Efficiency of modeling sunflower and *Amaranthus retroflexus* L. competition

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ABSTRACT

In order to evaluate the efficiency of empirical models of sunflower (*Helianthus annuus* L.) and redroot pigweed (*Amaranthus retroflexus* L.) competition, factorial experiments were established on randomized complete block design during 2005-2006. Treatments were three weed densities (8.3, 25 and 41.7 plants m^{-2}), three times of weed emergence (15 and 30 days after sunflower emergence) and three sunflower cultivars (Azarghol, Hysun and Allstar). Three weed-free sunflower plots were used as control. Yield was analyzed by three non-linear regression models. Results showed that in any sunflower cultivar, leaf area index (LAI) decreased significantly when weed density increased and redroot pigweed emerged with sunflower, and in full-season competition of 41.7 plants m^2, reduction of LAI in Allstar was two-fold compared with Azarghol. Reduction in Allstar LAI at interference with redroot pigweed took place earlier, compared with Azarghol and Hysun. Azarghol could tolerate 8.3 weeds/m^2 from 15 days and 41.7 weeds/m^2 from 30 days after sunflower emergence. In the short height cultivar Allstar, yield loss was higher than in Azarghol and Hysun. The model of Cousens (1985) was suitable for yield estimation of Hysun and Allstar, while the Model of Cousens et al. (1987) was the best description for the yield of Azarghol.

Key words: interference time – leaf area index – models of competition – redroot pigweed – sunflower – yield estimation.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the most important oil crops, considerably affected by weed interference. Herbicide weed control is usually expensive. On the other side, redroot pigweed (*Amaranthus retroflexus* L.) is a one of the most troublesome weeds in sunflower in Iran.

The aim of weed management is changing of competitive relationships between weeds and crops (Aldrich, 1984). High competition power increases light interception efficiency (Assemat and Allirand, 1995). In McLachlan et al. (1993) opinion, the inhibitory effect of one plant species in relation to light received by another plant is a main factor in weed-crop competition modeling. As reported by Oliver et al. (1976), leaf area index (LAI) is a suitable physiological trait for evaluation of the amount of competition and production in plants. Between crop yield loss and weed density there is a sigmoidal relationship, which has an asymptote. So that, in low weed density, crop yield loss rate is lower, but with increasing of density, the rate of yield reduction increases, while at higher densities, because of high intra-specific competition between weed plants, yield loss rate decreases again (Beckett et al., 1988). Cousens et al. (1987), Kropff and Lotz (1992) and Cousens (1985) have used hyperbolic equations for modeling the relationships between weed density and crop yield loss. With the application of weed density and interference time-based models, the accuracy of the model will increase (Knezevic et al., 1997; Bosnic and Swanton, 1997). Cousens et al. (1987) developed hyperbolic equations in which crop yield is estimated in relation to density and relative interference time of weeds. Harper (1983) reported that some variables such as density, growth rate and emergence time of weeds are the most important factors in weed-crop competition for light interception.

The objective of this study was to evaluate sunflower vs. redroot pigweed competition using several empirical models previously developed.

MATERIALS AND METHODS

This study was conducted during 2005-2006 in Research Station of Tabriz University (Latitude 38º53'; Longitude 46°17', elevation 1360m), located in the north-west of Iran, with a semiarid and cold climate. The experimental design was a factorial combination of three weed densities (8.3, 25 and 41.7 plants m^{-2}), three times of weed emergence (15 and 30 days after sunflower emergence), and three sunflower cultivars

(Azarghol, Hysun 33 and Allstar RM). Three weed-free sunflower plots were used as control. The fertilizer used before planting was 150 kg ha^{-1} potassium sulfate, 150 kg ha^{-1} ammonium phosphate and 75 kg ha^{-1} urea. Data were analyzed with MSTAT-C software. Comparison of means was done using the Duncan's Multiple Range Test.

To determine the relationship of weed density and sunflower yield, an hyperbolic model (Equation 1) was used, as described by Cousens (1985):

YL=(I.d)/[1+(.Id)/A] where YL is yield loss of sunflower, d is weed density and I and A are coefficients of the model.

For determination of relationship between weed density and emergence time with sunflower yield the model of Cousens et al. (1987), was used (Equation 2):

YL= (I.d)/[c.t+(I.d)/A] where YL is yield loss of sunflower, d and c are weed density and emergence time and I, A and c are coefficients of the model.

One parameter model (Equation 3) was used for determination of relationship between sunflower yield loss and weed relative leaf area.

YL=(q.Lw)/[1+(q-1)Lw] where YL is yield loss of sunflower and q is coefficient of relative damage. Lw is relative leaf area of weed, which was calculated by equation 4.

$Lw=LAI_r/(LAI_s + LAI_r)$ where r and s indicate redroot pigweed and sunflower, respectively.

In order to evaluate the validity of abovementioned yield estimation models, four statistics were used, as follows (Thornley and Johnson, 1990):

Correlation between estimated and observed yield values (equation 5):

$$r = \frac{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)\left(P_i - \overline{P}\right)}{\sqrt{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2} \times \sqrt{\sum_{i=1}^{n}\left(P_i - \overline{P}\right)^2}}$$

where O_i=observed yield loss, $\overline{O}$ mean of observed yield loss, P_i estimated yield loss and P mean of estimated yield loss.

Mean Percentage Error (Equation 6):

$$MPE=\left[\sum_{i=1}^{n}\left(\frac{\left|obs_i - sim_i\right|}{obs_i}\right)\times 100\right]/n$$

Where obs_i and sim_i are observed yield and estimated yield, respectively, and n is number of treatments.

Root Mean Square Error (Equation 7):

$$RMSE = \left[(\sum_{i=1}^{n}\left(sim_i - obs_i\right)^2)/n\right]^{0.5}$$

Mean Bias Error (Equation 8):

$$MBE = \left[\sum_{i=1}^{n}\left(sim_i - obs_i\right)\right]/n$$

RESULTS AND DISCUSSION

In the three sunflower cultivars, LAI decreased significantly as weed density increased and redroot pigweed emerged simultaneously to sunflower, and in full-season competition of 41.7 plants m^{-2}, reduction of LAI in Allstar was double compared with Azarghol (Table 1). Also, in high densities and early time of weed emergence, LAI and canopy light transmission of redroot pigweed increased significantly, and canopy closure happened earlier (data not shown). In full season competition of 41.7

weeds/m^2, LAI in sunflower decreased from 4.57, 4.20 and 3.90 in the controls to 3.69, 3.12 and 2.56 in Azarghol, Hysun and Allstar, respectively (Table 1). In Allstar, weed density was more effective than weed interference time. For each day delaying weed emergence time, sunflower LAI in i_0-i_{15} and i_{15}-i_{30} decreased 180 and 160 cm^2 per unit area, respectively (Fig. 1). On the other hand, in spite of same interference time duration (15 days) in the above mentioned treatments, reduction value in LAI at i_0-i_{15} was higher than i_{15}-i_{30}, as reported by Knezevic et al. (1994). In that study, when redroot pigweed emerged with corn, LAI in corn decreased by 36%, but in delayed interference time (3-5 leaves stage of corn), LAI reduction value was not significant. It seems that, between physiological characteristics in crops, LAI is more effective in compatibility of crops and influences the amount of light interception by canopy and availability of weeds to light.

Studying the effect of weed density on sunflower LAI at 30-90 days after emergence, it was observed that the difference between redroot pigweed density levels in the three cultivars, especially in Allstar, starts from early growth stages, and difference value is gradually increased. Reduction in Allstar LAI happened earlier, compared with Azarghol and Hysun. In 45-75 days after sunflower emergence, increasing rates of sunflower LAI at i_0, i_{15} and i_{30} were 750, 810 and 850 cm^2/day in Azarghol, 630, 700 and 770 cm^2/day in Hysun, and 550, 590 and 600 cm^2/day in Allstar, respectively (Table 1). Negative growth of LAI in Allstar at interference with redroot pigweed was in advance from 75 DAE, compared with control. This condition which arose from leaf senescence resulting from weed shading, caused a LAI reduction of 410 cm^2/day at 80-85 DAE in Allstar cultivar, while the negative growth of LAI in the control had not yet started. As reported by Hall et al. (1992), Tollenaar et al. (1994), Knezevic et al. (1994), and Bosnic and Swanton (1997), LAI is one of the most important characteristics indicating the competition power of plants and could be used in estimation of crop yield loss at interference with weeds. With regard to the effect of LAI on plant photosynthesis and the effect on yield of the latter, it is expected that redroot pigweed causing a reduction of sunflower LAI, causes also a significant reduction in yield.

Increasing of redroot pigweed density increased weed LAI, but the increased value in delayed weed emergence time was reduced, especially in Azarghol and Hysun (Table 1). Therefore, when increased weed density from 8.3 to 41.7 plants/m^2 at i_0, weed LAI increased from 0.66 to 0.76 (13% increase) in Azarghol, from 0.9 to 1.06 (15% increase) in Hysun and from 1.01 to 1.19 (15% increase) in Allstar. But at i_{30}, the effect of a similar density increase on LAI was not significant in Azarghol, whereas it increased from 0.75 to 0.78 (4% increase) in Hysun and from 0.95 to 1.07 (19% increase) in Allstar. These results showed that the weed interference time was more effective than density in Azarghol and Hysun, but weed density was more effective than interference time in Allstar, and canopy condition was suitable for development of weed LAI in Allstar (Fig. 2).

The three studied cultivars indicated different interactions of densities and interference times of redroot pigweed with grain yield (Table 1). Azarghol could tolerate 8.3 weeds/m^2 from 15 DAE and 41.7 weeds/m^2 from 30 DAE, without significant reduction in yield. Redroot pigweed could decrease sunflower yield of Azarghol only at high densities (>25 weeds/m^2). In Hysun, any of the studied treatments could produce similar yield to the control plot. Significant difference in sunflower yield arising from early emergence time of redroot pigweed was expected, as weed interference time in relation to crops is a main factor in crop yield loss (Kropff et al., 1992; Rajcan and Swantom, 2001).

Allstar experimented higher yield loss compared to Azarghol and Hysun. This was explained on the basis of its shorter stature, which favored the competitive power of redroot pigweed with this cultivar. Knezevic et al. (1997) reported that yield loss values in tall and short sorghum cultivars at interference with redroot pigweed were 16% and 75%, respectively, because of higher LAI in the taller cultivar. In the present study, a higher oil yield was obtained from treatments with greater grain yield, and the lowest oil yield was observed in treatments of full season interference of 41.7 weeds/m2 in the three cultivars.

In Azarghol and Hysun hybrids, correlation coefficients between redroot pigweed relative leaf area and sunflower yield loss were 0.99 and 0.92 and distinction coefficients of the model were 0.41 and 0.75, respectively; Also, higher RMSE values (378.32 and 342.62, respectively) indicated that this model has a low efficiency in estimating yield loss in these two hybrids. We obtained similar results in Allstar (data not shown).

In the comparison of observed and estimated yield values by the model in Hysun and Allstar hybrids, it was observed that MBE, RMSE and MPE values were +0.003, 28.87 and 8.01%, respectively in Hysun, and +0.003, 41.47 and 4.64%, respectively in Allstar. This model was suitable for yield estimation of these two cultivars (Fig. 3, 4).

Correlation between observed and estimated yield values in Azarghol hybrid was 0.99. Values of MBE, RMSE and MPE were calculated as being +0.09, 18.58 and 2.16%, respectively. With regard to reduction in RMSE value in this model as compared with the model of Cousens (1985), it seems that, this model was the best description for the yield of Azarghol (Fig. 5). Besides, as reported by Bosnic and Swanton (1997), if SE values of model parameters were lower than half the parameter main value, the model has a higher validity for the estimation of crop yield. The accuracy of Cousens et al. (1987) model in the estimation of yield loss in Hysun and Allstar hybrids was lower.

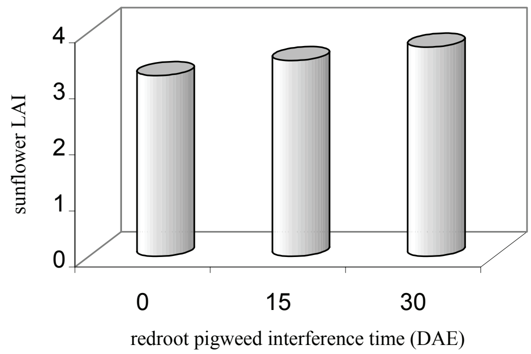

Fig. 1. Effect of redroot pigweed interference time on sunflower LAI at 90 days after emergence

Table 1. Mean comparisons for some of variables studied.

Treatments[1]	LAI of sunflower at 75 DAE[2]	LAI of redroot pigweedat 75 DAE[2]	Sunflower grain yield (kg/ha)[2]
$V_1D_1I_0$	4.07 k	0.66 w	3343 cd
$V_1D_1I_{15}$	4.35 e	0.57 z	3960 ab
$V_1D_1I_{30}$	4.49 b	0.53 z	4061 ab
$V_1D_2I_0$	3.96 i	0.72 v	3109 de
$V_1D_2I_{15}$	4.26 f	0.59 x	3884 b
$V_1D_2I_{30}$	4.39 c	0.55 z	4036 ab
$V_1D_3I_0$	3.69 q	0.76 t	2716 fg
$V_1D_3I_{15}$	4.09 i	0.61 x	3578 c
$V_1D_3I_{30}$	4.37 d	0.56 z	4081 ab
$V_2D_1I_0$	3.52 t	0.90 n	2151 h
$V_2D_1I_{15}$	3.91 m	0.80 q	2726 fg
$V_2D_1I_{30}$	4.11 h	0.75 u	3507 c
$V_2D_2I_0$	3.40 v	0.99 i	2032 hi
$V_2D_2I_{15}$	3.81 o	0.81 q	2556 g
$V_2D_2I_{30}$	4.08 j	0.77 r	3238 d
$V_2D_3I_0$	3.12 y	1.06 h	1722 j
$V_2D_3I_{15}$	3.40 v	0.85 o	2078 h
$V_2D_3I_{30}$	3.77 p	0.78 r	2960 ef
$V_3D_1I_0$	3.42 u	1.01 j	1581 j
$V_3D_1I_{15}$	3.58 s	0.95 m	1793 ij
$V_3D_1I_{30}$	3.62 r	0.90 n	2039 hi
$V_3D_2I_0$	2.92 z	1.09 f	830 lm
$V_3D_2I_{15}$	3.16 x	1.02 i	1032 kl
$V_3D_2I_{30}$	3.24 w	0.99 k	1226 k
$V_3D_3I_0$	2.56 z	1.19 c	535 n
$V_3D_3I_{15}$	2.80 z	1.11 e	651 mn
$V_3D_3I_{30}$	2.91 z	1.07 g	752 mn
V_1D_0 (control)	4.57 a	-	4171 a
V_2D_0 (control)	4.20 g	-	3858 b
V_3D_0 (control)	3.90 n	-	3153 de
LSD	0.005	0.2277	239.7

[1]V indicates sunflower variety; D and I indicate density (plants/m^2) and time of emergence (days after sunflower emergence) of redroot pigweed, respectively.
[2]Values within columns followed by the same letter have no significant difference at the 0.01 probability level.

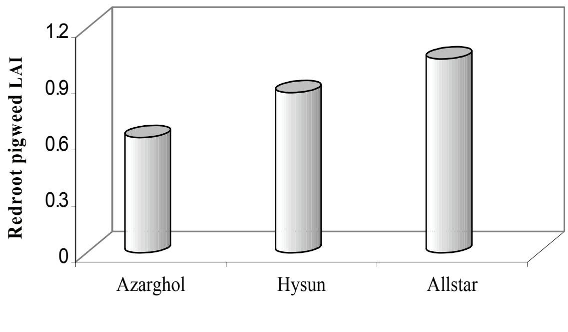

Fig. 2. Effect of sunflower cultivar on redroot pigweed LAI at 90 days after sunflower emergence

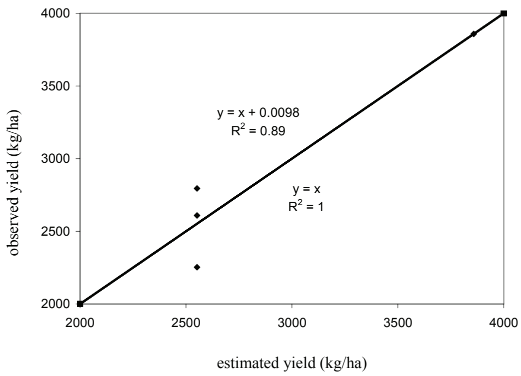

Fig. 3. Comparison of observed yield vs estimated yield by the model of Cousens (1985) at Hysun cultivar. YL=(1.1d)/[1+(1.1d)/33.84], where YL= estimated yield loss and d=weed density.

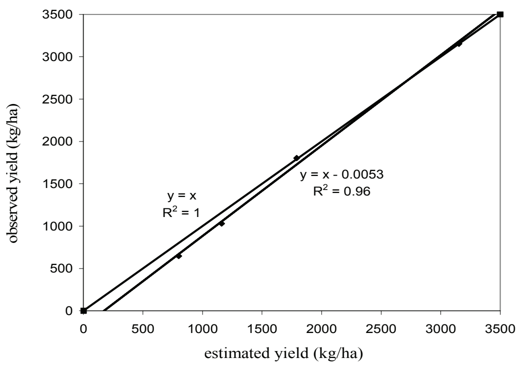

Fig. 4. Comparison of observed yield vs estimated yield by the model of Cousens (1985) at Allstar cultivar. YL=(1.4d)/[1+(1.4d)/23.22], where YL= estimated yield loss and d=weed density.

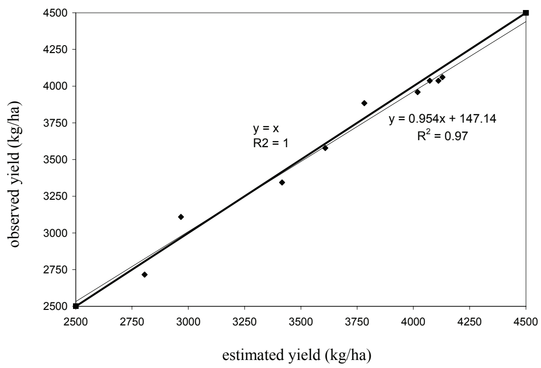

Fig. 5. Comparison of observed yield vs estimated yield by the model of Cousens et al. (1987) at Azarghol cultivar. YL= 4171[1-3.89d/100(Exp(0.14*t)+(3.89d)/41.00)], where YL= estimated yield loss and d=weed density, and t= relative interference time of weeds.

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