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Validation of a Model Relating Crop Yield and Weed Time of Emergence and Removal

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ABSTRACT
Understanding of weed-crop interactions is needed for the development of integrated weed management systems. A field study was conducted to evaluate an existing model to predict corn yield loss as a function of different time of weed emergence and removal. The treatments were consisted of two different periods of weed interference at different stages of corn development using a randomized complete block design with 12 treatments and 3 replications. The data sets were analysed by a Gompertz nonlinear function. The results of this trial approved that model was robust enough to predict yield loss caused by a mixed weed infestation with a single set of parameters. In term of critical period of weed control, outcomes of the model showed that on the basis of 5% acceptable yield loss this period was 21-98 days after sowing and with 10% acceptable yield loss this period was 44-76 days after sowing. It reveals that corn is able to tolerate early weed competition. Therefore, weed control management strategies can be postponed till 21 or 44 days after sowing on the basis of 5 and 10% acceptable yield loss, respectively. For that reason, pre-emergence treatments are unnecessary. However, it is necessary to protect corn from weeds for a long time to prevent high yield loss.

Key words: Corn, modelling, weed control, critical period, weed-crop competition, yield loss

INTRODUCTION
Corn (*Zea mays* L.) is one of the most popular crops in Iran, which is often cultivated for both human and animal consumption (Ghanizadeh, 2008). Weed infestation is one of the environmental factors which limited field crop production. They caused yield loss in corn when not controlled (Sheibany *et al.*, 2009). In order to manage weeds efficiently, it is important to know about weed biology and ecology to predict affects of weed infestation on crop yield loss (Sattin and Berti, 2003). Understanding the different time of weed emergence and removal is essential as a successful weed management strategy (Uremis *et al.*, 2005). Weather condition, soil type and cropping systems are most effective factors in weed germination patterns (Vleeshouwers and Kropff, 2000). Moreover, on the basis of species ecological perspective germination requirements (Moisture and temperature), seed characteristics (i.e. dormancy) and interaction between these factors and climate can Influence time of emergence (Eslami, 2011). It is well documented for several crops that relative time of weed-crop emergence and time of weed removal strongly effect crops yield (Yakubu *et al.*, 2006; Oad *et al.*, 2007; Yaghoobi and Siyami, 2008; Sheibany *et al.*, 2009; Keramati *et al.*, 2008). Therefore, the knowledge of the relationship between the duration of time that weeds compete with

crops and their affects on yield loss is necessary to develop decision support system for weed control. Identifying the critical period for weed control (CPWC) is the most common way to evaluate the influence of weed infestation on crops yield loss (Aghaalikhani and Yaghoobi, 2008). Controlling weeds base on CPWC lead to reduce costs and risks of intensive weed control and helps to optimize weed control methods. To determine CPWC two variables are considered: weed-free period (WFP) and duration of tolerated competition (DTC) (Masin *et al.*, 2010). The duration of the CPWC production issues (Rajcan and Swanton, 2001). In order to evaluate CPWC trails that conducted in different places, it is necessary to consider factors like duration of weed competition, the yield of a weed-free crop, timing of control, and the effect of delay in weed emergence on crop yield (Sattin and Berti, 2003). Many empirical models based on weed density and relative time of weed emergence have been developed In order to predict the effect of weed on crop yield loss (Zimdahl, 2004). For instance, Cousens *et al.* (1987) introduced a modified model based on weed density and relative time of emergence of the crop and weed. This model was used to describe the variations of crop yield loss on the basis of weed density. Although in this approach, weed density determination is simple in the field however it is difficult to control the time of emergence of the weeds in relation to that of the crop. In this case, other authors proposed relative leaf (L_w) as another variable in the modelling crop-weed competition (Kropff and Spitters, 1991). This model later modified by Kropff *et al.* (1995) and considers L_w instead of density which shows that the damage causes by a weed depends on the relative development of crop and weed and therefore also their relative time of emergence. However, these models have only provided information about one weed-crop species whereas infestations in fields include various weed species and therefore such information limited practical interest. Assessing these statements require estimating the competitive affects of mixed weed infestation. In this case, Berti and Zanin (1994) developed the concept of density equivalent (Deq). This concept is used to take a mixed weed infestation into account. According to this approach the Deq of a specific weed species is defined as the density of a reference species that determines a yield loss equal to that caused by the studied species at the measured density. In this case, Sattin *et al.* (1996) by using a common set of shape parameters showed that it could be possible to predicted crop yield loss caused by a mixed weed infestation with any time of weed removal and emergence by means of the Deq approach. However, the disadvantage of this model was that the rate of yield reduction due to weed competition was dependant not only on time of weed emergence and removal, but also on weed density that limited the generalization of model. More recently, Berti *et al.* (2008) extended a model using a Gompertz function to link initial slope of the hyperbolic relationship among weed density, time of emergence, time of weed removal and yield loss. This model was found to be flexible and confirmed the possibility of describing yield loos caused by a mixed weed infestation. The aim of our study was to validate the model developed by Berti *et al.* (2008) relating corn yield loss to weed time of removal and emergence in southwest of Iran. The objectives of our study were: validating the model developed by Berti *et al.* (2008) relating corn yield loss to weed time of removal and emergence in southwest of Iran investigating if this model was good enough to be used as a tool for predicting and assessing yield loss related to a mixed weed infestation and determining the duration of time that is required to prevent corn yield loss from weeds interference to achieve desirable yield.

MATERIALS AND METHODS

Location: A field experiment was conducted in 2008 at the Shushtar University experiment Station in the southern west of Iran (32°3' North latitude, 48°50' East longitude, 67 m). The soil type was clay loam with 0.2% organic matter and pH 7(Ghanizadeh, 2008).

Cultural practices: Soil preparation consisted of primary and secondary tillage as well as cultural practices was conducted according to local practices for corn production. Corn seeds, cultivar SC704, sown at a spacing of 20 cm within the row spaced 75 cm apart at a population density of 66,600 plants ha^{-1}. Plot size was five rows each 10 m long and plots were separated by two border rows. The middle three rows of each plot were used for data collection. Fertilizers were applied at the rate of 112 kg P ha^{-1} at sowing and 205 kg N ha^{-1} with 50% applied at the time of sowing and 50% at the time of 7-8 leaf-stage of corn approximately 28 DAP.

Treatments and experimental design: The experimental design was a Randomized Complete Block (RCBD) with 3 replications. Two sets of treatments were imposed to represent both increasing Duration of Tolerated Competition (DTC) and the length of the Weed-Free Period (WFP) measured after planting. The first set of treatments established five levels of increasing duration of weed interference by delaying weed control from the time of crop emergence up to predetermined crop growth stages (weedy up to Corn 3 leaf stage (V3), 6 leaf stage (V6), 9 leaf stage (V9), 13 leaf stage (V13) and tasseling (VT)) at which weed control was initiated and kept for the remainder of the growing season. The second set of treatments established five levels of increasing length of the weed-free period by maintaining weed control from the time of crop planting up to the above-presented crop growth stages before subsequently emerging weeds were left uncontrolled for the remainder of the season. In addition, season long weedy and weed-free controls were included. The progression of crop development was monitored for all weedy and weed-free controls by recording the average growth stage of 10 consecutive corn plants every 5 D. Natural weed populations were used in trial. Weeds were removed by hand pulling and hoeing.

Sampling: Weeds were harvested from three 1 m^2 quadrates staggered on each side of the three middles corn rows within each experimental plot two days before each weed removal. At each harvest weeds were excavated from the soil surface, sorted by species and counted. The corn ears were hand-picked from the centre two rows over 4 m within each plot. Ears were threshed and subsequently dried at 70°C to constant moisture content for 48 h and grain yield per plot was determined.

Model description: In this study the following model were used to evaluate the effect relating time of weed emergence and removal on corn yield:

$$Y_L = \frac{Deq_t}{EXP(EXP(d - ftr) + cte) + Deq_t} \tag{1}$$

where, Y_L is crop yield loss, tr is time of weed removal, te is time of weed emergence d, f, c are time parameters that which govern the effect of weed time of emergence and removal on yield loss. Deq_t is total weed density equivalent which was calculated by a recommended equation by:

$$Y_L = \frac{Y_{WF} - Y_W}{Y_W} \tag{2}$$

where, Y_{WF} is the yield of weed-free plot and Y_W is the yield of weeded plot. In order to evaluate model performance in predicting crop yields, the model Efficiency Index (EF) and Root Mean Square Error (RMSE) were calculated. The model EF is calculated as:

$$EF = \frac{\Sigma\ (O_i - O)^2 - \Sigma\ (P_i - O_i)^2}{\Sigma\ (O_i - O)^2} \tag{3}$$

where, O_i is the observed values, P_i is the predicted values and $\hat{O}$ is the mean of observed values. The value of EF can range from 1 downward. An EF value of 1 would mean that the model produced exact prediction. The RMSE is calculated as:

$$RMSE = \frac{100}{O}\sqrt{\frac{\Sigma (Pi - O_i)^2}{N}} \tag{4}$$

where, N is the number of observations and the range of RMES is from 0 (best fit) to ∝.

Statistical analysis: Data were analysed statistically by an Analysis of Variance (ANOVA), using SAS software (SAS, 1999). Means were compared in LSD test at 0.05 level of probability (Gomez and Gomez, 1984). The parameters of model were analysed using PROC NLIN in SAS.

RESULTS

In our study, barnyard grass (*Echinochloa cruss-galli*) and redroot pigweed (*Amaranthus retroflexus*) were dominant weeds and presented 42 and 29% of total weed population. The yield of corn in observed season-long weedy treatment decreased by 64.04% in comparison to weed-free plot. Table 1 demonstrates calculated regression parameters of model. The density equivalent in our trial was estimated at 1.78. The results of modelling the effect of different time of weed emergence and removal on corn yield loss is presented in Table 2. There was generally good agreement

Table 1: The estimated parameters of model (time parameters c, d an f) and standard error (SE). Efficiency index (EF) and root mean square error (RMSE) are Statics describing the model performance in predicting corn yield

Equation parameters				
EF	RMSEC	(SE)	D (SE)	F (SE)
0.914	11.49	0.0358 (0.007)	1.1538 (0.003)	0.0022 (0.046)

Table 2: Comparison of the observed and predicted corn yield under different duration of weedy and weed-free period

Corn stage	Predicted yield (t ha^{-1})	Observed yield (t ha^{-1})
Season long weedy	3.23^c	3.87^c
3W	10.14^a	10.01^a
6W	6.90^b	7.78^b
9W	4.32^c	4.41^c
13W	4.50^c	4.39^c
TW	4.30^c	4.42^c
Season long weed-free	10.59^a	10.77^a
3NW	3.77^c	3.98^c
6NW	9.40^a	10.72^a
9NW	9.17^a	10.70^a
13NW	9.39^a	10.49^a
TNW	9.64^a	10.45^a

Values having same superscript in each column indicate non-significant difference at 0.05 level of probability

Table 3: Weed-free period (WFP), duration of tolerated competition (DTC) and critical period (CP) estimated with Eq. 1

Accepted yield loss (%)	WFP	DTC	CP
5	98	21	77
10	76	44	32

between predicted and observed corn yields as confirmed by EF and RMSE values. The amount of yield in DTC and WFP were slightly underestimated in predicted values in compare to observed values (Table 2). However, these differences are negligible because the results of the predicted data closely matched the observed data for various periods of weed emergence and removal. Besides, the model accurately simulated the negative effects of increasing the duration of weed competition on corn yield. According to Table 2 increasing the duration of weed competition on corn decreased of yield gradually in both observed and predicted values were noted. However, the more the time of weed emergence was postponed, the higher corn yield was achieved. It demonstrates the strong sensitivity of crop yield loss to the relative time of crop and weed emergence.

The length of critical period (CP) in our trial was investigated based on the outcomes of the model (Table 3). The length of this period depends on the accepted yield loss and the relationship between time of weed removal and emergence and yield loss. In our study we considered two levels of accepted yield loss, 5 and 10%, respectively. As anticipated, there is an inverse relationship between the accepted yield loss and the length of WFP. Increasing in the accepted yield loss, decreased the length of WFP but increase the length of DTC and therefore reduced the length of CP. The length of this period with 5% accepted yield loss was 77 days and with 10% accepted yield loss it was 32 days. The onset of CP for 5 and 10% accepted yield loss were 21 and 44 days after emergence. This suggests that early weed control is unnecessary, but in order to keep yield loss lower than acceptable yield loss, it is necessary to protect corn from weeds for a long time.

DISCUSSION

The model which examined in this study provided a good forecasting of yield. In contrast with other empirical models (Zimdahl, 2004), in this model it was possible to take a mixed weed infestation into consideration in this model. Therefore, the results of this model are more precise to develop decision support systems for weed control. Moreover, there is a clear link with the variation of potential competitiveness and the time of weed removal/emergence (te and tr parameters). So the relationship between crop yield and the time of weed removal and emergence can be describe with just one set of time parameters (c, d and f parameters). Present findings here are in agreement with Berti *et al.* (2008). They revealed that it was possible to foresee the negative effects of a mixed weed population on crops. In our trial the model was able to predict negative effects of increasing the duration of weed competition at different time of weed emergence and removal on corn in southern west of Iran. In support to our results it was also well documented that this model was able to describe yield loss of crop in Italy (Masin *et al.*, 2010). In term of critical period (CP), the model determined the beginning of this period at 5% acceptable yield loss at corn fifth leaf stage and corn eighth leaf stage at 10% acceptable yield loss. The CP ended at corn milk stage and corn tasseling at 5 and 10% acceptable yield loss respectively. This suggests that early weed control is unnecessary, but in order to keep yield loss lower than acceptable, it is necessary to protect corn from weeds for a long time. A variety of critical period among different studies has been documented (Norsworthy and Oliveira, 2004). However, the majority of them are in agreement with our findings that early weed control management (Pre-plant and pre- emergence weed control management) in corn is unnecessary. For instance, Hall *et al.* (1992) reported the CPWC for corn at the 3- to 14-, and 4-6- to 10-12-leaf stages of corn, respectively. Dogan *et al.* (2004) reported that weed removal in corn must be carried out from corn 3-leaf stage. In a trial on critical period of weed control in corn showed that weed control must be carried out from 5- to 9-leaf stage (17-36 DAP) to prevent yield losses of 5%. This period was 6- to 8-leaf stage (21-29 DAP) southern west of Iran to prevent yield losses of 10% (Ghanizadeh *et al.*, 2010). However, the critical period of weed control in such studies have been calculated using functional approach based on fixed yield loss threshold (Van Acker *et al.*, 1993). In this approach the continuous relationship between crop yield loss and the time of weed removal/emergence was not considered (Sattin and Berti, 2003). It is necessary to consider site-specific factors and the parameters which link to WFP and DTC, to analyse results of different critical period of weed control experiments (Sattin and Berti, 2003). Moreover, it is important to represent this relationship in a compact model (Otto *et al.*, 2009). The ability of the model that examined in this study to describe the explicit pattern of relationship between crop yield and different time of weed emergence and removal were similarly mentioned by Berti *et al.* (2008).

CONCLUSION

The use of models relating to independent variables expressing weed competitiveness can improve weed control strategies. The results of the model examined in this paper tend to favour post-emergence treatments rather than pre-emergence ones. However, among growers generally tend to provide a long-term weed-free environment for crop and keep fields weed-free as long as possible immediately after crop emergence. For this reason, they may apply soil herbicides in many cases, and mechanical control and herbicide applications are often repeated several times unnecessarily. Consequently, it could lead to cost effective and harms the environment. According to present results, growers could improve timing of post-emergence herbicide applications and hand weeding. Further studies should be conducted to evaluate this model in Iran for several crops sites.

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