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Effects of common lambsquarters (*Chenopodium album* L.) emergence time and density on growth and competition of maize (*Zea mays* L.)

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Abstract

Common lambsquarters (*Chenopodium album* L.) is an important weed of maize fields in Iran. In order to study the effect of common lambsquarters relative time of emergence on maize (*Zea mays* L.), an experiment was designed with different densities of the weed. The experimental design was split plot based on a randomized completed block design with three replications. The emergence time of lambsquarters was assigned as main plots with three levels: emergence of the weed 14 and 7 days earlier and simultaneously with maize. Density of weed was the subplot treatment with 6 levels: 0, 4, 8, 12, 16 and 20 plants per m^2. The results showed that height and leaf area index of maize decreased with earlier emergence time and increasing lambsquarters density, so that 14 days earlier emergence of weed at high densities (16 and 20 plants per m^2) was led to maximum reduction. In contrast, height and LAI of lambsquarters increased with earlier emergence time especially at high densities. Common lambsquarters was a stronger competitor when emerged 14 days earlier than maize. Maize yield decreased more than 70% in the 7 and 14 days earlier emergence of lambsquarters at high density. It could be concluded that relative time of weed emergence compare to its density had a greater effect on maize growth. Therefore, controlling lambsquarters before maize emergence at any density is recommended to prevent maize growth and yield loss.

Keywords: Corn, Density, Emergence time, Interference, Leaf area, Yield loss.
Abbreviations: D-density of weed; E-relative time of weed emergence.

Introduction

Common lambsquarters is the most prevalent weed of soybean [*Glycine max* (L.) Merr.] and maize (*Zea mays* L.) cropping systems in the upper Midwest of the USA (Boerboom, 2009; Kruger et al., 2009; Forcella et al., 1992) and it is one of the most competitive annual broadleaf weeds in maize production in Ontario, Canada (Weaver, 2001). It is typically one of the first weeds to emerge in the spring (Buhler et al., 1997). Therefore, it has a competitive advantage by emerging early in the season, typically before crop emergence. Competitiveness of lambsquarters is determined by density, relative time of crop and weed emergence, and environmental conditions (Kempenaar et al., 1996). Common lambsquarters causes significant yield damage in many cropping systems because of its rapid growth characteristics, competition for nutrients (Vengris, 1955; Pandy et al., 1971), prolific seed production (Harrison, 1990), and seed germination, under a wide range of environmental conditions (Ogg and Dawson, 1984; Mulugeta and Stoltenberg, 1998). Weed density is a crucial factor in crop-weed competition. Crook and Renner (1990) observed a 20% reduction in soybean yield where lambsquarters was present throughout the entire growing season at a density of four plants m^{-2}. Conley et al. (2003) reported a 61% reduction in soybean yield due to season-long interference from lambsquarters densities of 64 plants m^{-2}. Sibuga and Bandeen (1980) found that maize yield was reduced by as much as 58% when lambsquarters density reached 277 plants m^{-2}. The timing of weed emergence relative to crop is important to crop growth and yield. Yield losses are usually high when weeds emerge earlier or at the same time as the crop (Blackshaw et al., 1981; Aldrich, 1987; Jakstaite, 1988). Yield losses are minimized if weeds emerge later than the crop. However, prevailing environmental conditions are also likely to influence the interaction between crop and weeds (Hakansson, 1991; Kropff and Van Laar, 1993). Kropff et al. (1993) indicated that if the maximum height of common lambsquarters was reduced to 60 cm (which equals the maximum height of the sugar beet), only early emerging weeds could cause severe yield loss. Two components of light affect the outcome of competition: quantity and quality. The quantitative component of light (i.e., intensity and the amount intercepted by a crop) determines canopy photosynthesis, whereas light quality is a driving variable of plant morphology. Both aspects of light are changed in a crop-weed competition situation when compared to the sole crop or weed canopy (Rajcan and Swanton, 2001). As a consequence, dry matter (DM) accumulation and yield (Staniforth, 1957; Thomas and Allison, 1975) as well as morphology of both maize and weeds (McLachlan et al., 1993) are altered compared to maize or weeds grown in the absence of competition. Leaf area index (LAI) defines the ability of a canopy to intercept incident photosynthetic photon flux density (PPFD) and is an important factor determining DM accumulation. Thus, any reduction in LAI below the canopy optimum implies less PPFD interception and influences yield directly (Loomis et al., 1968). There are two major light-competition strategies exhibited by weeds. One is the placement of leaves above the competing plants (over-topping), which is a typical strategy of jimsonweed (*Datura stramonium* L.) and velvetleaf grown in a shortstatured crop, such as soybean (Stoller and Woolley, 1985). Another strategy is a vertical (upward) shift in leaf area distribution within the canopy (McLachlan et al., 1993). Common lambsquarters is known as one of the most troublesome weeds in maize field of Iran. The majority of studies record effects of weeds on yield in the simultaneous emergence time or times after crop emergence, whereas weeds usually cause to yield loss when emerge before crops and interference with crops during the growing season. Therefore, the objectives of this study were to (1) evaluate the importance and influence of earlier emergence time of weed at different densities on maize growth characteristics and also to evaluate the response of weeds to these factors when grown in competition with maize, and (2) determine the competitiveness of lambsquarters and its effects on maize yield when emerged at different times and densities.

Results

Weed and maize height and leaf area index

The highest height of lambsquarters (151 cm) was obtained from 14 days earlier emergence time relative to maize at high density and the lowest (103 cm) was reached in simultaneous emergence time of weed at low density. In contrast, maize height decreased with increasing density of lambsquarters and earlier emergence of the weed, so that the lowest height (45.5 cm) was obtained when maize emerged 14 days after the weed at high density (20 plants m^{-2}) and the highest (205 cm) was recorded in simultaneous emergence time at low weed density (4 plants m^{-2}) (Fig. 2). Emergence time and density of lambsquarters had significant effect on weed leaf area index, so that the highest LAI (6.5) was observed in 14 days earlier emergence at high density. While, the lowest LAI (1.7) was achieved in density of 4 plants per m^2 in the same emergence time and due to competition by maize, weed LAI was never reached to 3 (data not shown). The result of this research showed that earlier emergence time and density of lambsquarters has remarkable effect on maize leaf area index. Maximum maize leaf area index (3) was obtained in the same emerging at low density of weed except of weed free check. In contrast, the lowest LAI (0.4 and 0.3) was observed when maize emergence was delayed 14 days at 16 and 20 plants m^{-2}, respectively (Fig. 3). Based on the coefficients of Equation 1, reduction in maize leaf area index per unit weed density as *D* approaches zero at 14 and 7 days earlier emergence of lambsquarters (*I*) was 17.63 and 9.09 percent respectively, while, in simultaneous emergence of weed was 2.71 percent. These coefficients show that first plant of lambsquarters impose more competition pressure to maize at the earlier emergence time especially in 14 days earlier emergence of weed. Also, maximum reduction in maize leaf area index was obtained at high densities in 14 and 7 days earlier emergence of weed than maize, so that maize leaf area index reduced by almost 100 percent. In contrast, maximum reduction in maize leaf area index was 78% in simultaneous emergence of weed, as density of weed reached to its highest (Table 1). Hence, the time of weed emergence is very important in competition between crop-weed, as earlier emergence of weed would be led to reduction of leaf area index of crop close to 100 percent and consequently the maximum yield loss.

Maize leaf number

Maize leaf number decreased significantly at 14 days earlier emergence of lambsquarters, so that maize plants had 6-7 leaves at weed density of 20 plants per m^2. Maize leaf number was decreased at 7 days earlier emergence of weed, but this reduction was not significant, so that maize at densities of 4 and 20 plants per m^2 of lambsquarters had 11-12 and 10-11 leaves, respectively (Fig. 4). Maize leaf number was not decreased when crop and weed emerged at the same time (data not shown).

Weed competitiveness and maize yield

Relative damage coefficient indicated that lambsquarters in 14 days earlier emergence was a stronger competitor than maize, so that at this time of emergence, *q* was larger than one (1.64 and 1.3 for one and two parameter model, respectively) and a convex curve is found above the diagonal line. In contrast, this coefficient was smaller than one (0.28 and 0.04) for both parameter model and a concave curve is found under the diagonal line. Hence, lambsquarters was not good competitor when emerged simultaneously with maize and crop was the stronger competitor. Coefficients also showed that maize and weed had equals competition ability at the 7 days earlier emergence, but maximum yield loss (*m*) was obtained at high densities showing that emerging lambsquarters in this time and 14 days earlier than maize was led to yield reduction by 75 and 79 percent, respectively (Table 2 and Fig. 5). These results show that crop yield would be reduce more than 70%, when weed emerged earlier than crop even though competitiveness of crop is the same as weed. But yield was not decreased too much in the same emerging time of weed and yield loss was as low as 15 percent even at high density of weed.

Discussion

The results of this experiment indicated that earlier emergence together with increasing density of lambsquarters cause to its competitive advantage over maize and less light receiving by maize due to overtopping by weed. Caranza et al. (1995) reported that early emergence of *Ridolfia segetum* made weeds about 1.5 times more competitive than late emergence due to higher height. Compared with the weed-free check, *Xanthium strumarium* reduced maize height by 33 cm at high density (16 plants per m^2) (Karimmojeni et al., 2010). In the earlier emergence of weed, height reduction was probably due to competitive pressure of weed population in exploitation of environmental resources such as light and nutrients. At the same time emerging, maize height was not severely affected by weed density.

Reduction in maize height was much less presumably due to receiving higher light quantity (PPFD) with better quality (R:FR), and equal exploitation of resources. It was reported that maize height decreased as green foxtail density increased under 0 kg N ha^{-1}. This relationship was less obvious under higher N rates, so that the height of maize grown in the presence of 250 green foxtail plants m^{-2} decreased 12% at 0 kg N ha^{-1} whereas height decreased only 1% at 200 kg N ha^{-1} (Cathcart and Swanton, 2004). Common lambsquarters has increased height and leaf area in the situation of resources frequency and no competition; so that expanding canopy has prevented light transmission when the competition was been initiated by maize plants. Colquhoun et al. (2001) expressed that greater lambsquarters net photosynthesis may have been partly attributed to its earlier emergence relative to maize and, thus, greater lambsquarters leaf area. This can be due to inability of maize plants to compete with lambsquarters and a higher photosynthetic active radiation received in earlier emergence time and high densities, so that with full shading

Table 1. Observed weed-free maize leaf area index and rectangular hyperbola parameter estimates for the first, second and third lambsquarters emergence times as a function of weed density.

Lambsquarters relative time of emergence	Weed-free maize leaf area index	Parameter estimates [a]			R^2
		LAI_{WF}	*I*	*A*	
	—	—	%	%	—
E_{-14} [b]	2.16	2.15 ± 0.05	17.63 ± 2.23	100 ± 7	0.99
E_{-7}	3.03	3.02 ± 0.06	9.09 ± 1.11	100 ± 9.44	0.99
E_0	3.42	3.38 ± 0.21	2.71 ± 2.31	78 ± 10.09	0.84

[a] LAI_{WF}, represents predicted weed-free leaf area index ± SE of maize; I, represents leaf area index loss ± SE as weed density approaches zero; A, represents leaf area index loss ± SE at high weed densities. The coefficient of determination (R^2) describes the fit of each model to the observed data.
[b] E_{-14}, E_{-7} are 14 and 7 days earlier emergence and E_0 is the same emergence of this weed with maize, respectively.

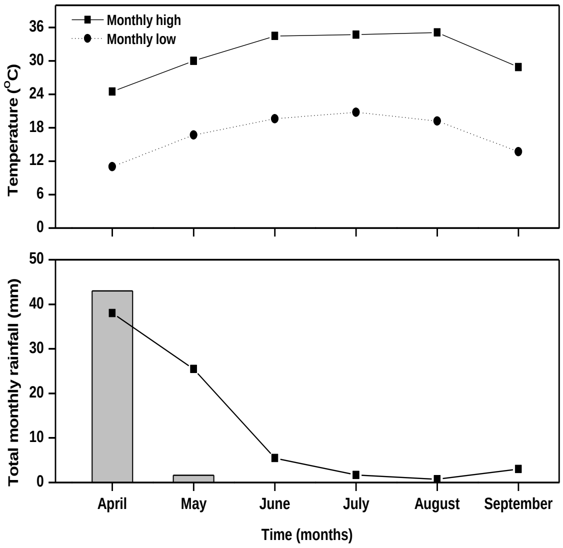

Fig 1. High and low monthly temperatures and total monthly rainfall for 2006 (bars) and 18-year average monthly precipitation (line) in Mashhad, Iran.

Table 2. Estimated parameters obtained from maize yield loss as a function of the relative leaf area of the lambsquarters for the first, second and third emergence times.

Model	Lambsquarters relative time of emergence	Parameter estimates [a]		R^2
		q	*m*	
One-parameter model	E_{-14} [b]	1.64 ± 0.27	—	0.99
	E_{-7}	1.1 ± 0.62	—	0.92
	E_0	0.28 ± 0.15	—	0.93
Two-parameter model	E_{-14}	1.3 ± 0.14	0.79 ± 0.89	0.99
	E_{-7}	0.83 ± 0.3	0.75 ± 0.27	0.92
	E_0	0.04 ± 0.23	0.15 ± 0.83	0.93

[a] q, represents the damage coefficient associated with lambsquarters; m, represents the maximum yield loss caused by weed. The coefficient of determination (R^2) describes the fit of each model to the observed data.[b] E_{-14}, E_{-7} are 14 and 7 days earlier emergence and E_0 is the same emergence of this weed with maize, respectively.

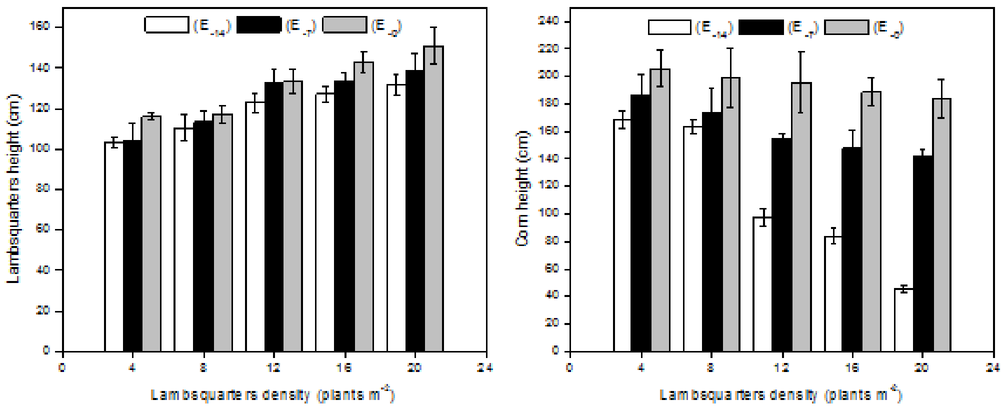

Fig 2. Common lambsquarters and maize height at the beginning of lambsquarters senescence as influenced by weed emergence time and density in Mashhad. E_{-14}, E_{-7} are 14 and 7 days earlier emergence and E_0 is the same emergence time of this weed with maize, respectively. Bars represent standard errors of means.

on maize, weed has reached the maximum leaf area index. Mahoney and Swanton (2008) reported that the rate of leaf appearance increased under high photosynthetic photon flux density, so that lambsquarters produced 0.85 leaves per day under $High_{PPFD}$ treatment which was 25% greater than Low_{PPFD} plants. Field crops such as maize use resources efficiently. While, broadleaf weeds such as lambsquarters have luxuriant accumulation in exploitation of soil resources. Depletion of resources especially nitrogen and canopy development by weed in the earlier emergence probably caused to reduction in nutrients, light quality and quantity at the time of maize emerging. Therefore, low N concentration in soil, low PPFD and R:FR at the lower layers of weed canopy was led to reduction in the rate of maize leaf appearance and consequently leaf area index. Liu et al. (2008) reported that exposure to low R:FR caused by the presence of *A. retroflexus* delayed leaf appearance and reduced shoot dry weight of maize. Maize LA was typically reduced only 4 to 35% at 200 kg N ha^{-1} but was reduced 40 to 57% when grown at 0 kg N ha $^{-1}$ and at the highest green foxtail density (Cathcart and Swanton, 2004). On the other hand, it seems that reduction in maize LAI in the late emergence of maize relative to weed could be due to allocation of resources to stem elongation for increasing height and receiving more radiation. The root:shoot ratio for the weedy treatment was 11% lower than for the weed-free treatment, although it tended to be greater in the weedy treatment at the 4-leaf tip stage (Liu et al., 2008). At the same emerging time, maize plants probably have allocated more photosynthetic dry matter to shoot development and increasing the height. While weed plants allocated for expanding roots and accessing more volume of soil. Because of the maize is a more efficient user of nitrogen, velvetleaf (*Abutilon theophrasti* Medik.) will partition a relatively greater proportion of new growth to roots under low N, resulting in a greater reduction in leaf area growth compared to maize. However, when nitrogen is non-limiting, velvetleaf will partition most dry matter into leaves and stems (Bonifas et al., 2005). By considering simultaneous competition between lambsquarters and maize, nutrients have not completely consumed by weed at the soil surface where maize roots were present. In addition, maize plants received higher PPFD and R: FR. Hence, leaf area and height of maize was not decreased much more because of better growth and development in the situation of concurrent emergence. In contrast, although lambsquarters plants have had lower leaf area in this emergence time due to root and shoot competition with maize plants, but using stored nutrients within organs in a luxury accumulation and having expanded root system have produced sufficient leaf area and dry matter during growing season for support and filling grains.

Materials and methods

Site description

An experiment was conducted in 2006 growing season at the Agricultural Faculty of Ferdowsi University of Mashhad, Iran (Lat. 36˚15' N, Long. 59˚28' E; 985m altitude) with dry and cold climate. High and low monthly temperatures and total monthly rainfall are reported in Figure 1. The experiment was a split plot based on randomized complete block design with three replications. Emergence time of lambsquarters as E_1, E_2 and E_3 (emergence of the weeds 14 or 7 days earlier and simultaneously with maize emergence, respectively) were assigned to main plots and density of weed at 6 levels of D0, D1, D2, D3, D4 and D5 (0, 4, 8, 12,

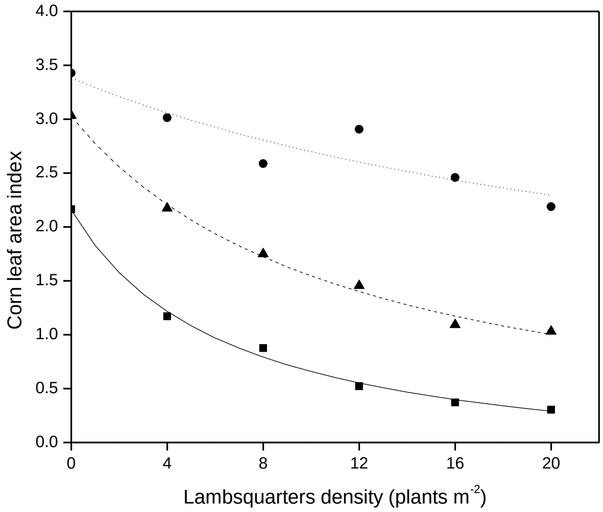

Fig 3. Observed and estimated maize leaf area index at the beginning of lambsquarters senescence as a function of weed density at the 14 days (■), 7 days (▲) earlier emergence of weed and simultaneous (●) emergence time. Regression lines were fitted using Equation 1.

16 and 20 plants m^{-2}) as subplot. Maize seed were planted 1.5 to 2 cm deep in 70-cm between and 20-cm in-row spacing at density of 7 plants m^{-2}.

Experimental procedures

The field was moldboard-plowed, harrowed and cultipacked in the spring to be prepared for planting. Starter fertilizer was broadcasted at a rate of 300-200-200 kg ha^{-1} N-P-K before planting based on local recommendations and was incorporated by cultivation and shallow disking for seedbed preparation. Nitrogen fertilizer was applied three times, 50% before planting, 25% at the six-to eight-leaf stage and 25% at the ten-to twelve-leaf stage of maize. Based on a pre-test it was determined that emergence took 15 days for lambsquarters and 7 days for maize. We adjusted sowing dates of lambsquarters to achieve emergence 14 and 7 days prior to maize emergence and also simultaneously with maize. Common lambsquarters emergence times were based on visual estimates of 50% emerged plants. To ensure emergence of maize seed, four seeds were placed in each hole and seven days after emergence were thinned to one plant. Field was irrigated once a week. In our research was not observed any disease or pest. All other weed seedlings including common purslane [*Portulaca oleracea* L.], barnyardgrass [*Echinochloa crus-galli* L.], yellow nutsedge [*Cyperus esculentus* L.], purple nutsedge [*Cyperus rotundus* L.], giant foxtail and redroot pigweed was removed by hand. Individual plots were 2.8 m wide by 3.0 m long and included four rows of maize. Two rows of borders were considered as a marginal and plant samples were harvested from two center rows. At the initiation of lambsquarters senescence, height of five tagged maize and lambsquarters plants and leaf number of tagged maize was recorded in each plot. The tagged maize plants with five plants of lambsquarters near to them were clipped at the soil surface, sectioned and placed in cloth bags. After measuring plants leaf area with leaf area meter (Delta-T Devices, Cambridge, England), plants were dried to constant weight in an oven for 70 h at 75°C and dry weights were recorded.

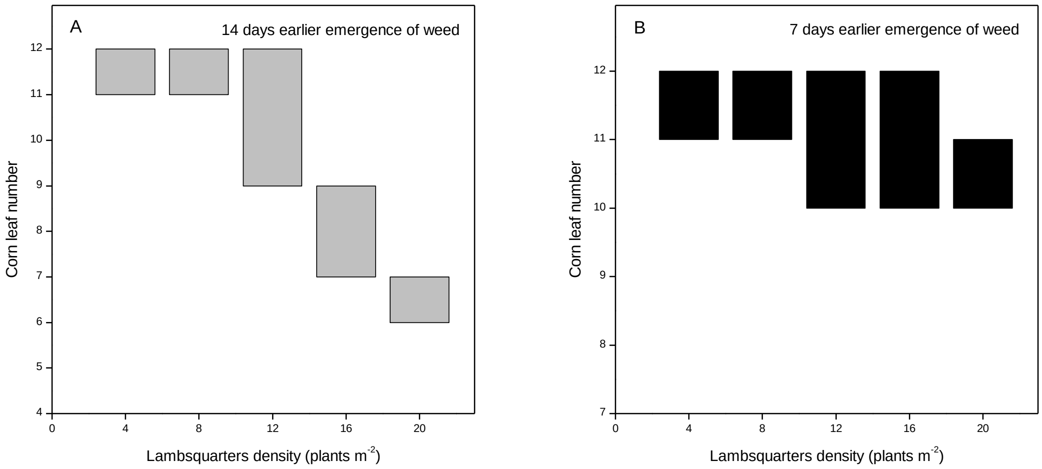

Fig 4. Box plots of maize leaf number at the initiation of lambsquarters senescence as influenced by weed emergence time and density in Mashhad. (A) Represents 14 days earlier emergence and (B) represents 7 days earlier emergence of weed.

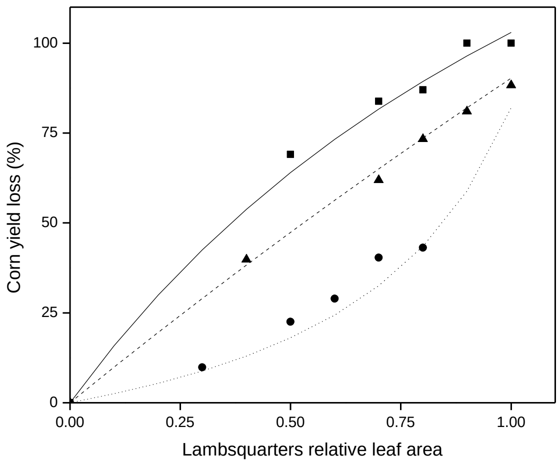

Fig 5. Relation between estimated yield loss in maize and relative leaf area of lambsquarters at the initiation of weed senescence for the 14 days (■), 7 days (▲) earlier emergence of weed and simultaneously (●) emergence date. Common lambsquarters densities were zero, 4, 8, 12, 16 and 20 plants m^{-2}.

Statistical analysis

The relationship between lambsquarters density and maize leaf area index was analyzed separately for each time of emergence by using a nonlinear hyperbolic model described by Cousens (1985). Equation 1 was used to describe relationship between lambsquarters density and maize leaf area index:

$$LAI = LAI_{WF}\left[1 - \frac{ID}{100\left(1 + \frac{ID}{A}\right)}\right] \quad [1]$$

Where LAI is maize leaf area, LAI_{WF} is estimated leaf area index in weed-free plots, D is weed density (plants m^{-2}), I is the percent leaf area index loss per unit weed density as D approaches zero, and A is the percent leaf area index loss as D approaches infinity. The relative leaf area of lambsquarters at the beginning of senescence was determined from Equation 2:

$$L_W = \frac{LAI_W}{LAI_W + LAI_C} \quad [2]$$

Where L_W is lambsquarters relative leaf area, LAI_W is the leaf area index of weed and LAI_C is the leaf area index of maize. The relationship between maize yield loss and weed relative leaf area was determined using Equation 3 (Kropff and Lotz 1992):

$$Y_L = \frac{qL_W}{1 + (q-1)L_W} \quad [3]$$

Where Y_L is the predicted proportional maize yield loss, q is the damage coefficient associated with weed and L_W is the relative leaf area of weed. Another version of the model was derived from the empirical model introduced by Cousens (1985). This model includes an extra parameter for the maximum yield loss caused by weed (m) (Equation 4):

$$Y_L = \frac{qL_W}{1 + \left(\frac{q}{m} - 1\right)L_W} \quad [4]$$

Conclusions

Overall, the highest reduction in maize height, LAI and leaf number is obtained from 14 days earlier emergence of lambsquarters relative to maize at high densities of weed. Maize yield decreased more than 70% in the 7 and 14 days earlier emergence of weed relative to crop by increasing density. Common lambsquarters was a stronger competitor than maize in the 14 days earlier emergence. In contrast, this weed was not good competitor in the simultaneously emergence with maize. Hence, this weed should be controlled in the earlier emergence time to prevent greater yield loss and in the same emerging time to prevent more plants of weed reaching reproductive growth and developing seed bank.

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