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Determination of Optimum Weed Control Timing in Maize (*Zea mays* L.)

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Abstract: In field experiments conducted in 2001 and 2002, the optimum timing for weed control in maize was investigated. Both experiments were designed according to randomized complete blocks, and *Cyperus rotundus* L., *Amaranthus retroflexus* L., *Portulaca oleracea* L. and *Chenopodium album* L. were naturally infested on experimental plots in both years. The study in 2001 was conducted to determine the critical period for weed control for maize. With this aim plots were maintained weed-free or weedy for different periods based on crop growth stage. The relationships between grain yield and different weedy or weed-free periods were determined via regression analyses in 2001. The results of this study suggested that a weed-free period between 3- and 10-leaf stages of maize was enough to provide acceptable grain yield. In the following year weed control was carried out during the critical period that was determined in 2001. Weed removal from plots was started at the 3-leaf stage of maize and plots were kept weed-free for different periods until the 5-, 7- and 10-leaf stages. Whole season weedy and weed-free plots were included in the experiment for yield comparison. The highest grain yield was obtained from plots kept weed-free between the 3- and 7-10-leaf stages. Results from both years suggest that weed control should be carried out between the 3- and 7-10-leaf stages of maize to provide maximum grain yield. Thus, it is possible to optimize the timing of weed control, which can serve to reduce the costs and side effects of intensive weed control.

Key Words: Maize (*Zea mays* L.), Weed control, Critical period

Mısırda (*Zea mays* L.) Yabancı Ot Mücadelesi İçin En Uygun Dönemin Saptanması

Özet: 2001 ve 2002 yıllarında yürütülen tarla denemelerinde, mısır ekim alanlarında optimum yabancı ot mücadelesi zamanının belirlenmesi amaçlanmıştır. Denemeler yazlık kültürlerde en sık rastlanan önemli yabancı ot türleri olan topalak (*Cyperus rotundus* L.), horoz ibiği (*Amaranthus retroflexus* L.), semizotu (*Portulaca oleracea* L.) ve sirken (*Chenopodium album* L.) ile doğal olarak bulaşık alanlarda yürütülmüştür. 2001 yılında yürütülen çalışmada mısır ekim alanlarında yabancı otların kontrolü için kritik dönem belirlenmiştir. Bu amaçla tesadüf blokları desenine göre 4 tekrarlı olarak kurulmuş olan denemede parseller bitki gelişme dönemine bağlı olarak farklı periyotlarca yabancı otlu yada yabancı otsuz bırakılmıştır ve sezon sonunda bu parsellerden elde edilen dane verimleri tüm yetiştirme sezonu boyunca yabancı otlu ve yabancı otsuz parsellerle karşılaştırılmıştır. Farklı periyotlarda yabancı otlu yada yabancı otsuz bırakılmış parsellerden elde edilen verim değerleri regresyon analizine tabi tutulmuş ve bu yöntemle yabancı ot mücadelesi için gerekli olan kritik periyodun mısırın 3 ile 10 yapraklı dönemleri arasındaki periyot olduğu belirlenmiştir. 2002 yılında yürütülen çalışmada ise yabancı ot kontrolü bir önceki yıldan elde edilen sonuçlar doğrultusunda yalnızca kritik dönem içerisinde farklı periyotlarda yürütülmüştür. Bu amaçla tüm deneme parsellerinde yabancı ot mücadelesi 3 yaprak döneminde başlatılmış ve farklı parsellerde 5, 7 yada 10 yaprak dönemine kadar yürütülmüştür. Karşılaştırma amacıyla tüm sezon yabancı otlu ve yabancı otsuz parseller çalışmaya eklenmiştir. Verim değerleri ele alındığında bir önceki yılın sonuçlarıyla benzer sonuçlar elde edilmiş ve yabancı ot kontrolünün mısırın 3 yaprak döneminde başlaması ve 7 ile 10 yaprak dönemine kadar sürdürülmesi gerekliliği tespit edilmiştir. Elde edilen sonuçlar mısır bitkisinde yabancı ot rekabetinden dolayı ortaya çıkan verim kayıplarının engellenmesi için uzun süreli yabancı ot kontrolü yerine yalnızca kültür bitkisinin 3 ile 7-10 yaprak dönemi arasında yapılan bir yabancı ot mücadelesinin kabul edilebilir bir verim seviyesini sağladığını göstermektedir. Böylelikle yabancı ot mücadelesinin üretim maliyeti içerisindeki payının ve yoğun mücadele önlemleri sonucunda ortaya çıkan bazı risklerin azaltılması mümkün olacaktır.

Anahtar Sözcükler: Mısır (*Zea mays* L.), yabancı ot mücadelesi, kritik dönem

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Introduction

Weeds are one of the most important factors in maize production. They cause important yield losses worldwide with an average of 12.8% despite weed control applications and 29.2% in the case of no weed control (Oerke and Steiner, 1996). Therefore, weed control is an important management practice for maize production that should be carried out to ensure optimum grain yield. Weed control in maize is carried out by mechanical and/or chemical methods. Weeds between plant rows are removed generally by mechanical cultivation, while weeds on the rows are controlled by hand hoeing or by herbicides. Although both methods are effective in controlling weeds, they increase production costs and have some disadvantages or side effects when applied intensively. Low efficacy against perennial weeds, short duration, soil erosion and crop injuries are the main disadvantages of intensive mechanical weed control, whereas the intensive use of herbicides is mostly associated with soil and water pollution (Hurle, 1996; Tortenson, 1996), and the selection of herbicide-resistant weed biotypes (Rubin, 1996).

To reduce the costs and risks of intensive weed control, the frequency or intensity of applications should be reduced or optimized. Critical periods for weed control (CPWC) are defined as the period in the crop growth cycle during which weeds must be controlled to prevent unacceptable yield losses (Knezevic et al., 2002). Controlling weeds based on CPWC is the most appropriate way to optimize weed control applications. With the aid of CPWC it is possible to make decisions on the need for and timing of weed control, and to control weeds only when efficient weed control is required.

Some previous studies were carried out to determine CPWC for maize. Ferrero et al. (1996) determined CPWC for maize in Italy as the period between the 1- and 7-leaf stages in 1992 and between the 7- and 10-leaf stages in 1993. Del Pino and Covarelli (1999) reported that a weed-free duration of 2 weeks starting 3 weeks after crop emergence is enough to provide acceptable grain yield. Another study, conducted in Southern Turkey, showed that keeping second crop maize weed-free from crop emergence to 9 or 11 weeks resulted in 2.5% and 5% yield losses, respectively (Üremis et al., 1997). It can be concluded from the results of previous studies that the CPWC values are variable depending on the location or growing season. These differences can be attributed to variations in the composition of weed species, initial density or ground cover of weeds, as well as to climatic conditions, in which crop and weeds interfere (Knezevic et al., 2002). In order to provide more precise information for growers, CPWC should be determined specifically for a particular region by considering the weed composition and climatic conditions (Rajcan and Swanton, 2001; Knezevic et al., 2002). Therefore, this study aimed to determine the optimum timing for weed control in maize under the growing conditions of Aydın province in Turkey.

Materials and Methods

Experiments were carried out on sandy loam soil with 2.01% organic matter content and a pH of 7.8 at the research station of Adnan Menderes University in 2001 and 2002. The experimental design was randomized complete blocks with 4 replications in both years. Plots consisted of 8 maize rows (distance between and within the rows 70 and 20 cm, respectively), 5 m long. A standard variety of maize (cv. Terebia) was sown on 1st May in both years. Common cultural practices were applied during the whole growing season except for weed control measures. In both experiments weeds were removed from the plots by hand hoeing between rows and by hand pulling on the rows.

Experiment in 2001

In the experiment conducted in 2001 it was aimed to determine the CPWC for maize. Plots were maintained weed-free or weedy for different durations. In weed-free plots, weed removal was started immediately after crop emergence and the plots were kept weed-free for different durations until the 4-, 6-, 8-, 10- and 12-leaf stages (row closure) of maize. Weeds emerging after each period were left on the plots. In weedy plots, weeds were allowed to compete with maize from emergence until the 2-, 4-, 6- and 8- leaf stages. Plots were kept weed-free starting from each growth stage to the row closure (12-leaf stage of maize). A whole season weedy plot was left on each block to determine the total yield loss in the case of no weed control. Weed species and their average ground cover on control plots at each weed control starting date are given in Table 1.

Table 1. Weed species and their ground cover at different removal dates in 2001.

Weed species	Weed control starting time (maize growth stage)			
	2-leaf	4-leaf	6-leaf	8-leaf
	Weed Ground Cover (%)			
Cyperus rotundus L.	4	10	22	25
Amaranthus retroflexus L.	1	8	20	16
Chenopodium album L.	1	5	9	13
Portulaca oleracea L.	2	3	5	10
Other weed species*	2	2	8	7
Total weed coverage (%)	10	28	64	71

**Echinochloa* spp., *Solanum nigrum* L., *Datura stramonium* L., *Sorghum halepense* L.

Experiment in 2002

In the experiment conducted in 2002, weed control was carried out for different durations based on the results of the previous year. Since the critical period for weed control in maize was defined as the period between the 3- and 10-leaf stages of maize, weed removal on the plots was started at the 3-leaf stages of maize and the plots were kept weed-free for different periods until the 5-, 7- and 10-leaf stages. Average weed ground cover at the 3-leaf stage of maize was 10% for *C. rotundus*, 5% for *A. retroflexus*, 3% for *C. album* and 2% for *P. oleracea* (total weed ground cover was 20%). During the whole season weed-free and weedy plots were included in the experiment for yield comparison.

At the end of the growing season all plots were harvested, and grain yield per plot was determined. Data from each year were subjected to analysis of variance, and means were compared using the LSD test at the 0.05 significance level. In order to determine CPWC, yield values from 2001 were expressed as the percentage in relation to yield from plots maintained weed-free until row closure. With the percentage grain yield values, regression analyses were performed. Because non-linear regression could not describe the experimental data adequately, relationships between grain yield and weedy and weed-free durations were determined via linear regression analysis. Data were fitted to the equation $y = a + bx$, where "y" denotes yield, "a" denotes maximum and minimum yields in the case of weed-free and weedy plots, respectively, and "b" denotes the regression coefficient. Furthermore, the relationship between maize growth stage and corresponding weed ground cover was determined by linear regression in 2001.

Results

Experiment in 2001

The differences for grain yield among the weed control periods were significant (Table 2). In the case of weed control from emergence until row closure (12- leaf stage of maize), grain yield was 14.4 t ha^{-1}; however, only 66% of this yield level could be provided in the case of no weed control (whole season weedy conditions).

Table 2. Influence of different weedy and weed-free periods on maize grain yield in 2001.

Weed control period		Yield (t ha^{-1})		% Yield
1	0-4 –leaf	10.4	cd	72
2	0-6 –leaf	11.7	bc	82
3	0-8 –leaf	12.5	ab	87
4	0-10–leaf	13.4	ab	94
5	0-12–leaf (row closure)	14.4	a	100
Weedy period				
6	0-2–leaf	14.4	a	100
7	0-4–leaf	12.6	ab	88
8	0-6–leaf	12.4	abc	86
9	0-8–leaf	12.9	ab	89
10	Whole season	9.5	d	66

LSD value: 2.89

Although maize grain yield was increased in all weed control periods, these increases were positively related with prolonged weed-free durations. However, yields obtained from plots kept weed-free until the 8- and 10-leaf stages of maize were not significantly different from those of plots kept weed-free from emergence until row closure.

As far as the influence of weedy periods on maize yield is concerned, it was observed that weed competition until the 8-leaf stage did not reduce grain yield significantly. The highest grain yield was provided from plots in which weeds were left for the shortest period, from emergence until the 2-leaf stage. Longer weedy periods (0-4-, 0-6- and 0-8- leaf stages) resulted in about 11-14% yield reductions, but these reductions were not statistically significant.

Regression analyses showed that there were positive and negative relationships between grain yield and weed-free, and weedy periods, respectively (Figure 1). Based on the determined regression equations, a weed-free period between the 3- and 10-leaf stages of maize provided 95% of the maximum grain yield, which is considered as an acceptable yield level for CPWC studies (Rajcan and Swanton, 2001; Knezevic et al., 2002).

The relationship between maize growth stage and average weed ground cover was described with the equation $Y = -2.05 + 8.84*X$ ($r^2 = 0.94$). With the aid of this equation the weed ground cover at the beginning of the critical period (3-leaf stage of maize) was determined to be 24.5 %.

Experiment in 2002

Similar to 2001, grain yield was significantly reduced by weed competition in 2002 (Table 3). As compared with whole season weed-free conditions, only 60% of the grain yield was obtained in the case of no control.

Although grain yield was increased in all weed control periods, the yield from the shortest weed-free period (between the 3- and 5-leaf stages) was not significantly different from that of whole season weed infested plots. Longer weed-free periods until the 7-10 leaf stages provided statistically similar grain yields as with the whole season weed-free conditions. Keeping plots weed-free until the 10-leaf stage provided maximum grain yield.

Table 3. Influence of different weed-free periods on maize grain yield in 2002.

Weed-free period	Average yield ($t\ ha^{-1}$)	% Yield
0 (whole season weedy)	6.28 c	60
Between 3- and 5-leaf stage	7.37 bc	71
Between 3- and 7-leaf stage	9.28 ab	89
Between 3- and 10-leaf stage	11.35 a	109
Whole season weed-free	10.43 a	100

LSD value: 2.16

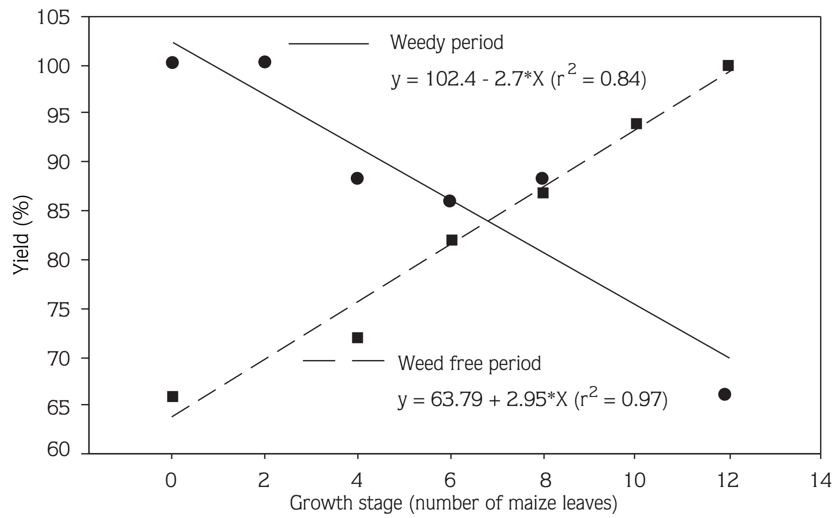

Figure 1. Maize yield as affected by different weedy and weed-free periods.

The yield recorded from the 3-10-leaf stage weed-free plots was even higher than that under whole growing season weed-free conditions; however, mean yield values were not statistically significant.

Discussion

The results recorded in these studies suggest that weed control in maize should be carried out between the 3- and 7-10-leaf stages of maize in Aydın province, Turkey. Similar critical weed control periods for maize were also reported by Hall et al. (1992) and Hurle et al. (1996), who defined the CPWC for maize as the 3- to 14-, and 4-6- to 10-12-leaf stages of maize, respectively. These results showed that the presence of weeds in maize fields until the 3-4-leaf stages of the crop generally does not affect grain yield adversely. This may be explained by the lower weed concurrence sensitivity of maize until the 6-leaf stage, because Hanway (1971) stated that the nutrient uptake of maize from soil is relatively small during the 2-4-leaf stages of development.

From the results of these studies it can be concluded that a short weed-free duration (3-4 weeks) starting from the 3-leaf stage of maize is enough to provide acceptable grain yield, as Berzensy et al. (1995) and Del Pino and Covarelli (1999) also suggested. However, there is a general tendency among growers to keep fields weed-free as long as possible immediately after crop emergence. To provide a long-term weed-free environment for maize, soil herbicides are applied in many cases, and mechanical control and post-emergence herbicide applications are often repeated several times unnecessarily. However, long-term weed control in maize is not cost effective and harms the environment, and is not always associated with the highest grain yield. Therefore, adjusting the weed control timing to CPWC is an important way of reducing the costs and potential hazards of weed control treatments. With the aid of CPWC it is possible to avoid unnecessary control measurements, to give up the use of long persistent soil herbicides and to use post-emergence herbicides more consciously, even with lower doses than recommended (Knezevic et al., 2001).

Conclusion

The studies presented in this paper showed that weeds cause 35-40% yield losses in maize in the case of no control. However, a weed-free period between the 3- and 7-10-leaf stages of the crop was enough to prevent these losses under the growing conditions of Aydın province, Turkey. Corresponding weed cover at the beginning of the critical period was 20-25%. These results are valuable for growers in optimizing the timing of weed control as well as in developing an integrated weed control strategy. Therefore, the efficacies of different weed control methods and/or their combinations should be evaluated in further studies to find out the most appropriate weed control strategy in maize during the critical period.

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