows of 2 m were harvested in each plot in order to evaluate the crop yield and weed biomass. At the same time, 10 plants of each crop and weed were selected to determine the yield components and the total biomass of weeds. Data were subjected to general linear model (PROC GLM) and means were separated (calculated) by Duncan's multiple range test ($P=0.05$) using SAS (SAS Institute Inc, 2002). To investigate yield advantages in pure stand and corn/soybean intercrop, land equivalence ratios (LER) were calculated.

**RESULTS AND DISCUSSION**

**Corn Yield**

The results showed significant effects made by mixing ratios of corn and soybean and weed infestation ($P<0.001$) along with significant interaction effects ($P<0.01$). The highest yield (9627.8 kg ha$^{-1}$) was obtained in P$_2$W$_1$ and lowest (3916.5 kg ha$^{-1}$) in P$_4$W$_4$ (Table 1 and Figure 1). The presence of both weed species had the highest effect on corn yield reduction. Yield reduction in treatments with low density of corn (P$_4$) is
due to two reasons. First, low number of plants (low corn density) and second, increased competition efficiency of weeds in the plots infested with two weed species for light interception and water and nutrients absorption.

In many intercropping experiments, consisting of legume and grass, higher yields were observed compared to monocropping (Morris & Garrity, 1993). In a legume/cereal intercropping, the nitrogen of the associated crop may be improved by direct nitrogen transfer from the legume to cereal (Banik et al., 2006). Legumes have adaptability to different cropping patterns and the ability to fix nitrogen, which may offer opportunities to sustain increased productivity (Jeyabal & Kuppuswamy, 2001). Therefore, productivity is potentially enhanced by the inclusion of a legume in a cropping system (Maingi et al., 2001). Legume intercrops are also potential sources for plant nutrients that supplement inorganic fertilizers (Banik & Bagchi, 1994; Banik et al., 2006). Li et al., (2001) showed that yield and nutrient uptake by intercropped wheat, maize and soybean were all significantly higher than sole wheat, maize and soybean with the exception of potassium uptake by maize. Intercropping advantages in yield are 40-70% higher in case of wheat intercropped with maize and 28-30% in case of wheat intercropped with soybean.

**Row Number Per ear**

Effect of mixing ratios of corn and soybean, and weed infestation on kernel row number per ear was significant ($P<0.001$). Also, highest row number per ear (18.33) was observed in $P_4W_1$ (Table 1). The results indicated that increase in the corn ratio in the mixture will decrease row number per ear. This was observed in all weed infestation treatments. By increasing the corn density, leaf area in each plant decreased and thus, assimilation rate was decreased. In this situation, intra specific competition between corn plants and inter specific competitions between corn and weeds increased. By increasing weed diversity, weed competitive ability increased,
and the high resource restriction caused lower yield in P1 compared to P4. With respect to reduction of kernel row number per ear before pollination, it could be concluded that weeds have negatively affected the reproduction stage of corn growth.

The lowest rate (14.59) of row number per ear was obtained in P1W4. Results indicated that the number of grains per row increased, as the dominance and shading of corn decreased. By using complementary pattern and good interaction between plant components in intercropping, more light was captured, and water and nutrients were absorbed compared to monocropping. In intercropping, the crop resource use occurred earlier and more efficiently than weeds (Liebman & Dyck, 1993).

**Kernel Number Per row**

Results showed that different mixing ratios and weed infestation had a significant effect on kernel number per row ($P<0.001$). Also, mean comparisons showed that the highest amount of kernel number per row (39.17) was obtained in P4W1 and the lowest (15.63) in P1W4 (Table 1), which expresses that increasing corn population decreased kernel number per row due to lower fecundation. In high corn density the competition between corn plants increased. Also, for the reason of shading in the flowering stage, reduced pollination may produce infertile flowers (Allen, 1983). Besides, lack of sufficient assimilate for filling the kernel, decreased the total number of fertile flowers in P1W4 treatment. Carruthers et al., (2000) reported that there were no differences in the kernel number per row between intercropping and monocropping. Results of mean comparison demonstrated different effects of corn and soybean ratios on kernel number per row in different weed infestations, in such a manner that increasing the corn density from P4 to P1 decreased kernel number per row in all weed infestation treatments (Table 1). This can be due to increase of corn intra specific competition. Corn kernel number per row in plots infested with both weed species was decreased compare to one species infested and weed free plots.
result could be attributed to more efficient resources captured at high inter specific competition of two weed species with the corn.

**1000 kernel weight**

All mixing ratios of corn/soybean and weed infestation significantly influenced the corn 1000 kernel weight ($P<0.001$). Highest amount of 1000 kernel weight (265.20 g) was seen in $P_4W_1$ and the lowest (214.0 g) was in $P_1W_4$ (Table 1). By increasing corn ratio in intercropping, the amount of 1000 kernel weight decreased (Table 1). This is due to corn intra specific competition. On the other hand, presence of both weeds caused a more efficient use of light and other resources than the crop. Diminishing kernel size was due to the competition for resource use. According to Hayder *et al.*, (2003) there was no significant effect on thousand kernel weight of corn when intercropped with soybean at any seeding rate.

**Harvest Index**

Corn harvest index was significantly affected ($P<0.001$) by all mixing ratios and weed infestation. The highest corn HI (0.45) was seen in $P_2W_1$ and lowest (0.20) in $P_4W_4$ (Table 1). In high density of weeds, harvest index decreased because of competition between plants, (Tetio Kago and Gardner, 1988) but Carruthers *et al.*, (2000) reported that intercropping didn’t affect corn harvest index. Mean comparison results revealed that at different levels of weed infestation, by increasing corn ratio in intercropping, HI raises due to the increase in corn density. Lower HI in 100% corn, comparing to 75% corn treatment is due to intra specific competition and more resource allocation to vegetative growth. Hence, plant allocates less resource to reproductive growth and grain yield.
Table 1. Mean comparison of mixing ratios and weed infestation on corn yield and yield components

<table>
<thead>
<tr>
<th>Weed infestation</th>
<th>Mixing ratios</th>
<th>Yield (kg ha⁻¹)</th>
<th>Row number per ear</th>
<th>Kernel number per row</th>
<th>1000 kernel weight (g)</th>
<th>Harvest Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>W₁</td>
<td>P₁</td>
<td>8233.4b</td>
<td>17.53a</td>
<td>20.17c</td>
<td>230.43c</td>
<td>0.42b</td>
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<td></td>
<td>P₂</td>
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<td>17.72a</td>
<td>24.11b</td>
<td>251.53b</td>
<td>0.45a</td>
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<td></td>
<td>P₃</td>
<td>8122.2b</td>
<td>18.23a</td>
<td>25.44b</td>
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<td>0.36c</td>
</tr>
<tr>
<td></td>
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<td>39.17a</td>
<td>265.20a</td>
<td>0.30d</td>
</tr>
<tr>
<td>W₂</td>
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<td>7461.1a</td>
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<td>18.89c</td>
<td>217.90c</td>
<td>0.32ab</td>
</tr>
<tr>
<td></td>
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<td>16.49ab</td>
<td>19.77c</td>
<td>242.57b</td>
<td>0.34a</td>
</tr>
<tr>
<td></td>
<td>P₃</td>
<td>6622.2b</td>
<td>17.42ab</td>
<td>24.57b</td>
<td>243.63b</td>
<td>0.30b</td>
</tr>
<tr>
<td></td>
<td>P₄</td>
<td>5411.3c</td>
<td>17.74a</td>
<td>27.80a</td>
<td>253.33a</td>
<td>0.25c</td>
</tr>
<tr>
<td>W₃</td>
<td>P₁</td>
<td>7733.0b</td>
<td>16.67a</td>
<td>19.85d</td>
<td>230.43c</td>
<td>0.36a</td>
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<td>P₂</td>
<td>8477.8a</td>
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<td>22.50c</td>
<td>243.60b</td>
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<td></td>
<td>P₃</td>
<td>6872.2c</td>
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<td>25.70b</td>
<td>245.07b</td>
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<tr>
<td></td>
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<td>17.75a</td>
<td>28.67a</td>
<td>262.47a</td>
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</tr>
<tr>
<td>W₄</td>
<td>P₁</td>
<td>6666.7a</td>
<td>14.59b</td>
<td>15.63c</td>
<td>214.00d</td>
<td>0.26b</td>
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<td>7066.7a</td>
<td>16.23ab</td>
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<td>21.90b</td>
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<tr>
<td></td>
<td>P₄</td>
<td>3916.7c</td>
<td>17.54a</td>
<td>27.57a</td>
<td>252.13a</td>
<td>0.20d</td>
</tr>
</tbody>
</table>

Means with the same letter at each column are not significantly different (P< 0.05) based on DMRT. (W₁): weed free, (W₂) redroot pigweed, (W₃) jimson weed and (W₄), simultaneous presence of redroot pigweed and jimson weed. (P₁) 100% corn (P₂) 75% corn (P₃) 50% corn, (P₄) 25% corn

Soybean Yield

Mixing ratios of corn and soybean along with weed infestation significantly influenced soybean grain yield (P<0.001). Also, the interaction effect between two factors was significant (P<0.001). Results indicated that in all weed treatments, sole soybean had higher yield than intercropping treatments (Table 2) which was due to higher soybean density and no competition with the corn. By lowering soybean ratio in intercropping, soybean yield was reduced because of competition. Soybean has less competitive ability than corn in intercropping systems. Naturally soybean allocates...
part of its resources to symbiosis association. Redroot pigweed and jimson weed infestations caused greatest soybean yield reduction in different ratios of intercropping. Simultaneous infestation of both weed species have more competitive ability with soybean than one species infestation and caused reduction in pod number per plant, grain number per pod, 1000 grain weigh, and finally caused more yield reduction. Banik et al., (2006) confirmed that higher grain yield of monocropped wheat and chickpea relate to intercropping treatments may be due to the fewer disturbances in the habitat with homogeneous conditions of monocropping systems. Highest amount of yield (5050.0 kg ha\(^{-1}\)) was seen in P\(_5\)W\(_1\) and lowest (365.67 kg ha\(^{-1}\)) in P\(_2\)W\(_4\) (Table 2 and Figure 2).
Pod Number Per Plant

Results showed significant effect by mixing ratios, weed infestation and their interaction effects ($P<0.01$). The highest amount of pod number per plant (46.85) was seen in P$_3$W$_1$ and lowest (20.39) in P$_2$W$_4$ (Table 2). The main reason for reduction of pod number per plant in P$_2$W$_2$ was the low soybean density. Of course, low ability of soybean in competition with redroot pigweed and jimson weed has an important role in diminishing this trait. Hume et al., (1985) reported that, among yield components, number of pods per plant is the most closely related with soybean yield and hence the most affected factor by competition. Carruthers et al., (2000) have also reported a
decreased production of pods per plant in intercropped soybean relative to it's pure stand.

**Grain Number Per Pod**
Results revealed that the effect of mixing ratio and weed infestation on grain number per pod was significant, while their interaction effect wasn’t significant. The highest amount (3.10) was observed in P$_5$W$_1$ and the lowest (2.27) was in P$_2$W$_4$. In all treatments, by diminishing the soybean ratio in intercropping, the grain number per pod decreased. This reduction is due to low competitive ability of soybean compared to corn. It could be concluded that soybean produced low grain number per pod because of changed light spectral quality and decreased light intensity under intense shade of corn canopy. Results indicated that according to morphology and competitive characteristics of redroot pigweed, the soybean grain number per pod in different mixing ratios could not be affected significantly. Jimson weed expanded most part of its leaf area above soybean canopy (data not shown) and thus prevented the light interception to soybean (Rengnier & Stoller, 1989). Carruthers et al., (2000) have also emphasized on lower soybean grain number per pod at intercropping.

**1000 Grain Weight**
There was significant difference in mixing ratios and weed infestation for 1000 grain weight of soybean ($P<0.001$). The highest 1000 grain weight (112.13 g) was seen in P$_5$W$_1$ and lowest (77.27 g) was in P$_2$W$_4$. By decreasing soybean ratio in intercropping, the 1000 grain weight diminished in all weed infestation treatments. This reduction was due to corn shading on soybean. In 25% of soybean ratio, corn shading on soybean caused reduction of spectral quality and quantity of intercepted light by soybean. Actually, increasing diversity of weeds, decreased soybean ability for nutrient uptake and water absorption, and then decreased soybean grain weight.
Hayder et al., (2003) had also reported similar results. These results may be due to competition between two weed species and soybean which affected soybean growth. This finding is in agreement with Thiyaga/rajan (1994), who reported a significant decrease in 1000 grain weight of the intercropped soybean.

**Harvest Index**
Mixing ratio, weed infestation and their interaction had significant effect on soybean harvest index. The lowest amount of HI (17.00) was seen in P₂W₄ and highest (49.01) was in P₅W₁ (Table 2). The reduction is due to corn shading effects on soybean, which causes soybean to allocate it's assimilate to vegetative growth and height increasing for competing with corn. More weed shading causes more decrease in soybean photosynthates. Carruthers et al., (2000) reported that HI was not affected by intercropping, which indicates that the overall partitioning of resources within the soybean plant was not affected.

**LER**
According to quantity of land equivalence ratio in all treatments, corn/soybean intercropping was superior to their pure stand (LER>1). LER values indicated that yield advantages in all mixing ratios are referred to crop complementarities. Corn-soybean intercrops have frequently out yielded monocrop corn (Carruthers et al., 2000). The lowest LER (1.05) was obtained in P₂W₃ and the highest (1.64) was seen in P₄W₂ (Table 2). Intercropping that consistently results in higher LERs are thought to be more efficient from a land use perspective than monocropping.

**Weed Biomass**
Different mixing ratios and weed infestation had significant effect on weed biomass. Result showed that the lowest amount of weed biomass (162.00 g m⁻²) was obtained in
the P3W2 treatment and the highest (376.73 g m\(^{-2}\)) in P5W4 treatment (Figure 3). The results emphasis on high interaction effects of weed infestation and corn/soybean intercropping. Less dry matter and density of weed under intercropping may be due to the suppression of the weed against monocropping. Researchers have reported that the performance of intercropping compared to sole cropping is enhanced by improvement in N fertility, moisture availability, and reduction in weed competition (Weil & Mcfadden, 1991). Intercrops may demonstrate advantages on weed control to sole crops by producing greater crop yield and less weed growth by limiting resources to weeds and also by suppressing weed growth through allelopathy (Banik et al., 2006).

The reduction of weed growth through the crop interference, has been referred as one determinant of yield advantage of intercropping, being a viable alternative to reduce the reliance of weed management on herbicide use (Liebman & Dyck, 1993; Liebman & Davis, 2000; Poggio, 2005).

It is concluded that intercropping can be used as a tool to improve competitive ability of a canopy with good suppressive characteristics. As observed, the highest rate of corn yield in intercropping system (9627.8 kg ha\(^{-1}\)) was in P2W1 treatment, whereas the highest weed biomass (376.73 g m\(^{-2}\)) was in P5W4 treatment (soybean monocropping) and lowest weed biomass(162.00 g m\(^{-2}\)) obtained in P3W2. Interaction between crops and weeds need to be studied in more details and applying an ecophysiological crop growth model is suggested to optimize the intercrop mixtures with respect to yield, quality and suppression ability of the crops against weeds.
Figure 3. Interaction effect of mixing ratios and weed infestation on weed biomass. (W2): redroot pigweed, (W3): jimson weed and (W4): simultaneous presence of redroot pigweed and jimson weed.
Table 2. Mean comparison of mixing ratios and weed infestation on LER and soybean yield and yield components

<table>
<thead>
<tr>
<th>Weed infestation</th>
<th>Mixing ratios</th>
<th>Yield (kg ha⁻¹)</th>
<th>Pod number per plant</th>
<th>grain number per pod</th>
<th>1000 grain weight (g)</th>
<th>Harvest Index</th>
<th>LER</th>
</tr>
</thead>
<tbody>
<tr>
<td>W₁</td>
<td>P₁</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td>P₂</td>
<td>1128.96d</td>
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<td>39.07c</td>
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</table>

Means with the same letter at each column are not significantly different (P< 0.05) based on DMRT. (W₁): weed free, (W₂) redroot pigweed, (W₃) jimson weed and (W₄): simultaneous presence of redroot pigweed and jimson weed. (P₁) 100% corn (P₂) 75% corn (P₃) 50% corn, (P₄) 25% corn:
REFERENCES


