

Critical Periods of Weed Competition in Cotton in Greece

D. Papamichail,¹ I. Eleftherohorinos,² R. Froud-Williams¹
and F. Gravanis^{*,3}

Four experiments were conducted in central Greece during 1997 and 1998 to determine the late-season presence of weeds in cotton (*Gossypium hirsutum* L.) and the critical times for removing weeds. Experiments were conducted in natural, heavily infested cropland. The presence of weeds for more than 3 weeks after crop emergence caused significant reductions in crop growth and lint yields. However, weeds that emerged 11 weeks or more after crop emergence did not adversely impact yields. Total weed biomass increased with increasing time prior to weed removal. A weed-free period of 11 weeks after crop emergence was needed to prevent significant reductions in cotton height, biomass, number of squares, and yield. These results indicated that postemergence herbicides or other control measures should be initiated within 2 weeks after crop emergence to avoid significant yield reduction. For greater efficiency, soil-applied herbicides in cotton should provide effective weed control for at least 11 weeks. Curvilinear regression equations were derived to describe the relationship between critical periods of weed presence and cotton growth and fruit development.

KEY WORDS: Weed interference; weed competition; cotton.

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is one of the most important and profitable crops in Greece. During the 3 years 1997–99, cotton production in Greece averaged 390,000 ha per year, which resulted in Greece being the tenth greatest cotton producer in the world.

Growth of cotton is significantly affected by weed competition. Yield reduction depends on weed species, density and distribution (10), as well as on the soil's moisture, temperature (1), type, fertility and pH (12).

The duration of weed presence with the crop, and the time of weed emergence, generally affect weed–crop competition. The critical period for weed–crop competition occurs when both the weeds and crop are in an active vegetative stage of growth. This period of weed–cotton competition varies from 3 to 9 weeks after sowing, and depends on environmental factors and those related to both crop and weeds (1,12). Buchanan and McLaughlin (3) reported that cotton – in two locations in Alabama – tolerated 4 to 7 weeks of weed competition after crop emergence. In Mexico, spring-sown cotton required a 9-week weed-free period to avoid significant yield reduction, whereas for winter-sown cotton that period was 17 weeks. However, some researchers (8,17) found that a 4–5 week weed-free period was needed for cotton growth to be unaffected, whereas Chandler (5) reported

Received Feb. 15, 2001; received in final form Aug. 6, 2001; <http://www.phytoparasitica.org> posting Dec. 4, 2001.

¹Dept. of Agricultural Botany, University of Reading, Reading RG6 6AU, UK.

²Lab. of Agronomy, Aristotle University of Thessaloniki, Thessaloniki 54006, Greece.

³Dept. of Crop Production, Technological Educational Institute, Larissa 41110, Greece. *Corresponding author [Fax: +30-41-613153; e-mail: f.t.gravanis@teilar.gr].

that this period was 11–13 weeks. These differences, according to Keeley and Thullen (10), could be attributed mainly to different density and species of the weeds present, as well as to environmental factors.

Several researchers (2,15,17) found that establishment, height, biomass, square and boll number of cotton were significantly affected by weed competition. Cotton yield was the most sensitive measurement of growth in response to weed competition, and yield reduction was related to duration of weed competition, spatial arrangement of weeds, weed species and density (2,6,11,17). Keeley and Thullen (9) found that full-season weed competition caused 80–100% reduction of cotton yield. Also, according to their findings, the presence of early-emerged weeds affected cotton yield more than late-germinating weeds. While late-germinating weeds did not reduce yield, they did interfere with mechanical harvesting and lowered crop quality (6).

The above mentioned studies were carried out in the USA and South America, but similar studies have not been conducted with cotton under field conditions in southern Europe. The objective of this research was to determine the effect of weed removal and weed emergence time on cotton growth in Greece.

MATERIALS AND METHODS

Four experiments were conducted at Larissa in central Greece during 1997 and 1998, on a clay soil with 45% clay, 32% silt, 23% sand, 1.1% organic matter and pH 7.95. The most common weeds in the experimental area were common cocklebur (*Xanthium strumarium* L.; 14% of the total) and redroot pigweed (*Amaranthus retroflexus* L.; 65% of the total). Other weeds present included tumble pigweed (*Amaranthus albus* L.), bristly foxtail (*Setaria verticillata* (L.) Beauv.), barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.), junglerice (*Echinochloa colonum* L. Link.) and spiny cocklebur (*Xanthium spinosum* L.).

Soil was prepared according to the local practice for cotton production. Following tillage, fertilizer was applied at 100 kg N ha⁻¹, 44 kg P ha⁻¹ and 83 kg K ha⁻¹ before sowing. Acala-Zeta 2 cotton variety was seeded at a rate of 24 kg ha⁻¹ with a six-row planter to a soil depth of 3.5 cm. At sowing time, phorate (Thimet) was applied at 1.2 kg a.i. ha⁻¹ to protect against wireworms (*Agriotes* spp.). Cotton was sown on April 26 in 1997 and on April 21 in 1998. The crop was irrigated as necessary to sustain growth.

Two of the four experiments were carried out to evaluate the effect of time of weed removal on cotton growth and two other experiments were conducted to determine the influence of time of weed emergence on cotton growth. In the weed removal trials, weeds were allowed to compete with cotton for 3, 5, 7, 9, 11 and 13 weeks after crop emergence (*wace*). Weeds were removed by hand and plots remained weed-free for the duration of the season until harvest. In the weed emergence experiments, plots were maintained weed-free manually for 3, 5, 7, 9, 11 and 13 *wace* and then left unweeded for the rest of the growing season. In each experiment, two control treatments were included: a season-long weed-free treatment and a season-long natural infestation of weeds.

The experimental design consisted of a randomized complete block with four replications for each treatment. Each plot consisted of six cotton rows (95 cm apart), 6 m long. The adjacent outer two rows of each plot were used as guard rows.

In all trials, height and biomass of cotton plants were determined at the time of each weed removal or emergence. Four cotton plants were harvested at ground level from a

35-cm-long row in each plot. A central area of two cotton rows \times 2.5-m long was left undisturbed for the final yield harvest assessments. Number of squares on cotton plants was recorded at 11 and 13 *wace*. All cotton assessments were performed on the central two rows of each plot. At harvest (22 *wace*), cotton was hand-harvested from the plants in the two central rows (2 rows \times 2.5 m long) in each plot and yield of seed cotton was determined.

Assessments of weed density and biomass were performed at each time of removal on samples collected from 1 m² in the two central rows of each plot. Weed density and biomass assessments were also performed near harvest in experiments on weed emergence time. At each assessment, plants of each weed species separately were cut at ground level, measured, dried at 70°C for 48 h, and dry biomass was determined.

Cotton and weed data for weed removal or weed emergence experiments were subjected to separate analyses of variance (ANOVA) for each growing season. Then, the treatment means were regressed against time (*wace*) in order to find the best regression equation that describes the relationship between cotton growth parameters and weed removal or emergence time, as well as between weed biomass and time (*wace*). In these regression equations, the cotton or weed parameter was the dependent variable (*y*) and the time (*wace*) the independent variable (*x*). The equation with the highest coefficient of determination was (*r*²) value was judged to be the most appropriate.

RESULTS AND DISCUSSION

Time of weed removal Height, biomass, square number and yield of cotton plants grown with weeds were reduced with prolonged delays in weed removal in both 1997 and 1998. However, the impact of weeds on cotton growth was not proportional with time (Table 1). The reduction of these growth parameters was greater in cotton plants grown during 1997 than during 1998, mainly because more weeds were present in 1997.

TABLE 1. Effect of weed removal time on height (cm), biomass (g plant⁻¹), square (number plant⁻¹) and yield (% of weed-free) losses of cotton plants grown in 1997 and 1998

Cotton	Weeks after crop emergence						
	0	3	5	7	9	11	13
<i>1997</i>							
Height	70.9	66.8	49.8	29.1	22.3	18.9	20.6
Biomass	43.5	38.0	21.4	4.5	1.2	0.8	0.6
Squares	18.2	16.4	10.2	3.1	0.1	0	0.1
Yield	0.0	8.0	13.0	70.0	96.0	100.0	100.0
<i>1998</i>							
Height	60.1	59.5	54.8	49.1	47.3	45.3	42.5
Biomass	35.0	32.6	25.0	18.0	13.1	12.5	11.4
Squares	12.7	12.4	10.5	8.3	6.3	5.4	5.0
Yield	0.0	13.0	23.0	55.0	81.0	87.0	100.0

Total weed biomass in both growing seasons increased with increasing time of weed removal, but this increase was not proportional with time (Table 2). Weed biomass in 1997 was 40% higher than in 1998. Weed density counts in all plots showed that the mean total weed density ranged from 195 to 280 plants m⁻².

The lack of cotton height reduction in plots where weeds were present for 3–5 *wace* (Table 1) is in agreement with results obtained by others (3,7). Also, the cotton height

reduction due to weed competition for 5–11 *wace* agrees with the findings of other workers (9,16,17).

The reduced cotton biomass with increasing duration of weed presence (Table 1) is in agreement with the findings of Bararpour *et al.* (2) and of Oosterhuis and Zhao (15). The significant reduction on cotton biomass at the early growth stages was expected, as a result of the faster plant growth rate of *X. strumarium* L., *Amaranthus* spp. and *S. verticillata*. During the first 3–4 weeks, these weed plants grew faster, became taller than cotton plants, and maintained that growth throughout the growing season. This resulted in a reduction of cotton plants' photosynthetic ability, as well as of growth and biomass accumulation rate. Keeley and Thullen (7) reported that competition for light during the early growth stages is more detrimental to cotton growth than competition for moisture and nutrients.

The number of cotton squares was also reduced by the presence of weeds for the first 5 *wace* (Table 1). This result is in agreement with Byrd and Coble (4), who found a significant reduction in cotton squares due to weed interference during the early growth stages.

Cotton yield in weed-free plots was higher (3900 kg ha⁻¹) in 1998 than in 1997 (2850 kg ha⁻¹). However, in competition with weeds for the first 3 weeks, yield of cotton plants in 1997 and 1998 was reduced significantly, by 8% and 13%, respectively, in comparison with that of weed-free control (Table 1). These results are in contrast with those of Aldrich (1), who found no yield reduction due to weed competition for the same period. These differences, according to Keeley and Thullen (10), could be attributed to cotton cultivar, agricultural practices, weed species, weed density, soil type, soil fertility, and soil moisture. The lack of beneficial effect on yield due to weed removal at any time later than 11 or 13 *wace* in 1997 and 1998, respectively, agrees with the findings of Keeley and Thullen (9). The severe cotton yield loss with increasing time of weed interference from 5 to 9 *wace* is in agreement with the findings of other researchers (2,6,10,14,17).

TABLE 2. Total biomass of weeds (g m⁻²) growing with cotton in 1997 and 1998, as affected by removal or emergence time

Time of Weed:	Weeks after crop emergence						
	0	3	5	7	9	11	13
<i>Removal</i>							
1997	0	100	500	900	1450	2000	2400
1998	0	40	360	560	1080	1160	1440
<i>Emergence</i>							
1997	2400	1650	1050	650	470	200	50
1998	1440	1340	850	400	320	120	40

The quadratic equation ($y=a+bx+cx^2$) provided the best fit for the regression of all the above mentioned parameters on time (Table 3). This could be attributed to the above reported lack of linear (proportional) increase of cotton growth with time. The higher slope *b* found for height, biomass, square number and yield of cotton plants grown in 1997 than in 1998 was due to the greater weed competition as a result of the larger biomass recorded in this growing season (Table 2).

The total weed biomass increase with increasing time before weed removal (Table 2) was due to the longer period the weeds grew. However, their density decreased during the same time, due possibly to both interspecific and intraspecific competition among the weed species present at high densities (5). The higher total weed biomass recorded in 1997 than

TABLE 3. Quadratic regression equations and coefficients of determination for the relationship between cotton growth parameters and weed removal time (*wace*)

Cotton	Intercept	Slope <i>b</i>	Slope <i>c</i>	<i>R</i> ²
<i>1997</i>				
Height	76.821	-7.367	0.208	0.92
Biomass	48.146	-7.129	0.254	0.92
Squares	20.276	-2.747	0.084	0.92
Yield loss	-11.438	10.260	-0.056	0.88
<i>1998</i>				
Height	61.376	-1.449	-0.003	0.95
Biomass	37.145	-3.018	0.071	0.94
Squares	13.368	-0.669	-0.002	0.95
Yield loss	-5.339	7.592	0.070	0.96

TABLE 4. Quadratic regression equations and coefficients of determination for the relationship between weed biomass and weed removal or emergence time (*wace*)

Time of Weed:	Intercept	Slope <i>b</i>	Slope <i>c</i>	<i>R</i> ²
<i>Removal</i>				
1997	-78.946	73.884	9.595	0.99
1998	-77.896	72.190	3.789	0.96
<i>Emergence</i>				
1997	2422.800	-316.620	10.371	0.99
1998	1558.000	-164.260	3.279	0.94

in 1998 could be attributed to the higher weed density in the former growing season.

A quadratic equation provided the best fit for the regression of total weed biomass on time (Table 4). This was due to the lack of linear (proportional) increase of weed growth with time. Slope *b* for weed plants grown in 1997 was similar to that in 1998.

Time of weed emergence Height, biomass, square number and yield of cotton plants increased with increasing duration of the weed-free period in both growing seasons, but their increase was not proportional with time (Table 5). The reduction in these growth parameters was greater in cotton plants grown during 1997 than in 1998.

Total weed biomass in both growing seasons decreased with increasing duration of the weed-free period (Table 2). Weed density during the same period followed a similar trend

TABLE 5. Effect of weed emergence time on height (cm), biomass (g plant⁻¹), squares (number plant⁻¹) and yield loss (% of weed-free) of cotton plants grown in 1997 and 1998

Cotton	Weeks after crop emergence						
	0	3	5	7	9	11	13
<i>1997</i>							
Height	16.0	32.4	51.5	55.1	60.5	63.5	71.4
Biomass	0.3	2.4	27.3	28.4	33.8	38.8	41.5
Squares	0.0	1.0	9.6	9.4	13.1	16.0	17.9
Yield loss	100.0	100.0	39.0	26.0	14.0	2.0	0.0
<i>1998</i>							
Height	44.2	50.3	50.7	55.8	58.4	58.9	59.4
Biomass	11.2	14.0	15.5	19.7	27.7	28.7	34.9
Squares	4.1	6.5	7.7	9.4	11.9	12.2	13.0
Yield loss	100.0	88.0	62.0	29.0	18.0	10.0	0.0

TABLE 6. Quadratic regression equations and coefficients of determination for the relationship between cotton growth parameters and weed emergence time (*wace*)

Cotton	Intercept	Slope <i>b</i>	Slope <i>c</i>	<i>R</i> ²
<i>1997</i>				
Height	15.860	7.338	-0.249	0.98
Biomass	-2.819	5.449	-0.153	0.91
Squares	-0.906	1.668	-0.015	0.94
Yield loss	110.680	-14.059	0.399	0.90
<i>1998</i>				
Height	44.030	2.065	-0.065	0.97
Biomass	10.800	0.802	0.083	0.97
Squares	3.904	0.940	-0.017	0.98
Yield loss	106.890	-11.084	0.200	0.96

to that of weed biomass. Moreover, as noted above (weed removal trial), the total weed biomass in the 1997 growing season was greater than in 1998.

The cotton height and biomass reduction with decreasing duration of the weed-free period (Table 5) is in agreement with results reported by Keeley and Thullen (10), Vencill *et al.* (17) and Bararpour *et al.* (2). The 7–11-week weed-free period required for cotton to avoid height and biomass reduction agrees with results obtained by Murray *et al.* (13). These findings show that the late-germinating weeds compete with the crop less severely than do weeds emerging earlier. Byrd and Coble (4) and Bararpour *et al.* (2) reported that the weeds which emerged during the first 7 weeks after crop emergence, were more competitive and caused a greater decrease in cotton biomass than the weeds which emerged later.

The 11-week weed-free period required for cotton to avoid a significant reduction in square number (Table 5) is in agreement with results reported by Oosterhuis and Zhao (15). The yield of cotton plants grown in plots kept weed-free for 11 weeks during 1997 and 1998, was reduced by 2% and 10%, respectively, in comparison with that produced in 100% weed-free plots (Table 5). The corresponding yield reduction in plots kept weed-free for 3 weeks was 100% and 88%. Cotton yield, in accordance with the other growth parameters, also decreased with decreasing duration of the weed-free period after crop emergence. Again, greater yield reduction was recorded with cotton plants grown in 1997 than in 1998. Additionally, cotton yield reductions were greater where weeds emerged earlier and competed with the crop for longer periods. These results agree with those of Keeley and Thullen (10) and others (2,6,14,17), who found that cotton yield was negatively correlated with the duration of the weed-free period after crop emergence.

A quadratic equation provided the best fit for the regression of all the above mentioned cotton growth parameters over time (Table 6), and for the same reasons as noted for the weed-removal results. Again, slope *b* for height, biomass, square number and yield of cotton plants grown in 1997 was higher than in 1998.

The weed density reduction with increasing duration of the weed-free period was related to species emergence pattern. For example, *X. strumarium* and *Amaranthus* spp., the most common weed species found in these trials, germinate in Greece in April and early May, when cotton is emerging. These weeds contributed an appreciable amount of the weed biomass. Total weed biomass decreased with increasing duration of the weed-free period. This reduction was due to fewer weeds, which emerged later and had a shorter period of growth. All of this reduced their ability to produce biomass in comparison with

weeds that emerged earlier and were allowed to compete with cotton for a longer time.

The quadratic equation provided the best fit for the regression of total weed biomass over time (Table 6), and for similar reasons to those reported for the weed-removal results. Slope *b* for weed plants grown in 1997 was higher than in 1998.

These findings showed clearly that cotton–weed competition starts 3 to 5 *wace*. Thus, weed management inputs should be implemented at that time and must be continued for 11 *wace* in order to avoid a reduction in cotton growth and yield. Weed management in cotton should include one or more of the following: soil-applied herbicides, cultivation, hand weeding, and/or postemergence herbicides for at least 11 weeks to maximize cotton yield potential. Cotton growers in Greece should take into consideration that their postemergence herbicide application (pyrithiobac on non-transgenic cotton; glyphosate, bromoxynil or glufosinate on transgenic cotton) or mechanical means in combination with hand weeding, must be performed within the first 4 weeks after crop emergence, in order to achieve a weed-free environment for optimal cotton growth.

REFERENCES

1. Aldrich, R.J. (1987) Predicting crop yield reductions from weeds. *Weed Technol.* 1:199-206.
2. Bararpour, M.T., Talbert, R.E. and Frans, R.E. (1994) Spotted spurge (*Euphorbia maculata*) interference with cotton (*Gossypium hirsutum*). *Weed Sci.* 42:553-555.
3. Buchanan, G.A. and McLaughlin, R.D. (1975) Influence of nitrogen on weed competition in cotton. *Weed Sci.* 23:324-328.
4. Byrd, J.D. and Coble, H.D. (1991) Interference of common cocklebur (*Xanthium strumarium*) and cotton (*Gossypium hirsutum*). *Weed Technol.* 5:270-278.
5. Chandler, J.M. (1977) Competition of spurred anoda, velvetleaf, prickly sida, and venice mallow in cotton. *Weed Sci.* 25(2):151-158.
6. Smith, D.T., Baker, R.V. and Steel, G.L. (2000) Palmer Amaranth (*Amaranthus palmeri*) impacts on yield, harvesting, and ginning in dry land cotton (*Gossypium hirsutum*). *Weed Technol.* 14:122-126.
7. Keeley, P.E. and Thullen, R.J. (1975) Influence of yellow nutsedge competition on furrow irrigated cotton. *Weed Sci.* 23:171-175.
8. Keeley, P.E. and Thullen, R.J. (1989) Growth and competition of black nightshade (*Solanum nigrum*) and Palmer Amaranth (*Amaranthus palmeri*) with cotton (*Gossypium hirsutum*). *Weed Sci.* 37:326-334.
9. Keeley, P.E. and Thullen, R.J. (1991) Growth and interaction of barnyardgrass (*Echinochloa crus-galli*) with cotton (*Gossypium hirsutum*). *Weed Sci.* 39:369-375.
10. Keeley, P.E. and Thullen, R.J. (1993) Weeds in cotton: Their Biology, Ecology, and Control. *U.S. Dep. Agric. Tech. Bull.* no. 1810.
11. Mercer, K.L., Pawlak, J.A., Murray, D.S., Verhalen, L.M., Riffle, M.S. and McNew, R.W. (1990) Distance-of-Influence of devil's-claw (*Proboscidea louisianica*) on cotton (*Gossypium hirsutum*). *Weed Technol.* 4:87-91.
12. Murray, D.S., Stone, J.F. and Green, J.D. (1988) Soil water relations of silverleaf nightshade (*Solanum elaeagnifolium*) with cotton (*Gossypium hirsutum*). *Weed Sci.* 36:740-746.
13. Murray, D.S., Verhalen, L.M., Riffle, M.S. and Weeks, D.L. (1989) Duration and intensity of unicorn-plant (*Proboscidea louisianica*) interference with cotton (*Gossypium hirsutum*). *Weed Technol.* 3:313-316.
14. Oliver, L.R. and Klingman, T.E. (1994) Influence of cotton (*Gossypium hirsutum*) and soybean (*Glycine max*) planting date on weed interference. *Weed Sci.* 42:61-65.
15. Oosterhuis, D.M. and Zhao, D. (1996) Effects of shade on cotton carbohydrate metabolism and square development. *Proc. Beltwide Cotton Conf. 1996* 2:1237-1238.
16. Vencill, W.K., Giraudo, L.J. and Langdale, G.W. (1992) Response of cotton (*Gossypium hirsutum*) to coastal bermudagrass (*Cynodon dactylon*) density in a no-tillage system. *Weed Sci.* 40:455-459.
17. Vencill, W.K., Giraudo, L.J. and Langdale, G.W. (1993) Soil moisture relations and critical period of *Cynodon dactylon* (L.) Pers. (coastal bermudagrass) competition in conservation tillage cotton (*Gossypium hirsutum* L.). *Weed Res.* 33:89-96.