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The Critical Period of Weed Control in Faba Bean and Chickpea in Mediterranean Areas

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Weeds are often the major biological constraint to growing legume crops successfully, and an understanding of the critical period of weed control (CPWC) is important for developing environmentally sustainable weed management practices to prevent unacceptable yield loss. Therefore, we carried out two field experiments to identify the CPWC for two grain legume crops traditionally grown in Mediterranean areas: chickpea and faba bean. The experiments were conducted at two sites both located in the Sicilian inland (Italy). In chickpea, when weeds were left to compete with the crop for the whole cycle, the grain yield reduction was on average about 85% of the weed-free yield, whereas in faba bean the reduction was less severe (on average about 60% of the weed-free yield). The onset of the CPWC at a 5% yield loss level varied by species, occurring later in faba bean than in chickpea (on average, 261 and 428 growing degree days after emergence for chickpea and faba bean, respectively). In both species, the end of the CPWC occurred at the early full-flowering stage when the canopy of each crop enclosed the interrow space. On the whole, the CPWC at a 5% yield loss level ranged from 50 to 69 d in chickpea and from 28 to 33 d in faba bean. The results highlight the fact that faba bean has a higher competitive ability against weeds than chickpea. This could be attributable both to more vigorous early growth and to the plant's greater height, both factors related to a greater shading ability and, consequently, to a better ability to suppress weeds.

Nomenclature: Faba bean, *Vicia faba* L. var. *minor*; chickpea, *Cicer arietinum* L.

Key words: Competition, grain legumes, time of weed removal, weed-free period, weed interference.

Grain legumes are potentially important components of rainfed Mediterranean cereal-dominated cropping systems. They provide many advantages, such as fixing atmospheric nitrogen that will then be partly available to the subsequent crop, breaking graminaceous crop disease cycles, and improving the quality of the soil (Jensen et al. 2010; Mohammadi et al. 2005; Ruisi et al. 2012; Unkovich et al. 1997; van Kessel and Hartley 2000). Yet a progressive decline in the amount of area sown to grain legumes has taken place in southern Europe in the past 50 yr; in Italy, the harvested area decreased from about 1,000,000 ha in 1961 to 90,000 ha in 2010 (FAOSTAT 2012). This has led to little interest in these crops among the agrochemical industry and, as a consequence, to limited technological innovation, in particular a scarcity of herbicides. Farmers often consider weeds to be the major biological constraint to growing legume crops successfully. In fact, compared with cereals, legume species generally have an open growth habit and a slow growth rate in the early stages of the crop cycle, characteristics that favor the emergence and growth of weeds (Al-Thahabi et al. 1994; Smitchger et al. 2012).

The present need to design cropping systems that are environmentally sustainable and less dependent on fossil fuel and agrochemicals suggests that it is time to revive the legume species in the agricultural systems of Mediterranean areas. The revitalization and success of legume species will depend on the development of integrated weed management systems that will be able to reduce reliance upon herbicides. Identifying the critical period of weed control (CPWC) for a given legume crop is essential for determining the appropriate timing of weed control and the efficient use of herbicides (Bukun 2004; Evans et al. 2003; Otto et al. 2009). The CPWC is the window of the crop cycle when weed interference results in unacceptable yield losses (Knezevic et al. 2002; Williams 2006). Weed growth prior to the beginning of the CPWC does not affect yield because the crop and the weeds are too small or too far apart to negatively influence each other (Rajcan et al. 2004). Similarly, weeds that emerge after the end of the CPWC do not appreciably affect yield because the crop has a high competitive ability.

Competition between the crop and weeds, and thus the CPWC, are dependent on site-specific factors, such as climatic conditions, management strategies, the composition of weed flora, weed density, and weed emergence time (Rajcan and Swanton 2001). The CPWC tends to vary widely within grain legume species (Fedoruk et al. 2011; Harker et al. 2001; Knezevic et al. 2003; Mohamed et al. 1997; Mohammadi et al. 2005). Moreover, few experiments on CPWC have examined legume crops under Mediterranean conditions, and even fewer have done so by investigating more than one species. Thus, we aimed to identify the CPWC for two typical grain legume species of the Mediterranean traditionally grown for both human consumption and feed: faba bean and chickpea (Bonanno et al. 2012). The results of this study will be useful in making recommendations to Mediterranean farmers on the optimal time for implementing and maintaining weed control procedures for these two crops.

Materials and Methods

Experimental Sites. The experiment was conducted during the 2007–2008 growing season at two sites at the experimental farm Pietranera, located about 30 km north of Agrigento, Italy (37.55 N, 13.52 E; 178 m above sea level). In one site (S1), the soil has a clay texture (498 g kg^{-1} clay, 232 g kg^{-1} silt, and 270 g kg^{-1} sand; pH 8.0; 17.1 g kg^{-1} total carbon [C]; and 1.24 g kg^{-1} total nitrogen [N]). In the other site (S2), the soil has a sandy clay loam texture (267 g kg^{-1} clay, 247 g kg^{-1} silt, and 486 g kg^{-1} sand; pH 8.0; 6.3 g kg^{-1} total C; and 1.08 g kg^{-1} total N).

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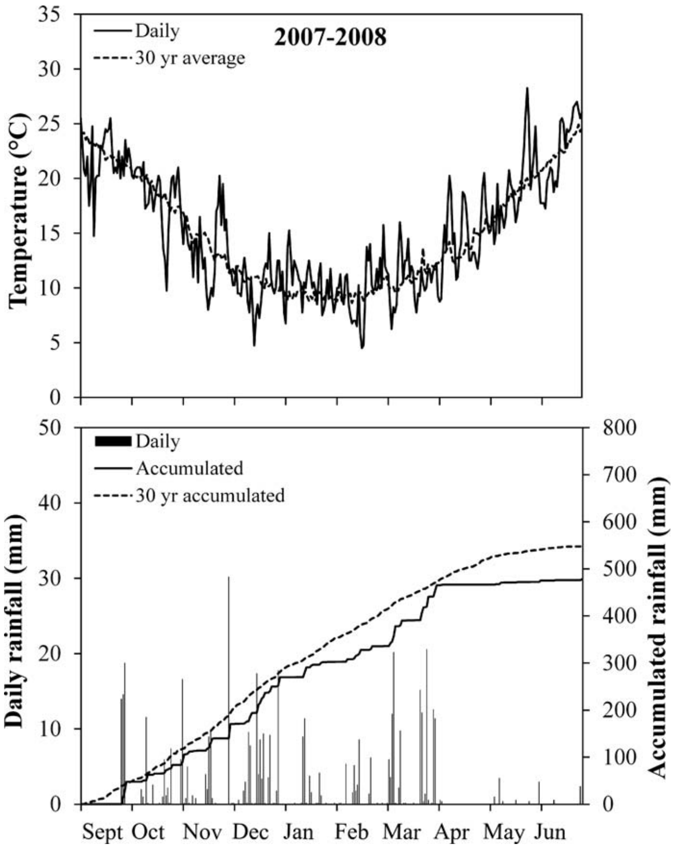

Figure 1. Daily air temperature and daily and accumulated rainfall at the experimental farm during the 2007–2008 growing season; 30-yr average daily temperatures and accumulated rainfall are also included.

The climate of the experimental site is semiarid Mediterranean with a mean annual rainfall of 551 mm, concentrated mostly during the autumn/winter period (September–February; 74%) and the spring (March–May; 18%). The mean air temperature is 15.9 C in autumn, 9.8 C in winter, and 16.5 C in spring. Total rainfall during the experimental year was 13% lower than the long-term average, but temperatures were similar to the long-term averages (Figure 1). Weather data were collected from a weather station located within 500 m of the experimental sites.

Experimental Procedure. At both sites, the previous crop was wheat, and the soil was plowed in August and harrowed after the first autumn rainfalls. Phosphate fertilizer was applied before sowing at 92 kg P_2O_5 ha^{-1} as triple superphosphate.

In both sites, the experimental design was a split plot with four replications, the main plot being the legume species: chickpea or faba bean. The subplots consisted of two sets of treatments of both increasing duration of weed interference (used to determine the critical timing of weed removal) and increasing length of weed-free period (used to determine the critical weed-free period), according to Knezevic et al. (2002). The area of each subplot was 72 m^2 (24 m by 3 m). The first set of treatments consisted of nine sampling areas (0.96 m^2, three rows 1.0 m long) in which weed control was delayed from crop emergence until predetermined dates (0 [emergence], 28, 42, 56, 70, 84, 98, 112, or 140 [harvest] d after emergence [DAE]), at which time weeds were removed by hand and the areas were maintained weed-free for the remainder of the growing season. The second set of treatments consisted of nine sampling areas (0.96 m^2, three rows 1.0 m long) that were kept weed-free for 0, 28, 42, 56, 70, 84, 98, 112, or 140 d starting from emergence and kept weedy for the rest of the growing season.

In both sites, plots were sown on December 22, 2007; chickpea (cv 'Sarah') and faba bean (cv 'Sikelia') were sown at 60 and 50 viable seeds m^{-2}, respectively. For both species, the sowing depth was 4–6 cm, and the interrow spacing was 0.32 m.

Naturally occurring weed populations were present in both sites. However, to augment the natural weed community, wild mustard (*Sinapis arvensis* L.) and Italian ryegrass (*Lolium multiflorum* Lam.), two of the most common and competitive weeds in the cereal-based cropping systems of the experimental area, were also seeded at 100 seeds m^{-2} for each species just before sowing the crops. In both sites, faba bean and chickpea emerged 15 d after sowing. At crop emergence, weed population was mainly composed of wild mustard (on average 52 and 37 seedlings m^{-2} in S1 and S2, respectively) and Italian ryegrass (on average 21 and 6 seedlings m^{-2} in S1 and S2, respectively); no appreciable differences in weed density between chickpea and faba bean were observed.

At each time of weed removal, weeds were cut at ground level within each sampling area, sorted by species, counted, and weighed after drying at 80 C to a constant weight. Before cutting, the plant height of the weeds and crops was measured. At chickpea and faba bean maturity, crop and weed biomass was harvested from each sampling area by clipping the plants at soil level. Weeds were sorted by species, counted, and weighed after drying at 80 C to a constant weight. Crop plants were counted and their biomass, grain yield, and yield components (number of pods per square meter, number of seeds per pod, 100-seed weight) were recorded.

Calculations and Statistical Analyses. For both crops, growing degree days (GDD) were accumulated from the date of emergence (time zero) using a base temperature (T_b) of 2 C; this value was assumed to be valid for both crops, being within the range of previous estimates for chickpea (Confalone et al. 2011; Dumur et al. 1990) and faba bean (Singh 1991; Summerfield et al. 1990). GDD for each day were calculated from the following formula:

$$GDD = (T_{max} + T_{min})/2 - T_b \qquad [1]$$

where T_{max} is the maximum temperature of the day (°C) and T_{min} is the minimum temperature of the day (°C).

The relationships between treatment (critical timing of weed removal and critical weed-free period) and weed biomass were calculated using the PROC REG function of SAS 9.2 (SAS 2008). Schumacher's (1939) equation was used to determine the relationship between the weed biomass accumulation and the weed-infested treatment:

$$W = e^{a + b/x} \qquad [2]$$

where W is the weed biomass (g dry matter [DM] m^{-2}), a is the logarithm of the maximum W value as x approaches infinity, b is the asymptote of the curve, and x is the length of the weed-infested period (in GDD).

Following Sit and Costello (1994), a type I exponential curve was fitted to the series of weed-free treatments:

$$W = de^{fz} \qquad [3]$$

Table 1. Weed composition and average weed density (plant m^{-2}; standard errors in parentheses) in unweeded chickpea and faba bean controls at harvest.

		Site 1				Site 2			
Weed species	Common name	Chickpea		Faba bean		Chickpea		Faba bean	
Sinapis arvensis L.	Wild mustard	90,8	(6,16)	82,5	(3,56)	59,3	(9,78)	47,0	(6,29)
Lolium multiflorum Lam.	Italian ryegrass	32,2	(11,06)	30,6	(3,28)	19,7	(2,59)	16,1	(2,90)
Convolvulus arvensis L.	Field bindweed	7,8	(6,25)	4,6	(4,10)	19,3	(11,24)	21,0	(9,59)
Papaver rhoeas L.	Corn poppy	0,3	(0,17)	1,1	(0,62)	6,5	(0,68)	3,9	(0,34)
Anethum graveolens L.	Dill	2,9	(0,23)	1,4	(0,23)	—		—	
Anagallis arvensis L.	Scarlet pimpernel	2,3	(0,92)	3,4	(1,55)	0,7	(0,52)	0,6	(0,16)
Polygonum aviculare L.	Prostrate knotweed	0,5	(0,13)	0,6	(0,20)	3,9	(2,40)	5,7	(4,65)
Lactuca serriola L.	Prickly lettuce	0,6	(0,07)	0,2	(0,17)	1,7	(0,21)	2,0	(0,52)
Kickxia spuria (L.) Dumort.	Round-leaved fluellen	0,1	(0,11)	0,1	(0,08)	0,6	(0,47)	2,0	(1,72)
Chenopodium vulvaria L.	Stinking goosefoot	—		—		0,3	(0,25)	1,4	(0,88)
Other		3,3	(1,33)	4,5	(1,65)	7,3	(1,15)	5,6	(0,81)
Total weed density		140,8	(12,48)	129,0	(4,84)	119,3	(22,98)	105,3	(7,02)
Number of species		13		13		15		14	

where W is the weed biomass (g DM m^{-2}), d is the W-intercept, f is the shape parameter of the curve, and z is the length of the weed-free period (in GDD).

For each crop and site, relative yields were analysed using a mixed-model (PROC MIXED procedure in SAS 9.2; SAS 2008) with replications considered as random; relative yield was calculated as a percentage of the weed-free control for each site and crop.

In line with the procedure outlined by Knezevic et al. (2002), a mixed-model, nonlinear regression analysis (PROC NLMIXED in SAS 9.2; SAS 2008) was used to fit the relative yield as a function of the increasing length of the weed-free period and duration of the weed-infested period. In particular, for each site and crop a three-parameter logistic equation, proposed by Hall et al. (1992) and modified by Knezevic et al. (2002), was used to describe the effect of the increasing length of the weed-infested period on the relative yield:

$$Y = \left[(1/e^{[c(x-p)]+g}) + (g-1)/g\right] \times 100 \qquad [4]$$

where Y is the yield as a percentage of the weed-free control, c and g are constants, p is the point of the inflection, and x is the length of the weed-infested period (in GDD).

For each site, the Gompertz equation was used to predict the effect of the increasing length of the weed-free period on the relative yield of both chickpea and faba bean (Hall et al. 1992):

$$Y = me^{\left(-qe^{(-kz)}\right)} \qquad [5]$$

where Y is the yield as a percentage of the weed-free control, m is the maximum yield in the absence of weed interference, q and k are constants, and z is the length of the weed-free period (in GDD).

Logistic Equation 3 and Gompertz Equation 4 were used to determine the onset and the end of the CPWC, respectively, hypothesizing acceptable yield loss levels of 2.5%, 5%, and 10%.

The goodness of fit of equations 3 and 4 was evaluated by calculating the model efficiency index (EF) and mean bias error (MBE) according to Otto et al. (2009). The EF was calculated as follows:

$$EF = \left[\sum_{i=1}^{n}(O_i - \bar{O})^2 - \sum_{i=1}^{n}(P_i - O_i)^2\right] \div \sum_{i=1}^{n}(O_i - \bar{O})^2 \qquad [6]$$

where O_i is the observed value, $\bar{O}$ is the mean of the observed values, and P_i is the predicted value. EF values can range from 0 to 1; the nearer the value to 1, the better the goodness of fit of the equation. The MBE indicates the average deviation of

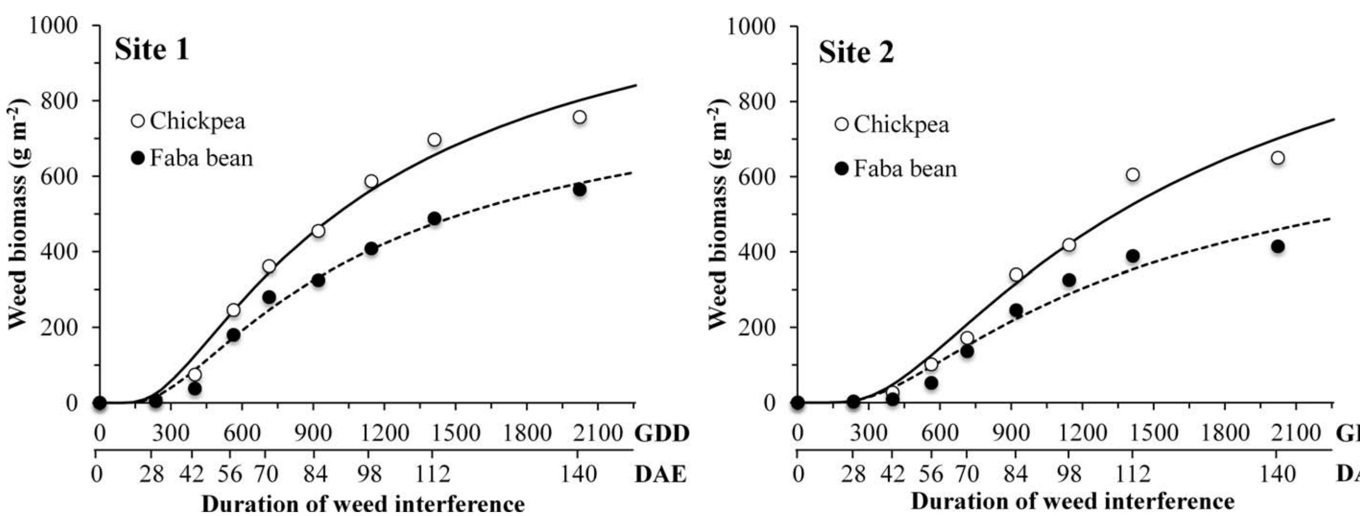

Figure 2. Weed biomass response to the increasing duration of weed interference for chickpea and faba bean at Site 1 and Site 2. Points represent observed mean values, and lines represent the fitted curves (Schumacher's model; Equation 2). Parameter estimates of the model used are listed in Table 2.

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Table 2. Parameter estimates (standard errors in parentheses) of the model used to calculate the effect of weed competition with chickpea and faba bean on weed dry weight accumulation at Site 1 and Site 2. See equations 2 and 3 in the text for the explanation of the abbreviations.

	A) Weed interference using Schumacher's model: $W = e^{a + b/x}$						B) Length of weed-free period using exponential model: $W = de^{fz}$					
	Site 1			Site 2			Site 1			Site 2		
Species	*a*	*b*	R^2	*a*	*b*	R^2	*d*	*f*	R^2	*d*	*f*	R^2
Chickpea	7.56 (0.097)	−120.7 (9.72)	0.995	7.81 (0.195)	−174.8 (21.28)	0.985	796.6 (81.13)	−0.03 (0.005)	0.944	868.3 (86.49)	−0.03 (0.004)	0.950
Faba bean	7.20 (0.084)	−116.6 (8.36)	0.996	7.21 (0.187)	−150.8 (19.82)	0.984	573.0 (36.44)	−0.05 (0.006)	0.975	467.0 (22.98)	−0.03 (0.003)	0.986

the predicted values from the observed values and is calculated as follows:

$$MBE\% = 100/NR \sum_{i=1}^{n} (P_i - O_i) \qquad [7]$$

where N is the number of observations and R is the range of observed values.

Results and Discussion

Weed Composition and Biomass. The weed population was composed of 13 species in S1 and 15 species in S2; no appreciable differences on weed composition were observed between chickpea and faba bean (Table 1). The weed density, measured at harvesting, averaged 135 plants m^{-2} at S1 and 112 plants m^{-2} at S2 and was always slightly higher in chickpea than in faba bean. The composition of the weed population was similar to that usually observed in the autumn–spring crops grown in the region (Giambalvo et al. 2012). Wild mustard and Italian ryegrass accounted for more than 85% and 60% of the total weed population in S1 and S2, respectively.

The total weed biomass (as dry matter) increased as the duration of weed interference increased, with a similar trend between sites (Figure 2; Table 2). In both sites the weed biomass was higher in chickpea than in faba bean, and the differences between the two crops increased with the duration of weed interference, probably because of the different early growth rates of the two crops (higher in faba bean than in chickpea). It is well known that the rapid creation of a dense canopy can contribute to the competitiveness of a crop against weeds (Berkowitz 1988).

The total weed biomass decreased rapidly in both sites as the duration of the weed-free period increased (Figure 3; Table 2). In faba bean, weeds that emerged later than about 600 GDD (60 DAE) had an almost null biomass; at this time the crop was about 40 cm tall (Figure 4), with the first raceme just visible, and the canopy just began to enclose the interrow space. In chickpea the weed biomass reached values of almost zero 20–30 d later than in faba bean.

Yields and Yield Reductions. The average grain yields of faba bean grown in weed-free conditions were 382 g m^{-2} at S1 and 363 g m^{-2} at S2, whereas chickpea in analogous conditions produced 353 g m^{-2} at S1 and 352 g m^{-2} at S2. These values are similar to average values observed for these two species in the experimental area (Ruisi et al. 2012).

The equations used to determine the onset and the end of the CPWC showed good predictive value for both sites and both crops, as indicated by the EF values (always greater than 0.94) and the MBE% (always close to 0; Tables 3 and 4).

In all cases, marked decreases in grain yield were observed when weeds were left to compete with the crops for the whole cycle (Figure 5). In chickpea, the grain yield was 6% and 21% of the weed-free yield at S1 and S2, respectively. These results are in line with Al-Thahabi et al. (1994), who found that chickpea seed yields in Mediterranean conditions were reduced on average by 81% when crops remained infested with weeds until harvest, compared with remaining weed-free. Mohammadi et al. (2005) found, in chickpea, average yield reductions slightly higher than 50%, whereas Tepe et al.

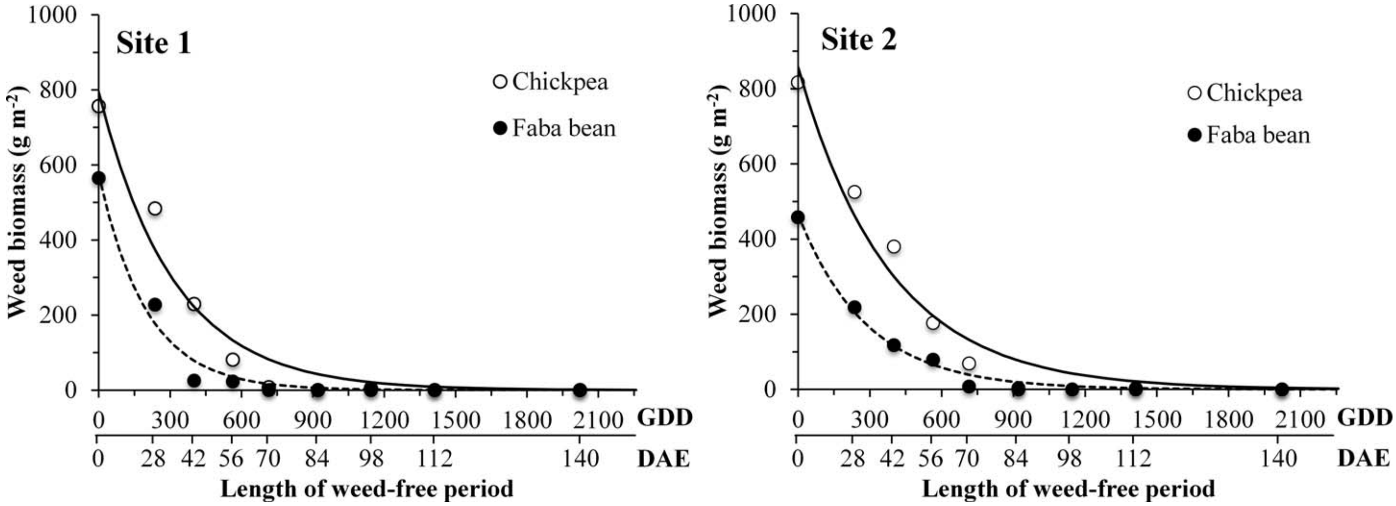

Figure 3. Weed biomass response to the length of the weed-free period for chickpea and faba bean at Site 1 and Site 2. Points represent observed mean values, and lines represent the fitted curves of the three-parameter exponential model (Equation 3). Parameter estimates of the model used are listed in Table 2.

(2011) observed losses due to weed competition of 25 to 31%. The variability in these results shows that the impact of weed competition on chickpea productivity is likely to be highly site-specific. This is not surprising, given the great variability in the climatic and agronomic conditions in which the experiments were performed, the unavoidable differences in weed density and composition, and the differences in the weed interference periods.

In faba bean the yield reductions caused by weed competition were less severe than those observed in the chickpea. The grain yield of the weedy control was 33 and 47% of the weed-free yield in S1 and S2, respectively. Similarly, Strydhorst et al. (2008) reported a mean yield reduction of 42% when faba bean was grown in the presence of weed interference, compared to a weed-free condition. The higher competitive ability of faba bean in comparison to chickpea might be attributable to a more rapid early growth of both shoots and roots, which is essential to competing with weeds for water and nutrients during plant establishment. Moreover, faba bean was taller than chickpea over the entire growing season (Figure 4); it is well known that plant height is generally strongly correlated with the ability to suppress weeds (Giambalvo et al. 2010; Gonzalez Ponce and Santin 2001) because it enables better interception of light by the crop and allows less light to reach the soil surface (Mohler 2001).

On average, for both crops and in both sites, grain yield reductions due to weed competition were mainly due to variations in the number of pods per square meter. This is in agreement with the findings of several authors who identified the number of pods per square meter as the component most closely correlated with seed yield for many grain legumes (Ayaz et al., 2004; French, 1990; Loss and Siddique, 1997). The variations observed in the number of pods per square meter were mainly attributable to variations in plant fertility (expressed as the number of pods per plant) rather than variations in plant density, because the latter was not appreciably affected by weed competition. Moreover, no differences due to weed competition were observed for the number of seeds per pod, whereas the 100-seed weight only showed a significant (but small) reduction when the duration of weed interference was long.

Onset and Duration of the CPWC. When we used an acceptable yield loss level of 5%, the onset of the CPWC

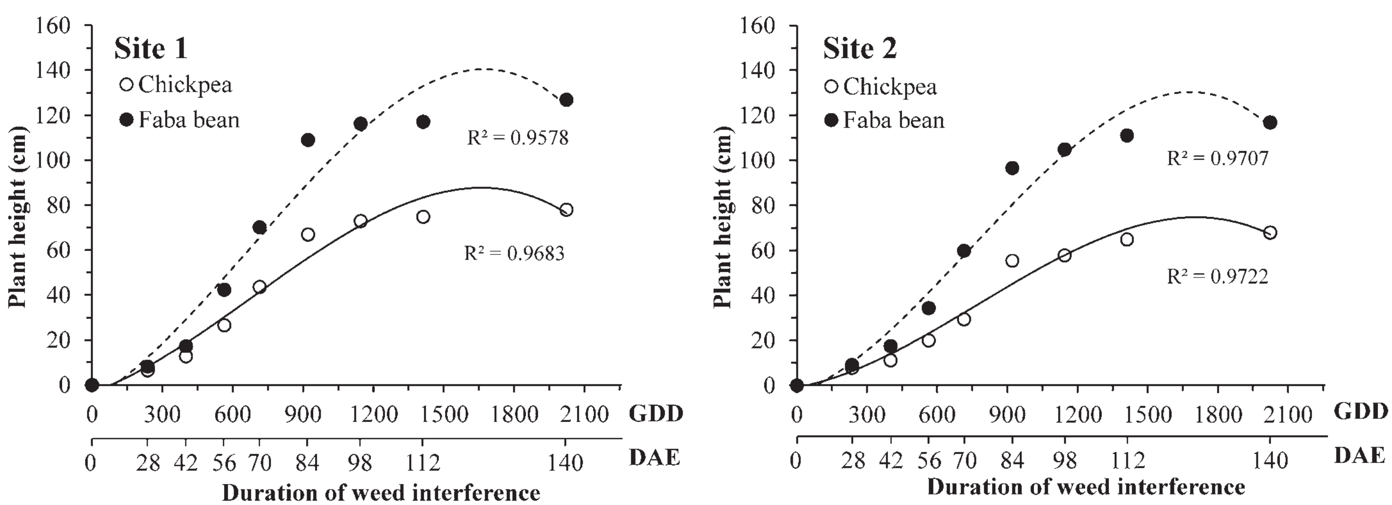

Figure 4. Plant height response to the increasing duration of weed interference for chickpea and faba bean at Site 1 and Site 2. Points represent observed mean values, and lines represent the fitted curves.

Table 3. Parameter estimates (standard errors in parentheses) of the three-parameter logistic model used to determine the critical timing of weed removal for chickpea and faba bean at Site 1 and Site 2. The model was fit to the relative yield of the two crops (expressed as a percentage of the weed-free control) as a function of the increasing duration of weed interference (in growing degree days). See equation 4 in the text for the explanation of the abbreviations of the parameter estimates.

		Parameter estimates							
Location	Species	*c*		*p*		*g*		EF	MBE%
Site 1	Chickpea	0.005	(0.001)	742	(62)	1.03	(0.06)	0.996	−0.013
	Faba bean	0.006	(0.002)	700	(78)	1.42	(0.12)	0.954	0.918
Site 2	Chickpea	0.005	(0.001)	900	(77)	1.32	(0.11)	0.976	−0.025
	Faba bean	0.004	(0.001)	904	(118)	1.94	(0.27)	0.989	0.034

[a] Abbreviations: EF, efficiency index; MBE%, mean bias error.

varied by species, occurring later in faba bean than in chickpea: 121 GDD (13 DAE) vs. 336 GDD (37 DAE) at S1 and 401 GDD (42 DAE) vs. 520 GDD (53 DAE) at S2 for chickpea and faba bean, respectively (Figure 5 and Table 5). The onset of the CPWC in our experiment occurred slightly later than that reported by Mohammadi et al. (2005; 17 DAE) for chickpea but was similar to that observed by Al-Thahabi et al. (1994; 35 DAE) and Saxena et al. (1976; 30 DAE) for chickpea and by Kavurmaci et al. (2010; 45 DAE) for faba bean. The fact that the onset of the CPWC occurred earlier at S1 than S2 can be due to the different environmental conditions, to variations in the composition and density of the weed populations, and finally to the timing of weed emergence relative to crop emergence (Knezevic et al. 2002). At S1, we observed a higher weed density in comparison with S2; many authors have reported that the onset of the CPWC tends to occur later with decreasing weed density (Hall et al. 1992; Martin et al. 2001; Stagnari and Pisante 2011). Moreover, weeds that germinate at the same time as the crop are more competitive than those that germinate later (Knezevic et al. 1994, 1997): in fact, we found a higher density of early-emerging species (mainly wild mustard and Italian ryegrass) in S1 than in S2, whereas the opposite was observed for late-emerging species (field bindweed, *Convolvulus arvensis* L.; corn poppy, *Papaver rhoeas* L.). The differences between faba bean and chickpea in the onset of the CPWC presumably could be due to the higher competitive ability against weeds of faba bean in the early growth stage. In fact, the differences between the two species in weed density, which, according to Martin et al. (2001), is one of the most important factors determining the onset of the critical period, were too small to explain the variation in the beginning of the critical period between the two crops.

The weed-free period for chickpea necessary to keep the yield loss under 5% was 893 GDD (82 DAE) at S1 and 1058 GDD (92 DAE) at S2, which coincided with the early- and full-flowering stages, respectively. By then, the chickpea canopy had enclosed the interrow space, and the weeds that emerged later did not significantly affect the yield, in line with others' findings (Malik et al. 1993; Martin et al. 2001; Mohammadi et al. 2005). For faba bean the weed-free period necessary to keep the yield loss under 5% was shorter than for chickpea: 714 GDD (70 DAE) at S1 and 879 GDD (81 DAE) at S2, coinciding in both cases with the early-flowering stage.

On the whole, the CPWC at the 5% yield loss level ranged from 50 to 69 d in chickpea and from 28 to 33 d in faba bean. When a 10% yield loss was considered, the critical period ranged from 24 to 40 d for chickpea but was particularly short for faba bean, varying from 1 to 8 d.

Conclusions. The results of this experiment show that weeds are a serious constraint to growing both chickpea and faba bean successfully in Mediterranean areas. Hence, to ensure an appropriate economic return on these crops, it is necessary to implement adequate weed control procedures. For both species the yield decreased markedly with the increasing duration of weed interference and increased with the increasing duration of the weed-free period. Overall, chickpea was less competitive against weeds than faba bean; we observed a higher weed biomass and a higher reduction in seed yield in chickpea than in faba bean in the presence of weed interference during the entire crop cycle. Moreover, in chickpea, the duration of the critical period of weed interference was greater than in faba bean (about 8 and 4 wk, respectively, when a 5% yield loss was considered). In both species the end of the critical period occurred from early to full flowering, a time when the canopies of the two crops have enclosed the interrow space. Weed control after canopy closure does not appear to be necessary because the weeds that emerged after canopy closure did not significantly affect the seed yield. The higher competitive ability against weeds of faba bean over chickpea appears to be attributable both to more vigorous early growth and to the plant's greater height; these factors play a key role in ensuring a greater shading ability and, consequently, in suppressing weeds effectively.

From a practical point of view, the definition of the critical period of weed control for faba bean and chickpea supports the early suppression of weeds using preemergence herbicides

Table 4. Parameter estimates (standard errors in parentheses) of the Gompertz model used to determine the critical weed-free period for chickpea and faba bean at Site 1 and Site 2. The model was fit to the relative yield of the two crops (expressed as a percentage of the weed-free control) as a function of the increasing length of the weed-free period (in growing degree days). See equation 5 in the text for the explanation of the abbreviations of the parameter estimates.

		Parameter estimates							
Location	Species	*m*		*q*		*k*		EF	MBE%
Site 1	Chickpea	100	(4.2)	3.01	(1.09)	0.005	(0.001)	0.985	−0.009
	Faba bean	104	(5.0)	1.19	(0.26)	0.004	(0.001)	0.974	0.075
Site 2	Chickpea	100	(4.1)	1.92	(0.38)	0.003	(0.001)	0.948	0.034
	Faba bean	102	(3.7)	0.75	(0.10)	0.003	(0.001)	0.980	0.196

[a] Abbreviations: EF, efficiency index; MBE%, mean bias error.

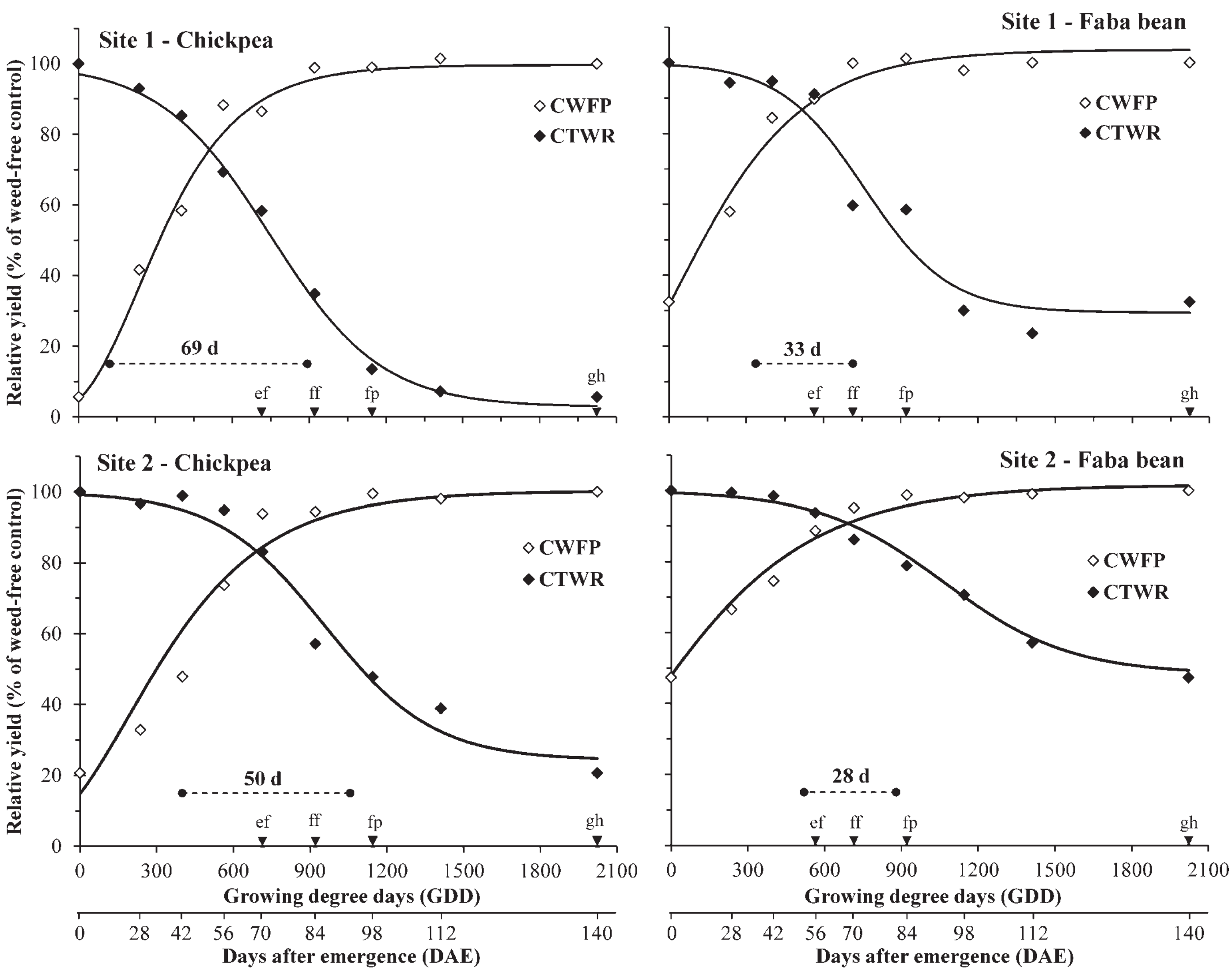

Figure 5. Chickpea and faba bean yield response to the increasing length of the weed-free period (critical weed-free period [CWFP]; empty symbols) and to the increasing length of the weed-infested period (critical timing of weed removal [CTWR]; solid symbols) at the two sites. The developmental stages of the crops, indicated by the arrows, are as follows: early flowering (*ef*), full flowering (*ff*), first pod (*fp*), and grain harvest (*gh*). Points represent observed mean values, and lines represent the fitted curves (Gompertz for CWFP and logistic function for CTWR), plotted against growing degree days (GDD). Parameter estimates of the models used are listed in Table 3 and Table 4. The dotted lines represent the critical periods of weed control based on an acceptable yield loss level of 5%.

or cultivation is necessary to prevent dramatic crop yield losses, particularly for chickpea. Data from this research provide useful information for growers of chickpea or faba bean to make a decision with respect to timely weed control measures, regardless of methodology. Moreover, the differences we observed between the two crops in their ability to compete against weeds should be of interest when one is choosing which legume species to include in a cereal–legume cropping system. This is particularly true for low-input or organic systems in which weed control is often a serious problem.

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Table 5. Beginning and end of the critical period of weed control (CPWC) for chickpea and faba bean at Site 1 and Site 2 for three level of yield loss (2.5%, 5%, and 10%) expressed as growing degree days after crop emergence (GDD).

		Beginning of CPWC			End of CPWC		
Location	Species	2.5%	5%	10%	2.5%	5%	10%
Site 1	Chickpea	29	121	278	1,054	893	724
	Faba bean	210	336	460	809	714	582
Site 2	Chickpea	238	401	558	1,250	1,058	848
	Faba bean	332	520	665	1,056	879	715

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