Effect of cowpea (Vigna unguiculata) intercropping on weed biomass and maize (Zea mays) yield

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Field experiments were conducted to investigate the influence of cowpea (*Vigna unguiculata*) density (0, 15 or 30 plants/m²) and sowing date (15 days prior to maize sowing or simultaneously with maize), and of maize (*Zea mays*) planting density (7.5 or 9 plants/m²) on weed biomass and maize crop yield. Results showed that increasing the maize density from 7.5 to 9 plants/m² reduced the weed biomass by 21.5%. Furthermore, cowpea acted as a living mulch, reducing weed biomass by up to 45.5% and 39.6% when intercropped with maize at a density of 7.5 and 9 plants/m², respectively. Under weed-free conditions, an increase in maize density from 7.5 to 9 plants/m² resulted in maize grain yield increasing from 8.92 to 9.40 t/ha; however, the addition of cowpea only increased the maize grain yield by about 4.2%, on average, under these conditions. Under weed-infested conditions, there was a large decrease in maize grain yield (up to 32%), but intercropping with cowpea reduced this to only a 16% decrease. Under weed-free conditions, there was no effect of sowing date on maize grain yield; however, under weed-infested conditions, yield was greater on the second sowing date. Thus, it is concluded that the planting of maize at a density of 9 plants/m² and simultaneously intercropping with cowpea at a density of 30 plants/m² could be an appropriate control measure for weed suppression.

**Keywords:** integrated weed management; sowing date; plant density; cover crop; living mulch

**Introduction**

Weed control technology has developed from hand weeding or simple tillage to the more expensive chemical control methods that we see today (Ghersa et al. 1994). In modern agriculture, chemicals have become the most frequently used weed control strategy. However, environmental and economic costs, as well as increased weed resistance to herbicides have led to a desire for less herbicide use on farms. Because of these potential problems and increased public pressure on conventional agriculture, there is increasing interest in organic farming systems across the world (Isik et al. 2009). However, weed control is recognized as the greatest production-related problem in organic farming systems and thus is one of the major reasons why conventional farmers do not convert to organic production (Kruithof et al. 2009). Use of a cover crop, planting density and sowing date are all considered important for improving the competitiveness of crops against weeds and preventing yield losses in crop plants (Williams 2009; Chauhan and Johnson 2010; Stephenson et al. 2010).

Maize (*Zea mays* L.) is an important cash crop in Iran, being cultivated on 240,209 ha of land and yielding approximately 1.73 million tons of grain per year (Faostat 2010). Other than environmental variables, the most important constraint to maize yield and thus economic returns is competition from weeds (Rajcan &
Swanton 2001; Karimmojeni et al. 2010). Weed competition results from the use of widely spaced maize rows, which allow a high portion of ambient light to penetrate. It is possible that maize could be intercropped with a short-duration legume such as cowpea (*Vigna unguiculata* (L.) Walp), however, to fill the uncovered spaces between the rows and thus act as a living mulch. Living mulches are cover crops that are planted between the rows of a main crop and are maintained as a living ground cover throughout the growing season of the main crop (Monaco et al. 2002), suppressing weed establishment and growth, and thereby reducing the number of weeds. For example, De Haan et al. (1993) reported that spring-seeded living mulches can reduce weed density by 80% with little effect on maize yield. Living mulches suppress weeds by competing for the use of growth resources, and changing environmental factors that affect weed germination and establishment, and can ultimately result in reduced herbicide application (Liebman and Davis 2000). They may also suppress weeds through allelopathy, whereby alkaloids are released from both the roots and leaves of living plants (Yoshida et al. 1993); for example, it has been found that weed growth may be suppressed by the secretion of allelochemicals from living rice plants (Olofsdotter et al. 1999).

It has previously been shown that increasing crop density can suppress weeds (Korres and Froud-Williams 1997), and evidence for the suppressive effect of crop seed rates above the standard has also been confirmed in organic systems (Samuel & Guest 1990). For instance, Bulson et al. (1997) found that weed biomass was significantly reduced when the densities of wheat (*Triticum aestivum* L.) and field bean (*Vicia faba* L.) intercrops were increased; and Arce et al. (2009) showed that soybean seeding rates (24–42 seeds/m²) were inversely related to weed biomass. Increased seeding rates lead to quicker canopy closure, increased crop interference and greater weed suppression, resulting in increased yields (Olsen et al. 2006; Kolb et al. 2012). Thus, the use of increased crop density as a cultural weed management practice can complement the use of cover crops for weed suppression. Ryan et al. (2011) found that the combination of use of a cover crop and increasing crop plant density produced a synergistic interaction that resulted in greater weed suppression than would have been predicted by the use of each tactic alone.

There is only limited information available on herbicide-free weed management practices that provide adequate weed suppression while maintaining acceptable yields, and despite reports on the effect of cowpea as a living mulch on weed suppression, to the best of our knowledge no study has investigated the interactions between crop density and sowing date in the presence of a living mulch. Therefore, the objective of this study was to determine the effect of cowpea density as a living mulch in combination with maize density and sowing date on weed infestations and crop yield of maize in a semi-arid environment.

**Materials and methods**

**Field experiments**

Two field experiments were conducted under furrow irrigation at the Research Farm of the University of Zanjan, Zanjan, Iran, in 2006 and 2007. This region is characterized by a semi-arid cool climate, with an annual mean temperature of 11°C and mean precipitation of 293 mm for the past 30 years. Mean daily temperature and precipitation data recorded near the experimental area during the growing season are given in Fig. 1. The soil type was a sandy loam, with a pH of 7.54 and 8.18, and soil organic matter of 1.6% and 1.31% in 2006 and 2007, respectively. The soil was ploughed using a mouldboard plough (20–25 cm) that was followed by two disks to prepare the seedbed. Based on soil analysis, fertilizers were applied prior to planting or as a topdressing. Fertilizer inputs were 37 kg/ha P (triple superphosphate) and 30 kg/ha N (urea) applied to the seedbed, and 30 kg/ha N (urea) split equally between 30 and 65 days after planting.

Maize (cv. Singles Cross 647) was sown at a row spacing of 0.75 m on 12 May 2006 and
16 May 2007. The plots consisted of five 9-m-long rows. Cowpea (cv. parasto) and maize were over-seeded to ensure uniform crop establishment, and were then thinned to the desired densities. Irrigation was carried out weekly until physiological maturity of the maize. Weeds were manually hoed in weed-free plots throughout the season; no chemicals were applied to the plots.

**Experimental treatments**

The first experiment was carried out in 2006 using a randomized complete block design with a factorial treatment arrangement and three replications. It consisted of two maize densities (7.5 and 9 plants/m²) × three cowpea densities (0, 15 and 30 plants/m²), which were intercropped with maize in the presence or absence of weeds.

The better performing density of maize was used in 2007. Cowpea (at 0 and 30 plants/m²) was intercropped with maize on two sowing dates: 15 days prior to maize sowing and simultaneously with maize sowing. The crops were again grown under weed-infested or weed-free conditions. Cowpea was uniformly sown after furrow preparation, following which maize was seeded within the established cowpea rows.
Plant sampling and statistical analysis
To determine grain yield, crops growing along a 2-m length of the centre two rows in each plot were hand clipped at maturity and dried to a constant weight at 70 °C for 48 h. Final maize grain yield was adjusted to 13% moisture. Data on the weed species in each plot were collected at 107 d after maize emergence. Weeds were cut at ground level from a 2.4 x 0.4-m area in each plot, and were taken to the laboratory for separation and dry weight determination.

Data were analysed using analysis of variance (ANOVA) with the PROC GLM procedure of SAS version 9.1 (SAS Institute 2002). The significance of differences between treatments was determined using Least Significant Differences (LSD) at a significance level of 0.05.

Results and discussion
Weed biomass
The experimental field site had an almost uniform infestation of *Echinochloa crus-galli* L., *Setaria viridis* (L.) P. Beauv., *Chenopodium album* L., *Amaranthus retroflexus* L. and *A. blitoides* S. Wats., and a low infestation of other weed species, which mostly comprised *Anchusa italica* Retz., *Sonchus oleraceus* L., *Glycyrrhiza aspera* Pall., *Xanthium strumarium* L. and *Convolvulus arvensis* L. In 2006, the biomasses of *E. crus-galli* and total weed biomass were significantly influenced by the density of both maize and cowpea (Table 1). By contrast, the biomass of *C. album* and *S. viridis* were only affected by cowpea density and the biomass of *A. blitoides* was not affected by the density of either species. There was no significant interaction between the factors (Table 1).

The pure stand of maize that was planted at a density of 7.5 plants/m² had the highest weed infestation. In the absence of cowpea, increasing the maize density from 7.5 to 9 plants/m² reduced the total weed biomass by 21.5% (Table 2). This illustrates the potential for suppressing weeds by increasing the density of maize to 16% greater than the normal planting density of 7.5 plants/m². The use of cowpea as a living mulch greatly affected weed growth and biomass, with the total weed biomass for a given density of maize decreasing as cowpea density increased (Table 2). Averaged across the two maize densities, the biomasses of *S. viridis*, *E. crus-galli* and *C. album*, and the total weed biomass were 44%, 64%, 42% and 46% lower, respectively, when cowpea was intercropped with maize at a density of 30 plants/m² than in the absence of cowpea.

In 2007, there was a significant interaction between cowpea density and sowing date on the biomasses of *A. retroflexus*, *C. album* and the other weed species category, and the total weed biomass (Table 1). This indicates that weed suppression by the cowpea living mulch did not function independently of cover crop sowing date. However, the biomass of *E. crus-galli* was

<table>
<thead>
<tr>
<th>Year</th>
<th>Factor</th>
<th><em>S. viridis</em></th>
<th><em>E. crus-galli</em></th>
<th><em>A. retroflexus</em></th>
<th><em>C. album</em></th>
<th><em>A. blitoides</em></th>
<th>Other¹</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>C</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>–</td>
<td>&lt;0.01</td>
<td>0.31</td>
<td>0.58</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>0.07</td>
<td>0.02</td>
<td>–</td>
<td>0.25</td>
<td>0.23</td>
<td>0.54</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>C x M</td>
<td>0.48</td>
<td>0.62</td>
<td>–</td>
<td>0.29</td>
<td>0.19</td>
<td>0.44</td>
<td>0.14</td>
</tr>
<tr>
<td>2007</td>
<td>C</td>
<td>–</td>
<td>&lt;0.01</td>
<td>0.67</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>–</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.02</td>
<td>0.26</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>C x S</td>
<td>–</td>
<td>0.22</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.08</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

¹Other species, mostly *Anchusa italica*, *Sonchus oleraceus*, *Glycyrrhiza aspera*, *Xanthium strumarium*, *Convolvulus arvensis*. 
only significantly influenced by the main effects and the biomass of *A. blitoides* was only affected by cowpea density (Table 1). The maximum total dry mass of weeds (458.2 g/m²) was recorded when maize was grown as a monoculture and on the first sowing date (Table 3). By contrast, total weed biomass decreased to 173 g/m² on the second sowing date, which reflects a reduction of approximately 62% compared with the first sowing date. When cowpea intercropping and the second sowing date were used, the total weed biomass decreased by 31%. Averaged over the two cowpea sowing dates, the biomasses of *E. crus-galli*, *C. album* and *A. blitoides* were 40%, 63% and 69% lower, respectively, when cowpea was intercropped with maize at a density of 30 plants/m² than in the absence of cowpea. For *A. retroflexus*, cowpea intercropping reduced the biomass by 41% on the first sowing date; however, on the second sowing date, intercropping did not affect the biomass production of this weed (Table 3).

These results clearly indicate that the use of cowpea as a living mulch has a significant effect on weed biomass (Tables 2 and 3). The utility of intercrops to suppress the growth of weeds has also been demonstrated for other crops (Rajeswara Rao et al. 1993). Cowpea had such a large effect on weed suppression due to its ability to develop over-ground runners, which occupied the inter-row spaces in the intercropped treatments and restricted the germination and growth of weed seeds. In other words, the lack of availability of uncovered inter-row spaces for weed establishment resulted in a severe reduction in the biomass of weeds. Many

**Table 2** Effects of maize planting density and cowpea living mulch on weed aboveground biomass (g/m²) per species and total at harvest time in 2006.

<table>
<thead>
<tr>
<th>Density (plants/m²)</th>
<th>Biomass (g/m²)</th>
<th><em>S. viridis</em></th>
<th><em>E. crus-galli</em></th>
<th><em>C. album</em></th>
<th><em>A. blitoides</em></th>
<th>Other¹</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize Cowpea</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.5</td>
<td>0</td>
<td>74.9±7.0</td>
<td>239.1±21.1</td>
<td>97.6±10.3</td>
<td>88.7±8.9</td>
<td>46.4±11.6</td>
<td>526.6±53.2</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>42.4±12.3</td>
<td>156.2±14.7</td>
<td>84.1±18.6</td>
<td>59.8±10.6</td>
<td>40.4±11.2</td>
<td>382.9±27.6</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>39.8±7.3</td>
<td>88.6±9.0</td>
<td>60.2±8.5</td>
<td>53.0±10.7</td>
<td>40.6±15.7</td>
<td>282.2±15.3</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>54.4±9.0</td>
<td>201.8±8.8</td>
<td>75.2±17.4</td>
<td>51.9±12.5</td>
<td>29.3±4.9</td>
<td>412.6±39.0</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>37.8±5.3</td>
<td>110.6±10.7</td>
<td>93.9±13.5</td>
<td>62.7±11.5</td>
<td>52.0±18.3</td>
<td>357.1±21.7</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>31.5±6.0</td>
<td>70.1±11.2</td>
<td>41.6±10.4</td>
<td>52.1±14.6</td>
<td>28.1±10.8</td>
<td>223.4±14.9</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td></td>
<td>21.0</td>
<td>43.9</td>
<td>32.9</td>
<td>34.8</td>
<td>36.3</td>
<td>64.7</td>
</tr>
</tbody>
</table>

¹Other species, mostly *Anchusa italica*, *Sonchus oleraceus*, *Glycyrrhiza aspera*, *Xanthium strumarium*, *Convolvulus arvensis*.

**Table 3** Weed aboveground biomass (g/m²) per species and total at harvest time in 2007.

<table>
<thead>
<tr>
<th>Cowpea</th>
<th>Biomass (g/m²)</th>
<th><em>E. crus-galli</em></th>
<th><em>A. retroflexus</em></th>
<th><em>C. album</em></th>
<th><em>A. blitoides</em></th>
<th>Other²</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sowing¹</td>
<td>Density</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>0</td>
<td>151.5±16.9</td>
<td>40.5±10.2</td>
<td>96.9±15.0</td>
<td>96.0±15.6</td>
<td>73.3±3.2</td>
<td>458.2±45.7</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>89.0±8.5</td>
<td>23.5±3.5</td>
<td>20.4±2.2</td>
<td>12.3±4.0</td>
<td>27.7±1.9</td>
<td>173.0±7.8</td>
</tr>
<tr>
<td>Second</td>
<td>0</td>
<td>78.7±11.7</td>
<td>10.1±4.5</td>
<td>35.6±6.1</td>
<td>87.9±8.1</td>
<td>40.4±0.9</td>
<td>252.7±18.9</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>49.5±6.8</td>
<td>23.6±4.2</td>
<td>28.6±8.1</td>
<td>44.0±11.2</td>
<td>27.7±0.9</td>
<td>173.4±7.5</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td></td>
<td>42.2</td>
<td>13.3</td>
<td>31.2</td>
<td>33.0</td>
<td>5.9</td>
<td>94.1</td>
</tr>
</tbody>
</table>

¹First sowing date: cowpea was sown 15 days before maize planting time. Second sowing date: cowpea was sown simultaneously with maize.

²Other species, mostly *Anchusa italica*, *Sonchus oleraceus*, *Glycyrrhiza aspera*, *Xanthium strumarium*, *Convolvulus arvensis*. 

**Effect of cowpea intercropping**

5
studies have reported lower dry weights of weeds in systems that use cover crops because covering the inter-row spaces suppresses weed emergence (Teasdale & Mohler 1993). In the present study, weed infestation levels generally decreased as the densities of both the cover crop and maize were increased (Tables 2 and 3). However, weed biomass was also significantly affected by sowing date. Previous research has demonstrated that planting date (Mirsky et al. 2009) and cover crop seeding rate (Hunsberger & Ryan 2010) can influence cover crop biomass in predictable ways. Mohammadi (2010) reported that maize yield and weed dry weight were not significantly influenced by the planting date of hairy vetch (*Vicia villosa* L.), when planted simultaneously with maize or 10 days after maize emergence, but that an increased planting rate of hairy vetch from 0 to 50 kg/ha improved maize yield by 11% and reduced weed dry weight by 50.9%. From these findings, it was hypothesized that as the density of the living mulch increased, canopy closure occurred more rapidly, decreasing the amount of photosynthetically active radiation available beneath the canopy.

**Maize yield**

The use of cowpea as a living mulch increased maize yield in both the weed-infested and weed-free conditions. Under weed-free conditions, maize grain yield increased from 8.92 to 9.40 t/ha as crop density increased from 7.5 to 9 plants/m² (Fig. 2). In these plots, the addition of cowpea as a living mulch increased the maize grain yield by an average of about 4.2%. Grain yield was much lower under weed-infested conditions than under weed-free conditions due to weed competition (Fig. 2). The maximum yield loss (32% and 30% at maize densities of 7.5 and 9 plants/m², respectively) occurred within the pure stand of maize (Fig. 2). However, cowpea intercropping affected the magnitude of these yield reductions, with a decrease in yield of only 16% at a cowpea intercropping density of 30 plants/m². Increasing cowpea density from 15 to 30 plants/m² had no significant effect on the maize yield loss though. Under weed-infested conditions, intercropping maize at a density of 7.5 plants/m² with cowpea at densities of 15 and 30 plants/m² increased maize grain yield by 15.8% and 22.3%, respectively. By contrast, the respective values increased even further to 18.9% and 26.8%, respectively, when

![Figure 2](image.png)

**Figure 2** Effect of maize crop and cowpea density on maize grain yield. Bars with the same letter are not significantly different according to a Least Significant Differences test at *P* ≤ 0.05. Vertical lines are standard errors.
the maize planting density was increased to 9 plants/m². The lowest maize yield and the highest weed biomass was observed in the maize monocrop grown under weed-infested conditions; however, even under these conditions, an increase in maize density from 7.5 to 9 plants/m² notably improved the yield and reduced the dry weight of weeds. It has previously been shown that practices such as creating narrow rows and increasing crop densities promote early crop canopy closure and help to maximize crop competitiveness (Monaco et al. 2002). Such rapid closure of the crop canopy over weeds decreases sunlight and thus directly limits weed growth. Furthermore, limited light on the soil surface can reduce subsequent germination and growth of weed seeds. Conversely, low crop plant densities, which delay crop canopy closure, will make weed control more difficult and costly (Monaco et al. 2002).

In the second experiment, the highest yield was obtained from weed-free plots that had been sown on the first sowing date in both the intercropped and monoculture plots (Fig. 3). Under weed-infested conditions, the maize grain yield decreased by 21% to 40%, depending on cowpea density (0 versus 30 plants/m²) and sowing date. Intercropping was successful in controlling weed growth and significantly increased maize yield (0.94 and 2.97 t/ha for the first and second sowing dates, respectively; and 2.4 and 0.94 t/ha for the weed-free and weed-infested conditions, respectively). However, although sowing time can be delayed to avoid early weed flushes, any advantages gained for weed control are often outweighed by decreased crop yield potential. Therefore, the cost of using delayed planting as a weed control strategy must be weighed up for each crop–weed–environment situation (Monaco et al. 2002).

The use of cowpea as a living mulch increased maize yield under both weed-infested and weed-free conditions. Previous research has also indicated that legume cover crop mulches have the ability to increase crop yield (Mennan et al. 2006; Isik et al. 2009), possibly by supplying nitrogen through the nitrogen fixation process. Non-legume cover crops, such as grasses and forbs, may also benefit crops by reducing nitrogen leaching during the wet season (Kuo and Sainju

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**Figure 3** Effect of cowpea density and sowing date on maize grain yield. Sowing date 1: cowpea planted 15 days before maize planting; and sowing date 2: cowpea planted simultaneously with maize. Bars with the same letter are not significantly different according to a Least Significant Differences test at $P \leq 0.05$. Vertical lines are standard errors.
The greater maize yield observed in the present study under weed-free conditions may have resulted from improved soil physical properties, nitrogen fixation or recycling, increased soil organic carbon and mineralization, and increased nutrient availability in the cover crop plots (Isik et al. 2009); however, it is the ability of living cowpea to suppress weeds that will have had the main role in increasing maize yield.

Our findings confirm that cowpea can be used as a living mulch in organic maize production to reduce the biomass of weeds. However, the use of cowpea did not provide reliable weed control throughout the season and so must be combined with additional weed management options to achieve acceptable control. Maize is characterized as a nitrophilic crop, and therefore the potential biological nitrogen fixing abilities of legumes such as cowpea would bring further benefits, reducing the amount of N fertilization needed for maize. Cover crops should be incorporated into weed management programmes as a more cost-effective and environmentally friendly method that will help to save the environment, improve soil fertility and improve yield.

Conclusions

Weed control is a key factor for the successful production of maize. The use of cowpea as a living mulch leads to a considerable reduction in weed biomass (about 46% at a density of 30 plants/m²). However, this weed control level was not entirely adequate, and so complementary management strategies such as adapted seedbed preparation techniques (e.g. stale seedbed) and the selection of cover crops with more allelopathic capabilities are important considerations for achieving complete weed control. The growth of weeds was suppressed in the presence of this cover crop, and maize yield increased in both the weed-free and weed-infested plots. However, both the density and sowing date of the cover crop were also important for achieving a high yield of maize, and maize density also affected the efficacy of this living mulch. In summary, the best maize yield was obtained when maize was planted at a density of 9 plants/m² and simultaneously intercropped with cowpea at a density of 30 plants/m².

References

Chauhan BS, Johnson DE 2010. Responses of rice flat sedge (Cyperus iria) and barnyardgrass (Echinochloa crus-galli) to rice interference. Weed Science 58: 204–208.


Williams MM 2009. Within-season changes in the residual weed community and crop tolerance to interference over the long planting season of sweet corn. Weed Science 57: 319–325.