DETERMINATION OF THE CRITICAL PERIOD OF WEED CONTROL IN CORN USING A THERMAL BASIS[1]

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ABSTRACT - Field studies were conducted over 3 years in southeast Buenos Aires, Argentina, to determine the critical period of weed control in maize (*Zea mays* L.). The treatments consisted of two different periods of weed interference, a critical weed-free period, and a critical time of weed removal. The Gompertz and logistic equations were fitted to relative yields representing the critical weed-free and the critical time of weed removal, respectively. Accumulated thermal units were used to describe each period of weed-free or weed removal. The critical weed-free period and the critical time of weed removal ranged from 222 to 416 and 128 to 261 accumulated thermal units respectively, to prevent yield losses of 2.5%. Weed biomass proved to be inverse to the crop yield for all the years studied. When weeds competed with the crop from emergence, a large increase in weed biomass was achieved 10 days after crop emergence. However, few weed seedlings emerged and prospered after the 5-6 leaf maize stage (10-20 days after emergence).

Index terms: weed interference, weed management, accumulated thermal units, nonlinear regression.

DETERMINAÇÃO DO PERÍODO CRÍTICO DE CONTROLE DE PLANTAS DANINHAS EM MILHO UTILIZANDO UMA BASE TÉRMICA

RESUMO - Conduziram-se estudos no campo durante três anos no sudeste da Província de Buenos Aires, Argentina, para determinar o período crítico de controle de plantas daninhas no milho. Os tratamentos consistiram de dois períodos diferentes de interferência das plantas daninhas: um período crítico livre de plantas daninhas, e um período crítico de remoção de plantas daninhas. O período crítico livre de plantas daninhas foi ajustado por meio da equação Gompertz, enquanto o período crítico de remoção de plantas daninhas foi ajustado mediante a equação logística. Foram utilizadas as unidades térmicas para descrever cada período de interferência de plantas daninhas. O período crítico livre e o período crítico de remoção de plantas daninhas variaram de 222 a 416 e de 128 a 261 unidades térmicas acumuladas, respectivamente, para impedir uma perda de rendimento de 2,5%. A biomassa das plantas daninhas variou ao contrário do rendimento do cultivo, em todos os anos estudados. Quando as plantas daninhas competiram com o cultivo desde a emergência, foi alcançado um grande incremento de biomassa aos dez dias após a emergência do cultivo. Porém, poucas plântulas de plantas daninhas emergiram e prosperaram depois do estádio de 5-6 folhas de milho (10-20 dias após a emergência).

Termos para indexação: interferência de plantas daninhas, manejo de plantas daninhas, unidades térmicas acumuladas, regressão não-linear.

INTRODUCTION

Understanding of critical period of weed control is one of the most important tools in integrated weed management (Swanton & Weise, 1991). The critical period of weed competition has been defined (Nieto H. et al., 1968; Zimdahl, 1980; Kropff et al., 1993b) as the time interval between the maximum weed-infested period, or the length of time that weeds which emerge with the crop can remain uncontrolled before they

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begin to compete with the crop and cause yield loss, and the minimum weed-free period, or the length of time that the crop must be free of weeds after emergence.

In this definition the results of different forms of competition research are combined. However, as was pointed by Hall et al. (1992), the critical period of weed competition is not necessarily the time of the most intense interference. Therefore, it may be better to use the term critical period for weed control instead of critical period of weed competition. The length of the critical period of weed control may vary depending on the acceptable yield loss first proposed in corn (Hall et al., 1992), and later in soybean (*Glycine max* L. Merr.)(Van Acker et al., 1993) and white bean (*Phaseolus vulgaris* L.) (Woolley et al., 1993). This concept is closely related to the use of "period thresholds", defined by Dawson (1986) as the length of time that a crop can tolerate weed competition before yield loss exceeds the cost of control. Early research on weed competition used multiple comparison tests to calculate the critical period (Zimdahl, 1980). However, Cousens (1988, 1991) suggested that regression analysis is more appropriate and reliable in calculating the critical period.

The critical period has traditionally been defined in days or weeks after emergence, not stages of crop growth. Several investigators, reported a weed-free period of 50 days from seeding for corn in order to prevent yield loss in Mexico (Nieto H. et al., 1968); whereas, in the United States they reported a period of 3 to 6 weeks (Knake & Slife, 1969). However, this method makes the comparisons among locations and years difficult because of different emergence dates and environments. In corn, leaf stages or accumulated thermal units could improve comparisons because the leaf appearence rate is highly dependent upon ambient temperatures (Tollenaar et al., 1979). Working from this hypothesis, Hall et al. (1992) determined that, in Canada, the beginning of the critical period for corn widely varied from the 3 to 14 leaf stages of corn and ended on average at the 14 leaf stage.

The objective of this study was to determine the critical period of weed control in corn in southeast Buenos Aires Province, Argentina.

MATERIAL AND METHODS

Field studies were conducted during the 1983-84, 1984-85 and 1985-86 growing seasons at the Balcarce Experimental Station of the Instituto Nacional de Tecnología Agropecuaria (INTA), Buenos Aires (37° 45' south, 58° 18' west, 130 m altitude), Argentina. The soils were Typic Argiudols (fine loamy, thermic, mixed illitic) containing 32% sand, 40% silt, 28% clay, 6.5-7.0% organic matter and pH 5-6. Naturally occurring weed populations were utilized in all experiments. Weed densities and species composition present 30 days after crop emergence are reported in Table 1. Plots were seeded on November 4, 1983, November 14, 1984 and October 26, 1985. Corn was seeded at a depth of 5 cm at a seeding rate of 72000 plants ha^{-1} at 70 cm row spacing. Each plot consisted of four rows 8 m long. The experimental design for each study was a randomized complete block design with four replications. Two series of weed removal treatments were included. In the first series, treatments of increasing duration of weed control were maintained weed free until 10, 20, 30, 40, 50 or 60 days after crop emergence (DAE). The weeds were subsequently allowed to develop until final harvest (95 days) when they were removed. In the second series, weed interference treatments of varying duration allowed weeds to compete with corn from crop emergence until 10, 20, 30, 40, 50, or 60 days; then the plots were weeded and kept weed-free until harvest (95 days). Control plots were kept free of weeds or left weedy throughout the growth period (95 days). Weeds were removed by hand pulling and hoeing.

Weed growth in each treatment was evaluated by harvesting three 0.25 m^2 quadrats per plot. Weeds were separated by species and weighed to obtain a measure of aboveground fresh weed biomass. Weed harvests were taken at the time of weed removal for treatments where weeds were allowed to grow for different periods after crop emergence and at the time of the final harvest in the case of treatments kept weed free for different periods after crop emergence.

At each 10 day period, the accumulated thermal units (ATU) were calculated according to the formula:

$$ATU = \sum_{i=1}^{n} (t_1 - 8^{o}C) \quad \text{when } t_i > 8^{o}C$$

where ATU is accumulated thermal units from emergence to day *n* and t_i is mean daily air temperature. Base temperature during the vegetative period (leaf expansion) was estimated to be 8°C according to local information (Andrade, 1995). The number of expanded leaves of crop (ligule fully developed) was recorded every 10 days until 60 days.

Corn was hand harvested from the middle 6 m of the center two rows of each plot and fed through a mechanical thresher. Seed yields were adjusted to 14% moisture.

Gompertz and logistic equations were fitted to the yield data, expressed as a percent of the weed-free check, for increasing length of weed-free period and increasing duration of weed interference respectively. The equations were fitted using the nonlinear technique described by Hall et al. (1992).

The yields of three-year treatments analyzed together were significantly different between years; thus, for this reason each year was analyzed separately using the Gompertz and logistic equations. The Gompertz equation used to describe the increasing duration of weed control on maize yield is defined as:

$$y = Ae^{-Be^{-kt}}$$

where y is the relative yield, A is the yield asymptote, B and k are constants and t is the time of weed free period from emergence (days). Logistic equation used to describe the increasing duration of weed interference on yield is defined as:

$$y = 100\left[\frac{C}{1+e^{-g+bt}}+1-C\right]$$

where y is the relative yield, 100(1-C) is the yield asymptote, g and b are constants and t is the time in days weeds competed from emergence so that t_0= g/b is the point of inflection. The expression of this equation was modified from original (Hall et al., 1992) so that the point of inflection is not previously fixed to the fit in such a manner that it becomes the function of parameters g and b. Parameter estimates of nonlinear equations were obtained employing the method of least squares using PROC NLIN of SAS (version 6.11). The coefficient of determination (R^2) was calculated for each fit as:

TABLE 1. Weed density and major species present in unweeded controls at 30 days from corn emergence.

Year	Total weed density	Weed species	Portion of weed density
	(plants m^{-2})		(%)
1983-84	486	*Galinsoga parviflora*	59
		Chenopodium album	10
		Portulaca oleracea	9
		Amaranthus hybridus	8
		Polygonum convolvulus	3
		Polygonum aviculare	2
		Setaria viridis	
		Digitaria sanguinalis	
		Panicum capillare	
		Total grasses:	9
1984-85	536	*Brassica campestris*	33
		Galinsoga parviflora	23
		Chenopodium album	10
		Amaranthus hybridus	3
		Polygonum convolvulus	3
		Setaria viridis	
		Digitaria sanguinalis	
		Total grasses:	28
1985-86	674	*Chenopodium album*	5
		Galinsoga parviflora	3
		Brassica campestris	2
		Amaranthus hybridus	1
		Polygonum aviculare	1
		Setaria viridis	
		Digitaria sanguinalis	
		Echinochloa crus-galli	
		Total grasses	88

$R^2 = 1 - SSE/SSTC$

where SSE are the error sums of squares and SSTC are the corrected total sums of squares. Estimated parameters are presented in Table 2.

The critical weed-free period and the critical time of weed removal were calculated by substituting relative corn yields (percent of control), into the Gompertz and logistic equations. Yields losses of 2.5, 5 and 10% were arbitrarily chosen to calculate the beginning and end of the critical period.

RESULTS AND DISCUSSION

Length of the weed-free period required to prevent yield loss varied for the different years and accepted levels of yield loss (Table 3). For all yield loss levels, the time required for weed-free maintenance was greater in 1984-85 than in 1983-84 and 1985-86. Likewise the greater the percentage loss, the less time required for all the years considered. The length of the weed-free period required to prevent more than a 2.5% yield loss ranged from 222 to 416 ATU (approximately 15 to 30 DAE or 6-7 leaves). When a yield loss of 10% was acceptable, the weed free period ranged from 158 to 294 ATU (approximately 10-20 DAE or 5-6 leaves) (Fig. 1).

The critical time of weed removal varied among years and accepted percentage of yield loss. The period in which weeds could compete with the crop without causing more than 2.5% yield loss ranged from 128 to 261 ATU (approximately 8 to 17 DAE or 5-6 leaves). In comparison when a yield loss level of 10% was chosen, the period ranged from 311 to 431 ATU (approximately 21 to 31 DAE or 6-7 leaves) (Table 3). The length of the weed removal period required in 1985-86 to prevent yield loss, was less than the other years probably due to a greater weed biomass accumulated up to 20 days after emergence.

The variation of weed biomass was the inverse to variation in crop yield throughout the term of the study (Fig. 2). Fresh weight of weeds declined at 50 DAE in 1983-84 and 1985-86 while in 1984-85 the decline was observed begin at 60 DAE. In contrast,

TABLE 2. Parameter estimates for the Gompertz[1] and logistic[2] equations.

Year	Gompertz parameters				Logistic parameters			
	A	B	k	R^2	C	g	b	R^2
1983-84	93.21	0.96	0.16	83	0.64	3.42	0.08	91
1984-85	97.31	1.56	0.14	89	0.83	4.85	0.09	92
1985-86	100.50	1.72	0.29	89	0.82	3.21	0.07	91

[1] A: yield asymptote (% of season-long weed-free corn); B and k: constants; R^2: coefficient of determination (%).

[2] 100 (1-C): yield asymptote (% of season-long weed infested corn); g and b: constants determined by the shape of the curve.

TABLE 3. Critical weed-free and weed removal periods in corn calculated from Gompertz and logistic equations respectively for three predetermined levels of crop yield loss[1].

Year	Period for indicated percentage yield loss											
	Weed-free						Weed removal					
	2.5%		5%		10%		2.5%		5%		10%	
	DAE	ATU	DAE	ATU	DAE	ATU	DAE	ATU	DAE	ATU	DAE	ATU
1983-84	23	365	19	296	14	218	10	149	16	257	24	387
1984-85	30	416	25	351	20	294	17	261	24	337	31	431
1985-86	15	222	12	183	10	158	8	128	14	208	21	311
Corn leaf stage	6-7		5-6		5-6		5-6		5-6		6-7	

[1] DAE: days after corn emergence; ATU: accumulated thermal units.

weed biomass at harvest was reduced when corn was kept weed free 20 days after emergence in years 1983-84 and 1984-85 and 10 days in 1985-86 (Fig. 2),

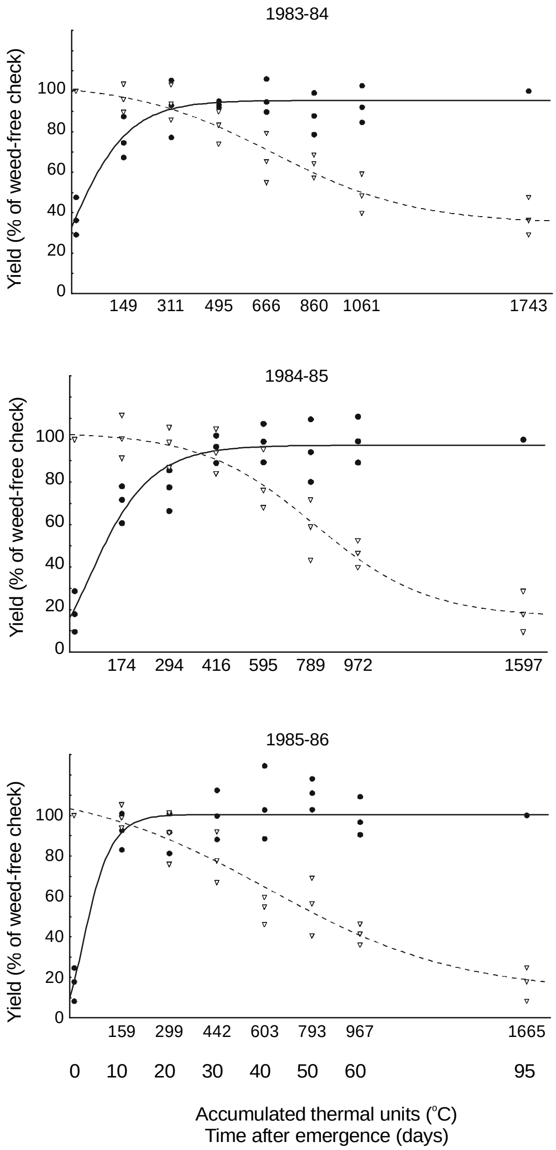

FIG. 1. Corn yield response to increasing length of weed-free period (——) or duration of weed interference (- -) at Balcarce in 1983-84, 1984-85 and 1985-86. Symbols (• or ∇) represent maximum, medium and minimum values of each point.

which corresponds with the 5th, 6th and 4th leaf stages respectively. Few weed seedlings emerged and prospered after the 5-6 leaf corn stage (10-20 DAE). Weeds that emerged in this case grew in a competitive disadvantage in comparison with the plants of the crop. Corn competition was sufficient to prevent yield losses from weeds that germinated 10-20 DAE.

Several researchers (Kropff et al., 1993a; Frantik, 1994) established the importance of time of emergence of the weeds. Generally, weeds that emerge simultaneously with the crop or shortly after the crop cause severe yields losses at very low densities. However, when the period of emergence is postponed the magnitude of yield loss decreases. Ford & Pleasant (1994) established that competition from weeds may be reduced when maize germinates quickly and forms a canopy that shades emerging weed seedlings.

The beginning of the critical period was defined as the crop stage or days after crop emergence when weed interference reduces yields by a predetermined level. The end of the critical period was defined as the crop stage or days after emergence until the crop must be free of weeds in order to prevent a predetermined level of yield loss (Hall et al., 1992). The length

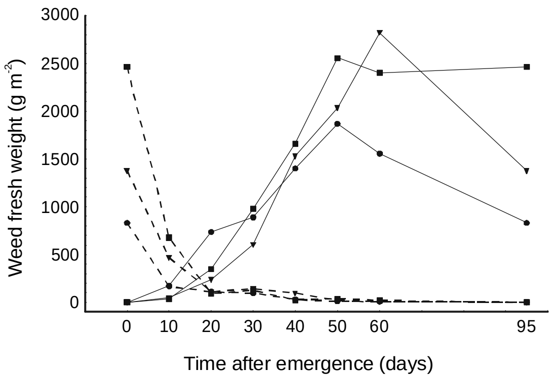

FIG. 2. Weed fresh weight as affected by increasing duration after emergence of corn crop maintained as weed free (- -) for increasing durations after emergence or weed infested (——) for increasing durations after emergence. Symbols represent means for each year: 1983-84 (■); 1984-85 (▼); 1985-86 (•).

of the critical period of weed control varied between years and levels of chosen yield loss. However, in 1985-86 with a 5% yield loss and a 10% yield loss for the other years, the critical period was rendered non-existent (Fig. 1).

Little overlap occurred in years 1983-84 and 1984-85 with a 5% yield loss between the length of time weeds can remain in the crop and the length of time required to be kept weed free. This suggests that a single weed removal could be sufficient to prevent 5% yield loss.

Based upon an arbitrary 2.5% level of yield loss, the critical period of weed control occurred between 149-365 ATU or 10-23 DAE in 1983-84, 261-416 ATU or 17-30 DAE in 1984-85, and 128-222 ATU or 8-15 DAE in 1985-86 (Fig. 1). Critical periods obtained here were shorter than those referred to by Nieto H. et al. (1968) and Hall et al. (1992). In this case the differences would be explained by narrower row spacing and earlier maize hybrid that possibly prevented a stronger competition with the crop. Regardless, variability in the extent and occurrence of the critical period of weed control, for an accepted yield loss may be attributed to the interaction of weed density, species composition, climate, soil, and the crop.

The critical period of weed control was variable across the years and varied between 128 to 416 ATU or 8-30 DAE, which is approximately 5 to 7 leaves. Comparing to previous information (Nieto et al., 1968; Hall et al., 1992), this may be considered a relatively short period in duration. This short weed-free period indicates that duration of a residual herbicide in corn need not be greater than 30 DAE, or 7 leaf stage of corn growth, in order to prevent a yield loss greater than 2.5%. Weed control under these conditions should be based on postemergence herbicides and/or cultivation, but if any yield loss is unacceptable, control practices must be begun as soon as possible after corn emergence.

It was suggested that weed interference will not reduce corn yields under normal environmental conditions if weeds are controlled in a timely manner with postemergence herbicides (Carey & Kells, 1995). The results establish that corn tolerates weed interference until the 5th leaf stage, although postemergence herbicides must be sprayed before this stage to effectively control the weeds.

CONCLUSIONS

1. The critical period of weed control, based upon an arbitrary 2.5% level of yield loss, varies between 128 to 416 ATU or 8-30 DAE, which represents approximately 5 to 7 leaves of the crop.

2. The variation of weed biomass is the inverse to variation in crop yield.

3. Weeds that emerge from crop emergence achieve a large increase in biomass 10 days after crop emergence.

4. Weeds that emerge after the 5-6 leaf corn stage (10-20 DAE) grow in a competitive disadvantage in comparison with the plants of the crop.

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