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Evaluation of Different Empirical Models of Crop/Weed Competition to Estimate Yield and LAI Losses from Common Lambsquarters (*Chenopodium album* L.) in Maize (*Zea mays* L.)

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Abstract: Usefulness and validity of different empirical yield loss models at describing the effect of common lambsquarters competition in maize were evaluated in a two year experiment in Karaj during 2001 and 2002 growing seasons. Experimental factors were density (1st year: 2, 5, 10 and 15 plants m^{-2}; 2nd year: 6.6, 13.3 and 20 plants m^{-2}) and the relative emergence time (1st year: simultaneous to, at 2-3 and 4-5 leaf stages of maize; 2nd year: simultaneous to, at 2-3 and 5-6 leaf stages of maize) of common lambsquarters. Results indicated that the highest maize yield and LAI losses were observed at simultaneous emergence of weed and maize resulted in 85 and 92% yield loss and 73 and 53% LAI loss in the first and second years of experiments, respectively. Also, delaying common lambsquarters emergence reduced its competitive ability against maize. Comparison of different empirical models revealed that the empirical yield loss models based on density and the relative time of weed emergence and the weed relative leaf area, also the rectangular hyperbolic yield loss model based on weed density were more reliable at predicting maize yield and LAI losses according to their high coefficient of determination (R^2). Also, results indicated that the negative effect of the relative time of common lambsquarters emergence on maize yield loss was more than weed density, so that the rectangular hyperbolic yield loss model based on weed density was more capable at predicting yield loss at each of weed emergence time.

Key words: Empirical yield loss model, relative damage coefficient, weed density, weed emergence time

INTRODUCTION

Maize plays an important role as a major cereal crop in Iran. The crop was grown on ≈ 172 thousand ha throughout in 2001, with total production of more than 1 million ton (Anonymous, 2002). Weeds are among major factors reducing maize yield, in case of no management practices they account for 86% yield loss (Moussavi, 2001). Several studies have reported maize yield loss due to weeds. For example, in Turkey maize yield loss was estimated 38 to 59% when it was cropped after wheat (Uremis *et al*., 2004). Rahman (1985) and Mickelson and Harvey (1999) reported 30 and 90% yield loss in maize, respectively, due to weeds.

Common lambsquarters is among the most important weeds infesting maize fields (Moussavi, 2001). It is also a weed of major economic importance in more than 40 crops, particularly sugar beet (*Beta vulgaris* L.), soybean (*Glycine max* L.) and potato (*Solanum tuberosum* L.) (Crook and Renner, 1990). Previous studies have shown various economic yield loss in different crops due to common lambsquarters, as an example it can be mentioned to 11 (Beckett *et al*., 1988) and 22% (Turner *et al*., 1996) yield loss in maize, 36% in barley (*Hordeum vulgare* L.) (Conn and Thomas, 1987) and 48% in sugar beet (Scheweizer, 1983).

Beckett *et al*. (1988) reported that common lambsquarters at 2 plants per 0.30 m of crop row reduced maize yield 11%. Harrison *et al*. (2001) studied the effect of *Ambrosia trifida* density and the relative time of emergence on maize yield loss. They showed that in simultaneous emergence of the crop and the weed, *A. trifida* at 1.7, 6.9 and 13.8 plants m^{-2} reduced maize yield 18, 46 and 61%, respectively. But with delay in weed emergence to 6-leaf stage of maize, the crop yield loss reduced 2, 8 and 15%, respectively. It has been also shown that a 10 week interference of common lambsquarters at 3.2 plants m^{-1} of crop row reduced soybean yield 20% (Crook and Renner, 1990).

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To date, different empirical yield loss models been suggested to assess crop yield loss due to weeds (Yenish *et al*., 1992; Ngouajio *et al*., 1999). These models use different parameters to describe crop yield loss, such as the crop and the weed density, the time of weed emergence relative to the crop and the weed relative leaf area (Ngouajio *et al*., 1999). Cousens (1985) evaluated and compared many current empirical yield loss models. He concluded that nonlinear models, particularly rectangular hyperbolic yield loss model (Eq. 1) was the best in this regard. He considered in his two parameter model that the crop yield loss is a function of weed density (Cousens *et al*., 1987).

$$Y_L = \frac{Id}{\left(I + \frac{Id}{A}\right)} \qquad (1)$$

Where, Y_L is equal to the observed crop yield as a proportion of the weed-free yield ,

$$(Y_L = 1 - \frac{Y}{Y_{wf}})$$

I is the initial slope of the hyperbolic yield loss curve at low weed densities (the yield loss per weed as the weed approaches zero), A is the asymptote for yield loss and D is the density of weed m^{-2}. I and A are affected by crop density, the time of weed emergence relative to the crop and soil type. These two parameters describe competition at low and high weed densities, respectively (Aldrich, 1987). This model assumes that (i) there is no yield loss in the absence of the weed, (ii) the negative effect of low weed densities is more than high weed densities, (iii) the yield loss never goes beyond 100% and (iv) at high weed densities the response of the crop to weed density is nonlinear (Cousens, 1985; Park *et al*., 2003). Because of the asymptotic nature of Eq. 1 at high weed densities, it is more biologically reasonable (Lotz *et al*., 1995; Swinton and Lyford, 1996). Although its extensive application, a weakness of the model is that it does not account for differences in individual weed size owing to variations in the time of emergence or vigor of the weed relative to the crop (Storkey *et al*., 2003). Cousens *et al*. (1987) added an additional parameter, the time of weed emergence relative to the crop, to Eq. 1 to have a more accurate prediction of the crop yield loss from weeds (Eq. 2), as:

$$Y_L = \frac{xN_w}{\exp(y \times T_{cw}) + \left(x/z\right)N_w} \qquad (2)$$

Where, N_w is the weed density, T_{cw} is the time between crop and weed emergence and x, y and z are nonlinear regression coefficients. This model has been fitted to different weed density and emergence dates. However, a weakness of the model is that it does not account for the weeds emerged early and during the growing season. Moreover, fitting the model needs a large number of data, because the effect of weed density should be examined in a broad range of the weed density.

Another model which is widely applied to assess the crop yield loss from the weeds, is that proposed by Kropff and Spitters (1992) (Eq. 3). The model has been derived from Eq. 1 and predicts the crop yield loss based on the weed relative leaf area, as:

$$Y_L = \frac{qL_W}{1 + (Q - 1)L_W} \qquad (3)$$

Where, q is the relative damage coefficient (yield loss per unit relative leaf area at low weed densities) and L_W is the weed relative leaf area which can be calculated from the following Eq. 4:

$$L_W = \frac{LAI_W}{LAI_W + LAI_C} \qquad (4)$$

Where, LAI_W and LAI_C are the weed and crop leaf area index, respectively.

Cousens (1985) also obtained another model derived from Eq. 3 in which an additional parameter has been added to account for the maximum of yield loss from weeds (m) (Eq. 5), as:

$$Y_L = \frac{qL_W}{1 + \left(\frac{q}{m} - 1\right)L_W} \qquad (5)$$

The objective of this research was to evaluate, assess and compare the reliability, accuracy and usefulness of different empirical yield loss models at predicting the effects of different densities and times of common lambsquarters emergence on maize yield.

MATERIALS AND METHODS

Two field experiments were conducted during 2001 and 2002 growing seasons at the research field of Department of Weed Research, Plant Pest and Disease Research Institute (1320 meter above see level, 35° 56' N, 50° 58' E), to study the effects of different densities and times of common lambsquarters emergence on maize yield loss. The climate of this region is cold and semi-arid with annual rainfall of 240-300 mm and mean long term annual temperature of 30°C. The soil type was sandy loam.

The experimental design was a randomized complete block with a factorial arrangement of treatments and three replications. The experimental treatments comprised of density (1st year: 2, 5, 10 and 15 plants m^{-2}; 2nd year: 6.6, 13.3 and 20 plants m^{-2}) and the relative emergence time (1st year: simultaneous to (V_E), at 2-3 (V_{2-3}) and 4-5 (V_{4-5}) leaf stages of maize; 2nd year: simultaneous to, at 2-3 and 5-6 (V_{5-6}) leaf stages of maize) of common lambsquarters. A weed-free plot was also considered to determine maize yield under no weed competition. Soil was sampled before tillage operation and was analyzed chemically. According to the chemical analysis results, fertilizers were applied at the rates of 114 kg N ha^{-1} and 112 kg P ha^{-1} for experiment 1 (2001) and 137 kg N ha^{-1} and 110 kg P ha^{-1} for experiment 2 (2002). Also, top dressed urea was applied at the rate of 45 kg N ha^{-1} at 7-8 leaf stage of maize. The soil preparation consisted of fall moldboard plowing (20-25 cm) following by spring disking and smoothing with a land lever. Plots were 10 m long and 4 rows spaced 75 cm apart.

The maize cultivar Single Cross 704 was overseeded on 20 May, both in 2001 and 2002, with 20 cm between holes within rows and finally thinned to one seed of maize per hole at 2-3 leaf stage, giving a potential plant density of 6.6 m^{-2}. Common lambsquarters seeds were collected from maize fields infested by this weed in Karaj. Prechilling was applied to break common lambsquarters seeds dormancy, in which seeds were kept 3 months at -2°C. The weed seeds were sown at high density at the both sides of maize rows and finally thinned to target densities at 2-3 leaf stage of maize. All other weeds were removed throughout the season by hand every 2 weeks. Furrow irrigation was applied at weekly intervals during the whole growing season to supplement rain in both years.

Measurements of maize and common lambsquarters LAI were taken from 5 m long of the center two rows of each plot. Plant samples were taken approximately every 2 weeks in both years of experiments. Sampling started from 30 DAE in 2001 and 34 DAE in 2002 and involved taking 2 plants from the selected sampling area. Leaf area was estimated by measuring the green leaf area of all leaves with a leaf area meter (Model LI-3000, LI-COR Inc., Lincoln, NE). The crop was harvested manually in September when seeds moisture reduced to 14%. At harvest, the middle 1.5 m of the centre two rows of each plot (a total area of 3 m^2) were harvested. Maize grain yield was determined after oven drying for 48 h at 75°C.

The empirical yield loss models (Eq. 1-3 and 5) were fitted to the values of grain yield and LAI using the statistical program Sigma Plot v8.0 (SPSS Inc.). Coefficient of determination (R^2) was determined for nonlinear regressions, as in other studies (Askew and Wilcut, 2001). The approximated R^2 was used to determine goodness and reliability of fit to different yield loss models.

RESULTS AND DISCUSSION

Performance of empirical yield loss model based on weed density

Grain yield: The rectangular hyperbolic yield loss model based on weed density was fitted to the values of grain yield. Results indicated that at simultaneous emergence of the crop and the weed, the parameter I, which describes the yield loss per weed as the weed density approaches zero, were 38.24 and 25.60 in 2001 and 2002, respectively, (Fig. 1). But delaying the time of common lambsquarters emergence to 4-5 (Exp. 1) and 5-6 (Exp. 2) leaf stages of maize, the value of this parameter reduced to 2.25 and 3.44%, respectively (Fig. 1). The same response was observed in case of parameter *A* (the maximum of yield loss), so that the values of parameter A were 85.13 and 92.38 in 2001 and 2002, respectively at simultaneous emergence of the crop and the weed, but reduced to 1.51 and 3.44 in 2001 and 2002, respectively, with delays in common lambsquarters emergence to 4-5 (Exp. 1) and 5-6 (Exp. 2) leaf stages of maize (Fig. 1). Many studies reported 5% as the maximum acceptable yield loss (Hall *et al*., 1992; Knezevic *et al*., 1994). In both experiments the effect of delaying in the relative time of common lambsquarters emergence resulted in an increment in the level of acceptable yield loss. At simultaneous emergence of the crop and the weed, the damage threshold was 0.2 plant m^{-2}, increased to 0.3 plant m^{-2} when common lambsquarters emerged at 2-3 leaf stage of maize and 1.3 plants m^{-2} when emergence occurred at 4-5 (Exp. 1) and 5-6 (Exp. 2) leafs stage of maize. Weed density and species are both important factors influencing the level of acceptable yield loss. For example, 0.23 plant m^{-2} of barnyardgrass (*Echiochloa crus-galli*) (Bosnic and Swanton, 1997), 2.2 plants m^{-2} of wild proso millet (*Panicum miliaceum*) (Wilson and Westra, 1991) and 12.5 plants m^{-2} of redroot pigweed (*Amaranthus retroflexus*) had been reported as the damage threshold in maize. Massinga *et al*. (2001) and Harrison *et al*. (2001) reported 0.4 and 4.2 plants m^{-2} as the damage threshold of weeds in maize when they emerged simultaneously to or at 5 leaf stage of maize.

In 2001, when common lambsquarters emerged at 4-5 leaf stage of maize, the relationship between the crop yield loss and weed density had linear pattern (Fig. 1). Cousens (1985) related this observation to no intra-specific weed competition.

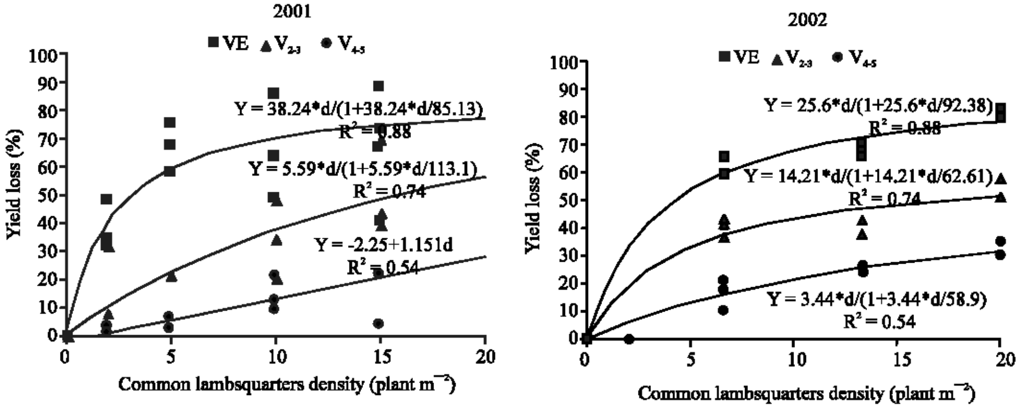

Fig. 1: Effect of density and the relative time of common lambsquarters emergence on maize yield loss fitted using the rectangular hyperbolic yield loss model

Leaf area index: Leaf area index determines the amount of light intercepted by the canopy (Loomis *et al.*, 1968). So any factor which reduces LAI will affect crop yield negatively. In the present study the rectangular hyperbolic yield loss model based on weed density was fitted to the values of LAI at silking (Massinga *et al.*, 2001). The effects of common lambsquarters density and the relative time of emergence on maize LAI loss are shown in Fig. 2. As it is observed the highest LAI loss occurred at simultaneous emergence of the crop and the weed, caused 73 and 53% loss in 2001 and 2002, respectively. In contrast, the lowest LAI loss occurred in common lambsquarters emergence at 2-3 leaf stage of maize, caused 37 and 31% loss in 2001 and 2002, respectively (Fig. 2). Knezevic *et al.* (1994) similarly fitted Eq. 1 to the values of maize LAI at silking and reported a 36% LAI loss at simultaneous emergence of the maize and the weed. They believe that the LAI loss calculated using this equation can describe the weed competitive pressure on maize well. Other studies have also shown that maize LAI is among the first factors which will be influenced by competition (Bosnic and Swanton, 1997; Hall *et al.*, 1992; Knezevic *et al.*, 1994; Tollenaar *et al.*, 1994). A comparison between maize yield and LAI losses shows the close relationship between these two factors (Fig. 1, 2). This is in agreement with those of Bosnic and Swanton (1997), where positively significant correlation found between maize yield and LAI losses at high plant densities of barnyardgrass.

The empirical yield loss model described above (Eq. 1) was also fitted to combined data of maize yield loss and LAI of different times of common lambsquarters emergence. Parameter estimates and corresponding R^2 and Standard Errors (SE) are given in Table 1. Comparison of R^2 and SE of the predicted parameters showed that in some cases R^2 is very low and in most cases SE is very high. Bosnic and Swanton (1997) stated that if the SE of each estimated parameters be >1/2 its value the model is not valid enough and it can not give a good estimate of yield and LAI loss. So to evaluate the reliability and accuracy of the rectangular hyperbolic yield loss model based on weed density in simulating maize yield and LAI losses using the combined data, the correlation coefficient between the estimated and measured values was calculated (Table 2). This approach is very common in fitting an empirical model to data obtained from experiments (Kobayashi and Salam, 2000). Table 2 shows that the regression of measured on estimated values of yield loss is not in the 1:1 line (Y = X), but agree with Y = aX+b, in which the slope of the regression line is not significantly different from 1 and the intercept is not significantly different from 0. So, it was concluded that the rectangular hyperbolic yield loss model based on weed density does not provide an adequate fit for the combined data of different times of common lambsquarters emergence and might result in bias when predicting yield and LAI loss. So the model is accurate and reliable in simulating maize yield and LAI losses when it is fitted to each time of the weed emergence separately (Fig. 1, 2), resulted in higher R^2. With an emphasis on difference in the weed competitiveness because of weed emergence date, Bosnic and Swanton (1997) stated that Eq. 1 does not provide an adequate fit and is not reliable at predicting maize yield loss from barnyardgrass when the weed is emerged in different times. Knezevic *et al.* (1994) also reported different estimations of Eq. 1 parameters at each time of redroot pigweed emergence in maize.

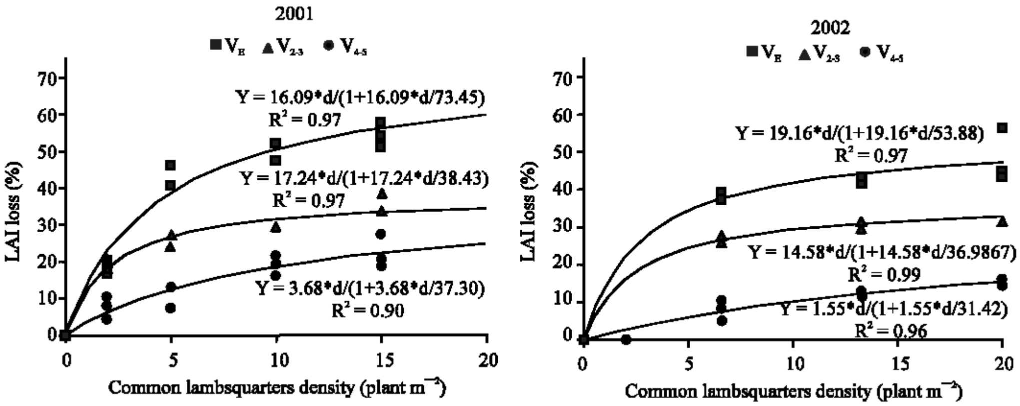

Fig. 2: Effect of density and the relative time of common lambsquarters emergence on maize LAI loss, fitted using the rectangular hyperbolic yield loss model

Table 1: Parameter estimates (±SE) and corresponding R^2 of combined data of maize yield loss and LAI of different times of common lambsquarters emergence using rectangular hyperbolic yield loss model based on weed density (Eq. 1)

	Maize LAI loss			Maize yield loss		
Years	R^2	A	I	R^2	A	I
2001	0.61	47.860±7.98	11.267±3.70	0.38	65.436±21.6	10.789±5.47
2002	0.55	37.887±9.07	9.9536±7.40	0.61	67.835±16.0	12.890±7.17

Table 2: Parameter estimates (±SE) and corresponding R^2 of the regression of measured on estimated values of maize yield and LAI loss using the rectangular hyperbolic yield loss model based on weed density (Eq. 1)

		2001				2002			
Parameters		V_E	V_{2-3}	V_{4-5}	T*	V_E	V_{2-3}	V_{5-6}	T*
Maize yield loss	Y	6.080±5.02	4.710±3.90	3.961±1.71	16.270±0.06	0.538±2.0	2.00±3.0	0.832±1.4	13.450±3.6
	a	0.870±0.08	7.820±0.12	0.530±0.12	0.387±0.19	0.990±0.1	0.94±0.1	0.956±0.1	0.615±0.08
	R^2	0.880	0.740	0.570	0.380	0.980	0.93	0.950	0.610
Maize LAI loss	Y	1.328±1.54	0.443±1.18	0.817±1.19	8.575±2.09	0.839±1.9	0.67±0.4	0.310±0.1	9.450±2.3
	a	0.965±0.03	0.977±0.04	0.923±0.08	0.617±0.07	0.970±0.1	0.99±0.1	0.964±0.1	0.550±0.1
	R^2	0.970	0.970	0.970	0.610	0.970	0.99	0.960	0.550

*Combined data of maize yield loss and LAI of different times of common lambsquarters emergence

Performance of the empirical yield loss model based on weed density and the relative time of emergence: As mentioned earlier, a weakness of Eq. 1 is that it does not account for differences in the time of emergence of the weed relative to the crop and the great differences observed in the estimated parameters of Eq. 1 in the present study at each of the weed emergence time can be attributed to this weakness. To account for different emergence dates, we applied Eq. 2 to simulate maize yield loss from common lambsquarters (Fig. 3). Using this model, the yield loss was simulated with R^2 of 0.88 and 0.95 in 2001 and 2002, respectively. The estimated yield loss was 86.38±7.96 and 83.15±4.71% in 2001 and 2002, respectively (Table 3), which is in agreement with the measured values (data not shown). This shows that increasing common lambsquarters density beyond the highest weed density tested, will not reduce maize yield considerably, but common lambsquarters emerges earlier than maize. The results also indicate that delaying in the time of weed emergence will change the yield loss-weed density relationship from a hyperbolic form to a linear form (Fig. 3). The linear regression of measured on estimated values of yield loss showed that it is in the 1:1 line in which the slope of the regression line is not significantly different from 1 and the intercept is not significantly from 0 (Table 2). So, Eq. 2 is reliable and accurate enough to estimate maize yield loss from common lambsquarters. Bosnic and Swanton (1997) reported that barnyardgrass emergence after 4-leaf stage of maize reduced the crop yield 0-6%. Tollenaar *et al.* (1994) also concluded that maize yield loss will not be considerable if weeds emerge before 3-4 leaf stage of maize. These are in agreement with the results of the present study, where the yields reduction at the latest time of weed emergence were 60 and 70% in 2001 and 2002, respectively, while they were 9 and 24% at simultaneous emergence of the crop and the weed.

Table 3: Parameter estimates (±SE) and corresponding R^2 of maize yield loss using empirical yield loss model based on weed density and the relative time of emergence (Eq. 2)

Years	Z	x	y	df	R^2
2001	86.380±7.96	36.210±9.27	0.110±0.01	42	0.88
2002	83.155±4.71	41.404±12.3	0.105±0.01	29	0.95

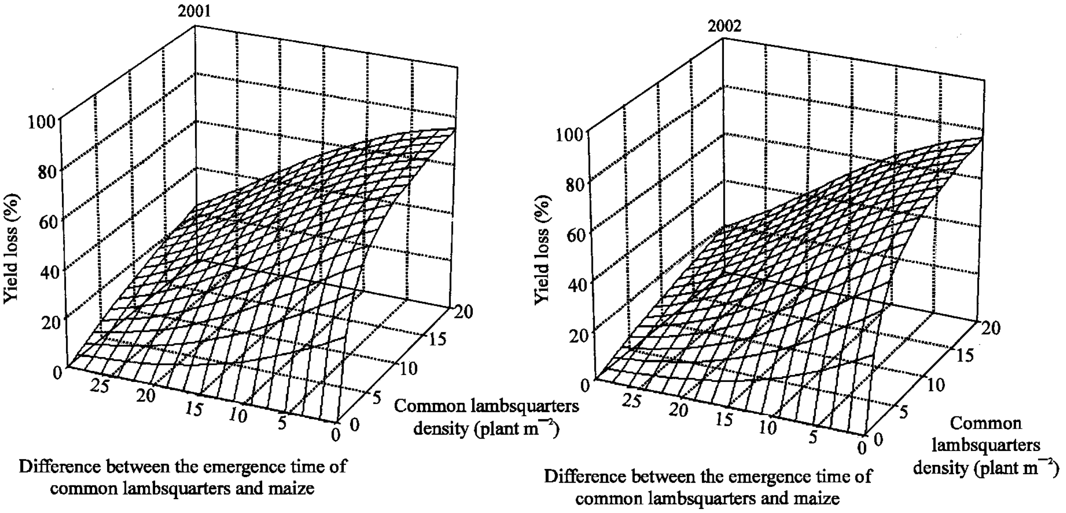

Fig. 3: Fitting maize yield loss due to common lambsquarters using the empirical yield loss model based on weed density and the relative time of emergence

Simulation of maize yield loss using Eq. 2 showed that common lambsquarters at 1 plant m^{-2} reduced maize yield by 25 and 27% in 2001 and 2002, respectively, at simultaneous emergence with maize. With delays in emergence by common lambsquarters to 4-5 and 5-6 leaf stage of maize, the similar yield reductions were occurred at 20 and 25 weed plants m^{-2}, respectively. Bosnic and Swanton (1997) also reported that barnyardgrass at 30 plants m^{-2} reduced maize yield by 14% at simultaneous emergence with maize, while delays in emergence by this weed to 7-leaf stage of maize, reduced the yield loss to 4%. They also concluded that the empirical yield loss model based on weed density and the emergence time relative to the crop was reliable at predicting maize yield loss from barnyardgrass. In contrast, some other researchers emphasized on more reliability and accuracy of the empirical yield loss model based on the weed relative leaf area (Knezevic *et al*., 1994; Lotz *et al*., 1996).

The empirical yield loss model based on the weed relative leaf area: The relative damage coefficient of the weed, q, in this model covers the differences in emergence dates between the crop and the weed through the species relative leaf area. Equation 3 and 5 show that the effect of many small size weeds is equal to that of a great old one. If the value of q falls near 1, it means that the crop yield in monoculture is similar to the yield in competition. But when the weed is more competitive than the crop, q will be >1 and the regression curve of the yield loss on the relative leaf area is convex. Figure 4 illustrates a two parameter yield loss model (Eq. 5) fitted in both years of experiments. As it is observed, q was 2.53, 1.24 and 1.53 when common lambsquarters emerged simultaneously to, at 2-3 and 4-5 leaf stages of maize in 2001 experiment, where all of them were >1. So, it can be concluded that in all the emergence time of the weed relative to the crop, common lambsquarters had been more competitive than maize. In 2002, q was >1 in the two first dates of the weed emergence, while it was equal to 0.74 in the last emergence time (5-6 leaf stage of maize) which indicates that maize was more competitive than common lambsquarters (Fig. 4). Figure 5 shows the simulated yield loss fitted by one parameter yield loss model (Eq. 3) in both years of experiments. As it is observed considerable differences exist in the yield loss among different times of the weed emergence, so that at simultaneous emergence of the crop and the weed, where common lambsquarters produced the highest relative leaf area, the highest yield reduction occurred, but the slope of the regression lines declined with delayed weed emergence. In both years of experiments and all the weed emergence times, q was <1, which shows that maize had been more competitive than common lambsquarters (Fig. 5). In fact the difference between the two parameter (Eq. 5) and one parameter

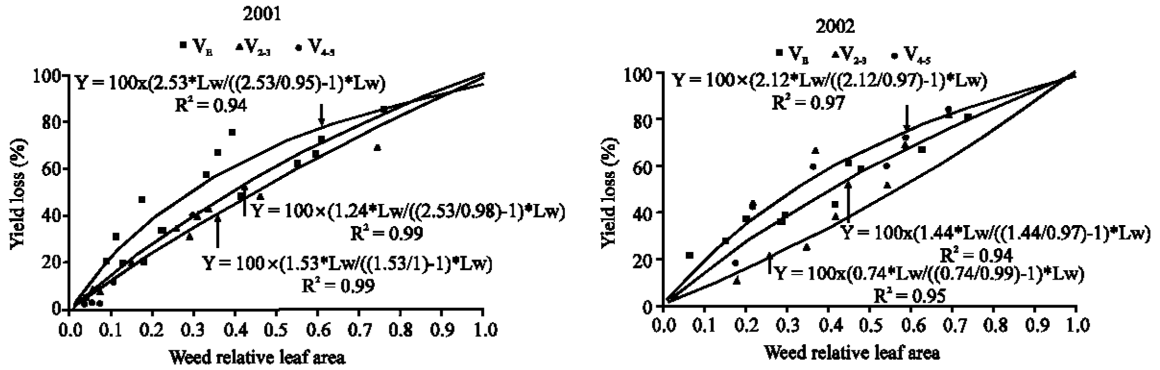

Fig. 4: Fitting maize yield loss due to common lambsquarters using the two parameter yield loss model based on the weed relative leaf area

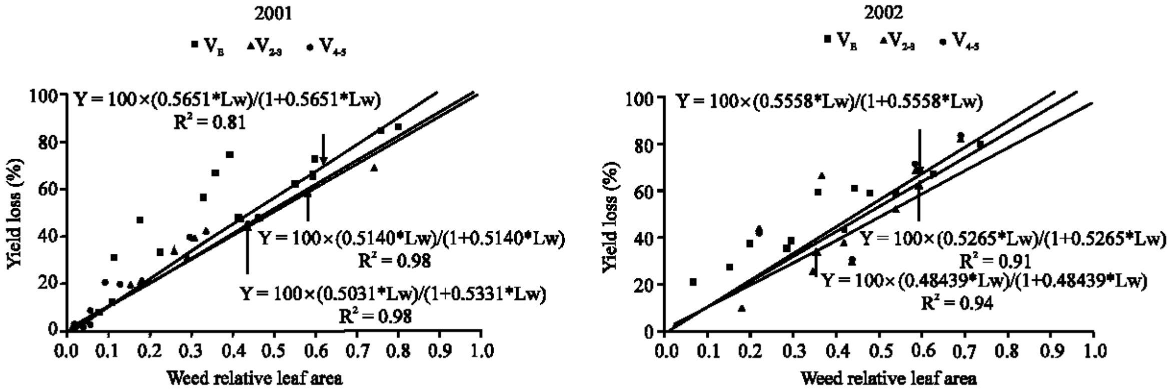

Fig. 5: Fitting maize yield loss due to common lambsquarters using the one parameter yield loss model based on the weed relative leaf area

(Eq. 3) yield loss models origins from an additional parameter (m) which has been added to Eq. 3 and accounts for the maximum of yield loss from weeds (Fig. 6). The value of m was found to increase with delayed weed emergence which is not consistent with actual condition.

To evaluate the reliability and accuracy of these two empirical yield loss models based on the weed relative leaf area (Eq. 3 and 5) in simulating maize yield loss due to common lambsquarters, the regression of measured on estimated values of yield loss was fitted (Table 4). In both models, the slopes of the regression curves (a) were near 1 at the two first weed emergence times, but considerable difference existed from 1 at the last weed emergence time (Table 4). But in 2002, a was near 1 only when fitting was performed using Eq. 5 and common lambsquarters emerged simultaneously with maize. In other times of weed emergence, a was considerably different from 1. Generally, it can be concluded that with delay in the weed emergence time, the accuracy of both models reduces. Also in 2002, Eq. 3 was not reliable enough at predicting maize yield loss due to common lambsquarters, but in 2001, the accuracy and reliability of this model was acceptable.

Equation 3 and 5 were also fitted to combined data of maize yield loss of different times of common lambsquarters emergence (Fig. 6). In 2001, the two empirical yield loss models tested did not have any significant difference with each other ($\alpha = 1\%$). But in 2002, the difference was significant ($\alpha = 1\%$) and the one parameter yield loss model (Eq. 3) was in the 1:1 line (Fig. 6). As it is also observed both models had high R^2 in both years of experiments (Fig. 6). In 2001, both models were similar at predicting maize yield loss from common lambsquarters until the weed relative leaf area was <0.5, but Eq. 3 predicted higher yield loss once the weed relative leaf area was exceeded (Fig. 6). The same result was obtained in 2002, with only difference that the predicted maize yield losses using Eq. 3 and 5 were similar up to the weed relative leaf area 0.7 (Fig. 6). These findings are in agreement with the two parameter yield loss model of Kropff and Lotz (1992). The values of m

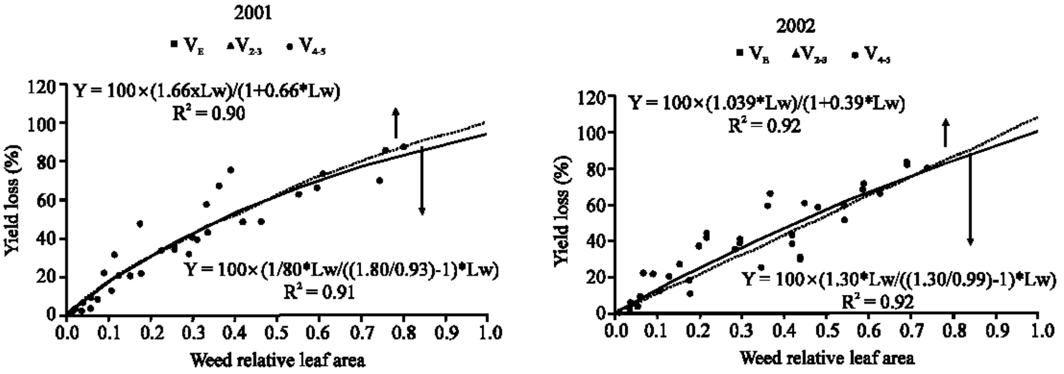

Fig. 6: Fitting maize yield loss due to common lambsquarters using the two parameter (–) and the one parameter (----) yield loss models based on the weed relative leaf area

Table 4: Comparison between parameter estimates (±SE) and corresponding R^2 of the regression of measured on estimated values of maize yield loss predicted by the one (Eq. 3) and the two (Eq. 5) parameters empirical yield loss models based on the weed relative leaf area

		2001				2002			
Parameters		V_E	$V_{2\text{-}3}$	$V_{4\text{-}5}$	T*	V_E	$V_{2\text{-}3}$	$V_{5\text{-}6}$	T*
One parameter model	Y	-22.380±13.1	-4.440±2.57	1.039±0.88	-0.9520±2.37	-17.640±4.3	-17.600±9.5	11.480±8.3	1.8100±0.0
	a	1.199±0.20	1.062±0.07	0.666±0.05	0.8735±0.05	1.246±0.0	0.585±0.1	0.615±0.1	0.8618±0.19
	R^2	0.760	0.950	0.920	0.8700	0.960	0.570	0.670	0.8100
Two parameter model	Y	3.065±10.3	-1.922±2.07	1.994±1.09	0.7013±0.32	-3.530±5.2	24.430±9.2	7.025±7.9	4.6730±3.1
	a	0.959±0.16	1.071±0.05	0.866±0.07	0.8880±0.04	1.152±0.1	0.549±0.1	0.603±0.1	0.8560±0.0
	R^2	0.770	0.960	0.930	0.9100	0.940	0.560	0.680	0.8100

*Combined data of maize yield loss of different times of common lambsquarters emergence

obtained in the present study were 0.93 and 0.99 in 2001 and 2002, respectively. Dieleman *et al*. (1995) concluded that the empirical yield loss model based on the time of weed emergence relative to the crop gives more accurate estimation compared to the empirical yield loss model based on the weed relative leaf area. They also reported that the one parameter yield loss model was more reliable and accurate compared to the two parameter one. In contrast Knezevic *et al*. (1994) reported inverse results in maize-redroot pigweed competition. They attributed the more accuracy of the two parameter yield loss model to not high reduction in maize yield, obtained between 24-41%. It seems that in the present study, the no significant preference of Eq. 5 vs. 3 is related to the high reduction in maize yield due to common lambsquarters. The estimated value of q in Eq. 5 was also more than that in Eq. 3, which is in agreement with those of Knezevic *et al*. (1994). In fact, q demonstrates the relative competitiveness of the weed against the crop, the more in the value, the more competitiveness of the weed and higher reduction in the crop yield (Kropff and Spitters, 1992). Kropff and Spitters (1992) reported that q >1 indicates more competitiveness of the weed, q <1 indicates more competitiveness of the crop and q = 1 indicates that the crop and the weed were behaving as equal competitors. The regression curve of the crop yield loss on the weed relative leaf area is convex when q >1, concave when q<1 and in the 1:1 line when q = 1 (Ngouajio *et al*., 1999).

According to the values of *q* obtained in the present study using Eq. 5 (1.81±0.19 in 2001 and 1.30±0.15 in 2002) it was revealed that common lambsquarters is more competitive than maize. Ngouajio *et al*. (1999) reported the values between 0.14 and 5.05 for q in maize-common lambsquarters competition. These researchers also concluded that the empirical yield loss model based on the weed relative leaf area did not provide an adequate fit for maize yield loss data. They attributed the low accuracy of this model to individual weed size owing to variations in the time of emergence or vigor of the weed relative to the crop. They also reported that the regression of maize yield loss on common lambsquarters relative leaf area were convex and concave in the first and second years of their experiment, respectively. As a result, not only they highlighted the great effect of environmental conditions on competitive ability of the crop and the weed in their experiment, but also they emphasized on unreliability and inaccuracy of the empirical yield loss models based on the weed relative leaf area.

To evaluate the reliability and goodness of the empirical yield loss model based on the weed relative leaf area, the correlation coefficient between the estimated and measured values was calculated. Results showed that the regression of measured on estimated values of yield loss is close to 1:1 (Table 4). So it can be concluded that the empirical yield loss mode based on the weed relative leaf area is accurate and reliable enough to simulate maize yield loss due to common lambsquarters.

CONCLUSIONS

Generally the results of the present study revealed that the two empirical yield loss models based on density and the relative time of common lambsquarters emergence and the weed relative leaf area were the most reliable and accurate models at predicting maize yield loss due to common lambsquarters. These models had the highest R^2 and the slope of the regression of measured on estimated values of yield loss was near 1 (Table 2, 4). But among the models fitted to combined data of maize yield loss of different times of common lambsquarters emergence, the rectangular hyperbolic yield loss model based on weed density was most reliable. It is noteworthy to mention that although the empirical yield loss model based on the weed relative leaf area was valid, but lack of a fast method in estimating the weed leaf area is one of the important challenges in case of this model (Knezevic *et al*., 1994; Lotz *et al*., 1996; Ngouajio *et al*., 2001). On the other hand, although the empirical yield loss model based on weed density and the relative time of common lambsquarters emergence is reliable at predicting maize yield loss due to common lambsquarters, but irregular germination of this weed seeds had made the determination of its density difficult at each relative time of the weed emergence. A better understanding of the effects of the environmental factors on emergence and growth of the weeds can help minimizing this problem.

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