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Competition of velvetleaf (*Abutilon theophrasti* M.) weed with cotton (*Gossypium hirsutum* L.). Economic damage threshold

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Abstract

The effect of the weed *Abutilon theophrasti* M. (common name: velvetleaf) on the growth of cotton grown in the Guadalquivir Valley, was studied by examining the influence of weed density on growth of the weed and that of cotton. Velvetleaf impeded normal cotton growth caused production losses as a result of the stress the cotton was subjected to. Additionally there was competition among velvet leaf plants at high velvet leaf densities. The influence of velvetleaf density in coexistence with cotton has been also studied evaluating weed effect on the biomass of cotton and its production. Additional determinations included the velvetleaf seed production capacity per unit area and seed production per plant. These determinations were adjusted to hyperbolic, inverse linear and logistic models. Last, the economic damage threshold (EDT) was calculated using the efficiency level in control of velvetleaf in cotton. In this calculation the treatment cost and losses caused by the weed, in the crop, were taken into account. The EDT varied between 0.1-0.5 velvetleaf plant m^{-2}, depending on the control methods used.

Additional key words: competition model, plant density, weed thresholds.

Resumen

Competencia de abutilon (*Abutilon theophrasti* M) en algodón (*Gossipium hirsutum* L). Umbral económico de daño

Se ha estudiado el efecto de *Abutilon theophrasti* M. (nombre común: abutilon) sobre el crecimiento del algodón en el Valle del Guadalquivir, examinando la influencia de la densidad de la mala hierba sobre su propio crecimiento y el del algodón. *Abutilon theophrasti* impidió el crecimiento normal del algodón y causó pérdidas de producción como consecuencia del estrés al que fue sometido. Además, se observó una reacción de competencia intraespecífica bajo condiciones de alta densidad de *A. theophrasti*. También se ha estudiado el efecto de la densidad de la maleza en el seno del algodón sobre su propia biomasa, la del algodón y su producción. Adicionalmente, se determinó la capacidad de producción de semillas de la mala hierba por superficie y la producción de semillas por planta. Estos valores fueron ajustados a modelos hiperbólicos, linear inversa y logística. Por último, se calculó el umbral económico de daños (EDT) utilizando los niveles de eficacia en el control químico de *A. theophrasti* en algodón. También se tuvo en cuenta el coste del tratamiento y las pérdidas de cosecha inducidas por la maleza. El EDT varió entre 0,1 y 0,5 plantas de *A theophrasti* m^{-2} dependiendo de la medida fitosanitaria utilizada en su control.

Palabra clave adicionales: densidad de planta, modelo de competencia, umbral económico de daño.

Introduction

Abutilon theophrasti Medik (common name: velvetleaf) is an annual weed which, like cotton (*Gossypium hirsutum* L.), is a member of the family Malvaceae. For a long time this weed has infested crops of cotton, maize, potato and irrigated sunflower. A few years ago started to invade citrus, peach and asparagus crops, in the Guadalquivir river valley (southern Spain) (Cortés-Martín *et al.,* 1998). Velvetleaf has become a major

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Abbreviations used: DM (dry matter), EDT (economic damage threshold), ETT (economic treatment threshold), EWRS (European Weed Research Society), VTRR (price of transgenic cotton seed).

problem for cotton growers in the region since it was introduced in the early 1980s. Cotton, which accounts for the largest area of crop production in Andalusia, due to its high economic value (Rodríguez-Ocaña and Ruiz-Avilés, 1996), is currently the crop most severely affected by velvetleaf in Andalusia. Velvetleaf has infested *ca.* 32% of the total cotton area cultivated in Andalusia (Cortés-Martín *et al.,* 1998).

Velvetleaf competes with cotton during crop vegetative growth and flowering due to its biomass accumulation, fecundity and reproductive efficiency (Mabry and Wayne, 1997). Velvetleaf seeds take only 15-24 days to ripen (Zanin and Sattin, 1988), and exhibit high viability and long seed bank life (Lueschen and Andersen, 1980). These properties allow them to form persistent soil seed banks with an annual germination ranging from 6.6% (Calvet and Recasens, 1993) to 11% (Blaise *et al.,* 1983).

Velvetleaf is an effective competitor for light (Benvenuti *et al.,* 1994), water (Salisbury and Chandler, 1992) and nutrients (Parris and Bazzaz, 1985) in irrigated crops. Competition for light is the principal source of production losses caused by velvetleaf in various crops (Zanin and Sattin, 1988) and it is highly efficient at utilizing available light to produce dry matter (DM) (Akey *et al.,* 1990). In addition, the small amount of light reaching infested cotton crops reduces their water (Munger and Chandler, 1986; Salisbury and Chandler, 1992) and nutrient use capacity. In contrast, velvetleaf can utilize the increased nutrient concentration to produce more inflorescences and seeds, as well as giving increased vigour to germinating seedlings (Parris and Bazzaz, 1985). Already established crops compete with velvetleaf seedlings that germinate later than the crop, when the crops close their canopy. These velvetleaf seedlings are less competitive and less productive, although they still have reduced transpiration and photosynthesis. Late germinating velvetleaf plants are subject to total shading by the crop, which has the potential to reduce production of velvetleaf DM by up to 40% through a decreased number of fruits plant^{-1}, and seed production by 60% (Benvenuti *et al.,* 1994). In soybean fields, velvetleaf plants can only compete if they emerge simultaneously with the crop plants or up to 2 days later (Bello and Owen, 1986). Production losses as a consequence of competition among velvetleaf and other crops is not constant, and varies in the same crop from one year to another. However; they adjust to functions of different types for each crop. This is a linear adjustment between the percentage of soybean production loss and velvetleaf density (Bauer *et al.,* 1991). In maize fields, however, production losses due to the presence of velvetleaf fit a hyperbolic model with a peak value of 37.2-40% and a loss weed unit^{-1} of 3.5-4.4% (Zanin and Sattin, 1988; Scholes *et al.*, 1995).

Increased velvetleaf density leads to intra-specific competition on growth and decreased (up to 99%) stem diameter, inflorescence length and fruit number (Jordan, 1982). Further; DM production exhibits a strong negative correlation with grain production and total aerial biomass in maize (Czimber *et al.,* 1987). Velvetleaf densities of 20-30 plant m^{-2} resulted in the highest number of viable seeds for reseeding (Zanin and Sattin, 1988) and the weed increased biomass plasticity relative to maize crop (Lindquist and Mortensen, 1997).

Velvetleaf plants are highly competitive and grow rapidly in cropping systems as is evidenced in cotton where the weed is often twice the height of the cotton. Smith *et al.* (1990) found an inverse linear relationship between the amount of DM produced by the weed and cotton lint obtained. They also found that the weed could compete with the crop for up to 95 days after emergence (*i.e.,* until the onset of senescence). According to these authors, the decrease in lint production was correlated with linear increases in velvetleaf height. A study involving an intermediate velvetleaf density (*viz.* 3.2 plant m^{-2}) exposed the mechanism by which the weed interacts with cotton. The mechanism, however, should be further investigated using variable velvetleaf densities with a view to constructing an accurate competition model of use in designing integrated management (Smith *et al.,* 1990). According to Cousens (1987), such a model should be of the rectangular hyperbolic type.

Because velvetleaf is thought to be difficult to eradicate once it has a well-developed soil seed bank (Saavedra *et al.,* 1995), the present work was undertaken to: 1) examine competition of the weed with cotton, 2) establish an economic damage threshold for treating cotton crop infested with the weed.

Material and methods

Competition from velvetleaf

The effect of velvetleaf infestation on cotton crop experiment was conducted in the Guadalquivir valley in 1997 and 1998. Table 1 shows the locations of the

Table 1. Experimental conditions of the study

Site	Los Rosales	Coria del Río
Area	Guadalquivir plains	Plain-to-marshland transition
Location	37°33'12" N; 05°44'48" W	37°18'29" N; 06°02'15" W
Soil texture	Silt loam	Silt clay loam
Sowing date	16/04/97, 21/04/98	14/04/97, 22/04/98
Cotton cultivar	Crema 111	Bravo
Plant density (plant m^{-2})	20	20
Distance between rows (m)	0.95	0.95
Experimental design	Randomized complete block	Randomized complete block
Replications	4	4
Plot size (m^2)	50 (10 × 5)	50 (10 × 5)
Fertilizer rate (kg ha^{-1})	200 N, 52.4 P and 83.0 K	250 N, 65.5 P and 117.1 K
Tearing of plastic cover	7-8/05/97, 12/05/98	12/05/97, 11/05/97
Removal of cover	20/05/97, 19/05/98	12/05/97, 15/05/98
Cotton harvested area (m^2)	10	10
Velvetleaf harvested area (m^2)	10	10

test sites, soil types and typical cultivation practices of the region.

All plots were velvetleaf free at the start of the study. Velvetleaf seed was harvested the previous summer and scarified by heating in a water bath at 70°C for 5 min (Khedir and Roeth, 1981). Seed was sown along the rows simultaneously with the cotton, on April 1997 and 1998 (Table 1). Cotton was sown with a conventional seed drill at the typical sowing depth for the crop (2 cm) at 30 kg ha^{-1} to obtain a density of 20 plant m^{-2}. Velvetleaf seed was hand sown at 60 seed m^{-1} on the soil surface near the cotton seed prior to covering with a plastic, and were subsequently thinned.

The weeds emerged simultaneously with cotton plants. Weed seedlings were thinned at the 2-4 the leaf stage to obtain the infestation densities required to assess competition, namely: 0 (control), 1, 2, 5, 11 and 25 plant m^{-2}. The experimental design was a completely randomized block with six infestation densities and four replicates. Plots were kept free of weeds, other than velvetleaf, throughout using a pre-sowing herbicide (trifluralin) and hand weeding as required. Temperature and rainfall data were obtained from the weather station on each farm (Table 2).

Velvetleaf bolls were collected weekly and at the end of the growing season in all plots. Plant material was oven dried at 70°C for 48 h and weighed. The number and dry weight of bolls from each plot were determined, and so was the seeds per boll after threshing. Finally, the average number of seeds produced m^{-2} and $plant^{-1}$, were calculated to estimate the re-infestation capacity of the weed. The data obtained for each infestation level was used to determine the following regressions:

a) Velvetleaf density (plant m^{-2}) and total aboveground biomass production (kg ha^{-1}) in the cotton field.

b) Cotton production (kg ha^{-1}) and weed infestation density (plant m^{-2}).

Table 2. Mean temperature and rainfall in the Guadalquivir valley over the study period

Month	Temperature (°C)				Rainfall (mm)			
	Los Rosales		Coria del Río		Los Rosales		Coria del Río	
	1997	1998	1997	1998	1997	1998	1997	1998
April	17.2	15.0	20.5	17.8	43.0	6.0	48.0	35.0
May	17.9	18.5	20.6	20.9	23.0	67.0	16.0	85.0
June	20.6	23.2	23.9	25.2	28.0	7.0	29.0	34.0
July	24.1	26.9	26.9	27.5	2.0	0.0	0.0	0.0
August	25.8	26.4	26.7	27.4	0.5	16.0	0.0	0.0
September	25.4	23.0	26.7	25.5	5.0	46.0	42.0	67.0

c) Weed density and percent cotton loss.

d) Weed biomass (kg ha^{-1}) and cotton production (kg ha^{-1}).

e) Weed seed density (seeds m^{-2}) and infestation density (plant m^{-2}) in competition with cotton, and

f) Number of weed seeds $plant^{-1}$ (seeds $plant^{-1}$) and plant density (plant m^{-2}).

These relationships were established from the best fits of the experimental data to appropriate functions available in the software Curve Expert 1.3. The resulting functions, of the hyperbolic, linear or logarithmic type, coincided with those previously reported by Zanin and Sattin (1988).

Economic damage threshold

The economic damage threshold (EDT) or economic treatment threshold (ETT) was determined using data for the two test sites and years. The competition data fitted an equation of the form:

$$y = \mathrm{a}x/[1 + (\mathrm{a}x/\mathrm{b})] \qquad [1]$$

similar to that previously reported by Zanin and Sattin (1988) relating velvetleaf density (x), to crop losses (y), expressed in monetary units relative to the weed-free control for each site and year.

The velvetleaf control measures used to calculate EDT were those providing a weed control efficiency of 87.5-92.7% as per the recommendations of the European Weed Research Society (EWRS) (Cortés-Martín and Castejón-Muñoz, 2004), namely:

A) Pendimethalin at 1 kg a.i. ha^{-1} + fluometuron at 1.25 kg a.i. ha^{-1} during preemergence period plus a postemergence treatment of 0.63 kg a.i. cyanazine ha^{-1}. The mean total efficiency and cost of the treatment was 87.6% and €206.8, respectively.

B) Cyanazine at 1.5 kg ha^{-1} preemergence plus a second application of 0.5 kg ha^{-1} with droppers. The mean total efficiency and cost were 89.1% and €108.18 ha^{-1}, respectively.

C) Trifluralin at 0.72 kg a.i. ha^{-1} applied presowing plus 2.0 l glyphosate ha^{-1} during cotton vegetative growth (0.9 l ha^{-1} at 4 leaves + 1.1 l ha^{-1} at 6 leaves). Mean total efficiency and treatment costs were 89.9% and €212.95 ha^{-1}, including the VTRR (overprice of transgenic cotton seeds) respectively.

D) Trifluralin at 0.5 l ha^{-1} plus fluometuron at 1.0 l ha^{-1} at preemergence period plus two hand-weeding as a standard weed control strategy. The mean total efficiency (Cortés-Martín and Castejón-Muñoz, 2004) and treatment cost were 95% and €263.36 ha^{-1}, respectively.

The EDT was calculated using the efficiency levels to control velvetleaf in cotton fields by chemical weeding (Cortés-Martín *et al.,* 1999) and the range for each treatment cost, in plant m^{-2}, determined by solving a system of equations of crop monetary losses and treatment costs for each site and year.

Results

Competition from velvetleaf

Biomass production of velvetleaf as a competitor with cotton increased with increased weed density (plant m^{-2}) (see Fig. 1). The results fitted a hyperbolic function of the form [1] with determination coefficients of 0.997 for both sites and years, where x is the number of velvetleaf plants m^{-2} and y the amount (in kg) of velvetleaf DM m^{-2}. Best fits were obtained at Coria site, with asymptotic values of:

$$y = 13{,}088.51 - 14{,}265.4 \text{ kg ha}^{-1},$$

This was followed by the Los Rosales site, where:

$$y = 7{,}372.9 - 7{,}777.9 \text{ kg ha}^{-1} \text{ (data not shown).}$$

The most frequent plant densities among those studied, *viz.* 1 and 2 plant m^{-2}, produced 2,000 and 3,000 kg ha^{-1}, respectively.

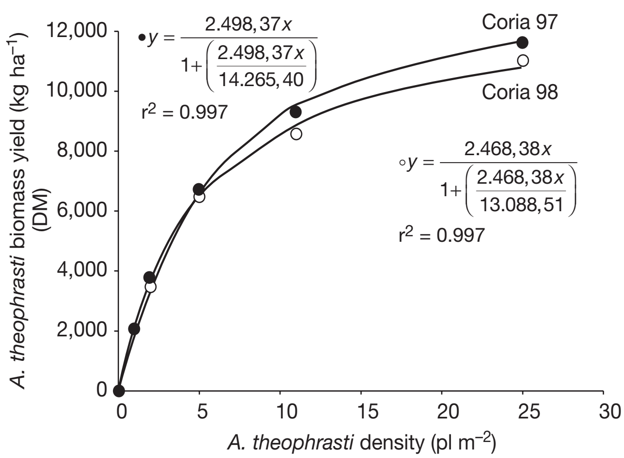

Figure 1. Relationship between *Abutilon theophrasti* density and its dry matter (DM) biomass.

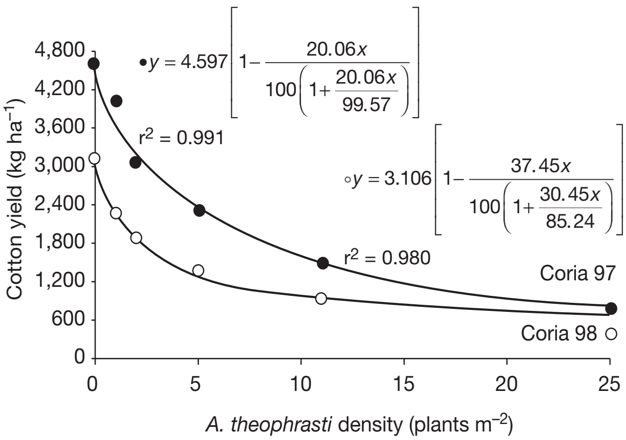

Figure 2. Relationship between *Abutilon theophrasti* density and coton yield.

Cotton yield and velvetleaf density were highly correlated via a decreasing hyperbolic function (Fig. 2) of the form:

$$y = a\{1 - [bx/100(1 + bx/c)]\},$$

where x was the number of velvetleaf plants m^{-2} and y was cotton yield (kg ha^{-1}) with determination coefficients of 0.99. Therefore, the crop profitability threshold was *ca.* 2 velvetleaf plant m^{-2}. Mean cotton production in plots containing one velvetleaf plant m^{-2} was 2,272-4,021 kg ha^{-1} at Coria and 2,269-3,453 kg ha^{-1} at Los Rosales. Production in plots containing 5 weed plants m^{-2} was 1,397-2,325 kg ha^{-1} at Coria and 1,301-2,345 kg ha^{-1} at Los Rosales.

Cotton crop losses due to the presence of the weed conformed to a rectangular hyperbolic equation (Fig. 3a, b) with the form [1], where x was the number of velvetleaf plants m^{-2} and y the percent loss of cotton at a weed density of 1 or 2 plants m^{-2} (which reduced cotton yield by about 20 to 40%). Losses decreased linearly with increased weed biomass; thus, 1 velvetleaf plant m^{-2}, which produced 1,700-2,100 kg of biomass, caused a cotton loss of 513-820 kg ha^{-1}.

The reduction in cotton production was inversely proportional to the biomass of velvetleaf DM, and followed a linear relationship:

$$y = -ax + b$$

where x is velvetleaf biomass (kg ha^{-1} DM) and y cotton production in kg ha^{-1}. Crop production was reduced by 29-39 kg ha^{-1} per 100 kg of velvetleaf ha^{-1} DM at Coria and by 22-32 kg ha^{-1} (DM) at Los Rosales (Fig. 4a, b). If a velvetleaf density of 1 plant m^{-2} produced 1,700-2,100 kg of biomass ha^{-1}, it resulted in a loss of 513-820 kg cotton ha^{-1}.

At both sites the number of velvetleaf seeds produced m^{-2} increased with increased weed density and fitted a hyperbolic function of the form:

$$y = a + b \cdot \ln x \text{ (Fig. 5)}$$

with a determination coefficient of 0.89-0.86.

The number of seeds produced by velvetleaf growing in cotton field decreased with increased weed density following a decreasing logistic function of the form:

$$y = a/(1 - b \cdot e^{cx})$$

with a determination coefficients of 0.995 (see Fig. 6), where x is the number of velvetleaf plants m^{-2} and y seeds plant^{-1}. Thus, a density of 1 and 2 plant m^{-2} produced 5,546 and 4,318 seeds plant^{-1}, respectively. Above 2 velvetleaf plants m^{-2}, seed production fell more than

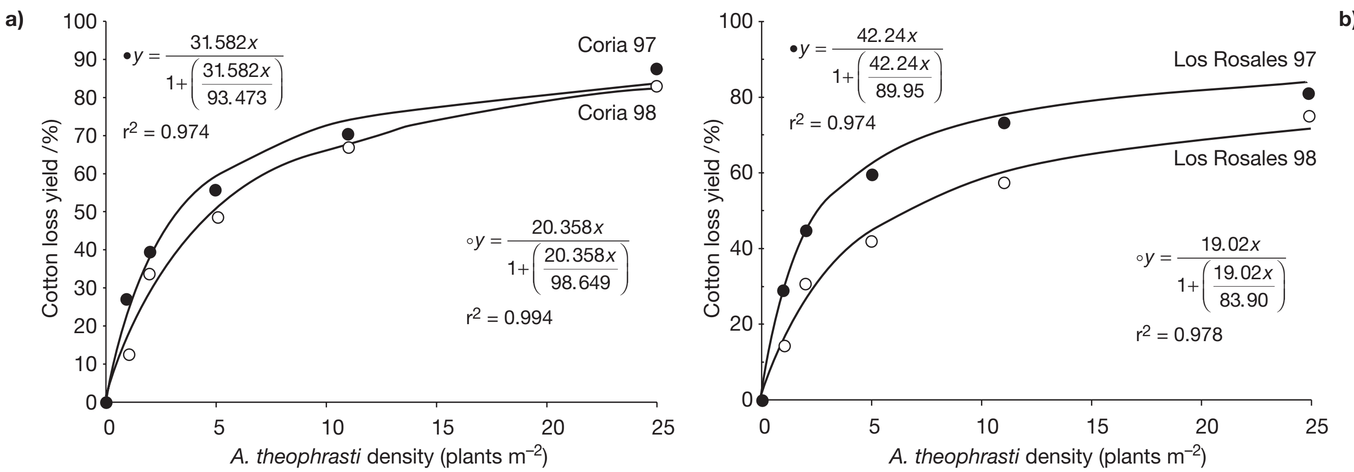

Figure 3. Relationship between cotton loss yield and *Abutilon theophrasti* density at the two sites: a) Coria del Rio, b) Los Rosales.

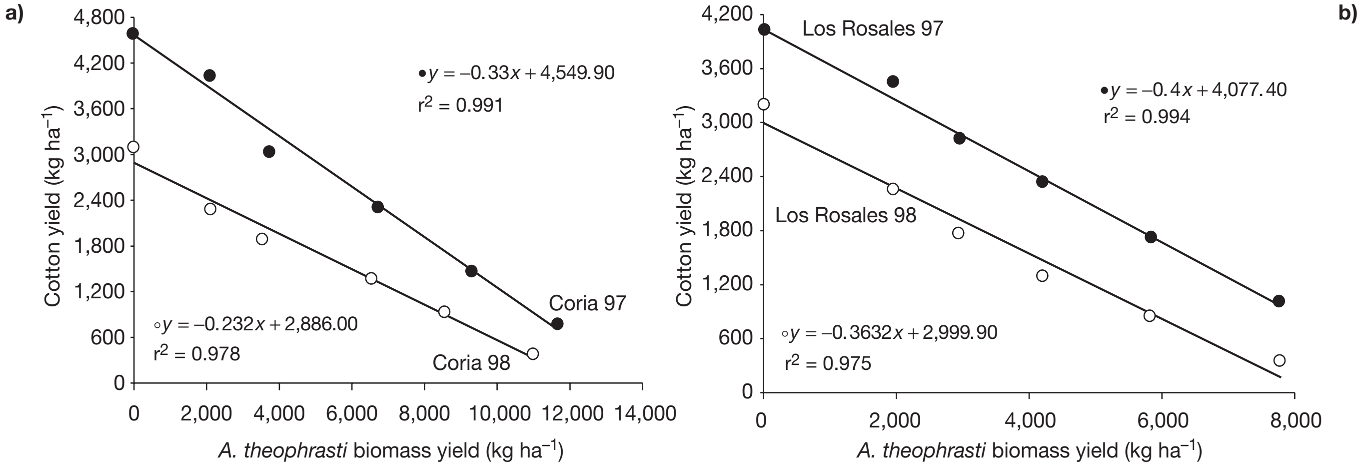

Figure 4. Relationship between cotton yield and *Abutilon theophrasti* biomass at the two sites: a) Coria del Río, b) Los Rosales.

40%. Low velvetleaf densities increased the number of seeds plant^{-1}, but not seeds per unit surface area.

Economic damage threshold

Once the relationship between velvetleaf density (in plant m^{-2}) and yield losses was established, the cotton production loss function, in the presence of velvetleaf, for each site and year was determined.

The EDT was calculated from the monetary loss function for the crop in terms of the velvetleaf density (plant m^{-2}) for each site and year using appropriate crop yield functions. The functions included the cotton production value at zero weed density, the price of cotton in 1999 currency units (*viz.* €0.99 kg^{-1}) and the herbicide control measures for velvetleaf exhibiting an efficiency of 87.5-92.7% –hand-weeding in combination with a standard preemergence treatment herbicide included. The functions obtained, and their statistics are shown in Table 3.

The EDT for velvetleaf in a cotton field subjected to the above control measures ranged from 0.1 to 0.5 plant m^{-2} (*i.e.* 1-5 plant 10 m^{-2}). It fell in the ranges 0.1-0.2, 0.2-0.3, 0.3-0.4 and 0.3-0.5 for treatments A to D, respectively (Table 3).

The cost of velvetleaf control ranged from €108 to €264 ha^{-1} and the price of cotton was €0.90 kg^{-1}.

Discussion

Velvetleaf biomass production in competition with cotton, at high weed densities was higher at Coria than

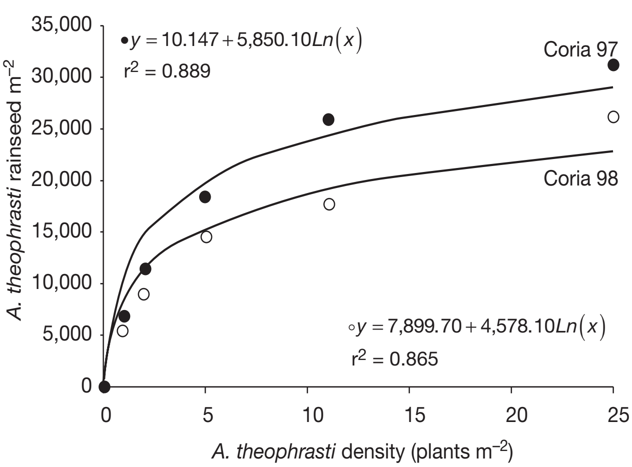

Figure 5. *Abutilon theophrasti* seeds number per square meter as a function of plant density.

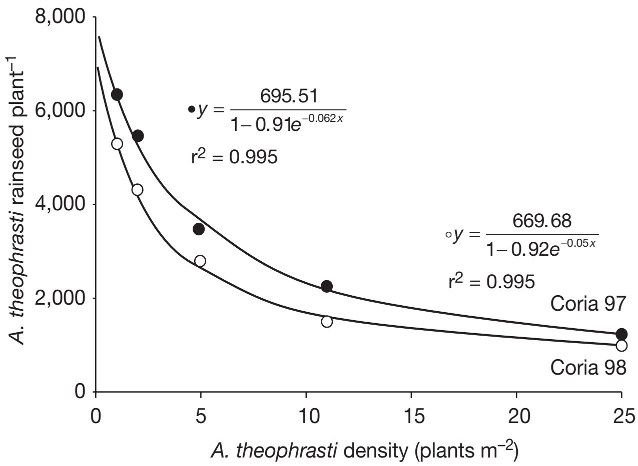

Figure 6. *A. theophrasti* rainseed number/plant according to its density in cotton.

Table 3. Economic damage threshold (x) range as a function of herbicide cost for the treatment of cotton fields

Site and year	Loss function[a]	Tratment[b]			
		A	B	C	D
Coria, 1997	$y = \dfrac{114.33x}{1 + \dfrac{114.33x}{751.64}}$	0.28	0.16	0.33	0.41
Coria, 1998	$y = \dfrac{169.321x}{1 + \dfrac{169.31x}{409.90}}$	0.19	0.11	0.34	0.29
Los Rosales, 1997	$y = \dfrac{202.88x}{1 + \dfrac{202.88x}{432.04}}$	0.16	0.09	0.29	0.24
Los Rosales, 1998	$y = \dfrac{115.48x}{1 + \dfrac{115.48x}{509.32}}$	0.28	0.16	0.33	0.42
	$\Delta EDT(x)$	0.2-0.3	0.1-0.2	0.3-0.4	0.3-0.5

[a] x = ABUTH m^{-2}, y = treatment cost / 100 (inferred from equation Fig. 3). [b] Treatments: A) pendimenthalin + fluometuron + cyanazine, y = 30.04; B) cyanazine + cyanazine, y = 18.00; C) glyphosate + glyphosate, VTRR seeds, y = 35.43; D) fluometuron + trifluralin + 2 hand-weeding operations, y = 43.18.

at Los Rosales. This was probably due to higher soil fertility at the former site. The low cotton production and velvetleaf biomass figures obtained at Los Rosales relative to Coria —where the soil was more productive for cotton and more efficiently fertilized— suggests that velvetleaf production in cotton field is influenced by nutrient availability.

The hyperbolic model obtained from the competitive effect of velvetleaf on cotton yield coincides with that proposed by Zanin and Sattin (1988) for maize losses in presence of velvetleaf, and in broader terms, also with that of Cousens (1987) who said that the equation has two agronomically meaningful parameters which can be used together as indices of competitiveness. On the other hand, the linear relationship obtained by the effect of velvetleaf biomass on cotton production is consistent with the results of Czimber *et al.* (1987).

The function obtained when the evolution of velvetleaf seed number produced m^{-2} was studied with respect to increased weed density differs from the function $y = a + b \cdot \ln(x\text{-}cx^2)$, reported by Zanin and Sattin (1988). The results presented here, and theirs, can be ascribed to their calculations including production values obtained at much higher seed densities (up to 80 plants m^{-2}). Such high weed densities are unlikely for cotton fields as they differ markedly from those found in naturally infested fields. Specifically, the velvetleaf seed density obtained at a 5 plant m^{-2} ranged from 13,000 to 14,000 seeds m^{-2} at Los Rosales and from 15,000 to 19,000 seeds m^{-2} at Coria. These densities are much higher than those of Zanin and Sattin (1988), who found seed production per unit surface area did not increase indefinitely with increased weed density. They also found that seed production declined when weed density was above 30 plant m^{-2} (from 40,000 to 30,000 at 80 plant m^{-2}); this suggests that the reproductive plasticity of velvetleaf facilitates adaptation of the weed to variable cropping conditions (Thompson and Grime, 1979).

The EDT values presented here are lower than those obtained in maize by Zanin and Sattin (1988) (0.3-2.5 plant m^{-2}), and Sattin *et al.* (1992) (0.3-1.7 plant m^{-2}), and in soybean by Scholes *et al.* (1995) (4.3 plant m^{-2}), as a result of increased velvetleaf competition with cotton relative to these crops. Velvetleaf shades cotton plants as it grows and therefore strongly competes with them for light.

Some authors have deemed the use of EDT inappropriate on the grounds that small numbers of plants may restrict production of subsequent crops unless their populations are maintained in a balanced condition. According to McDonald and Riha (1999), EDT should not be used in the integral management of this weed in maize fields; in this respect, they agree with Sattin *et al.* (1992) that, below the EDT level, the cost of weed control exceeds crop losses avoided. The potential problems posed by seeds from uncontrolled velvetleaf individuals should be avoided by careful hand removal from newly infested fields. One should bear in mind that this weed is highly prolific and produces long-lasting seeds which can form a persistent soil seed bank; also, the weed exhibits high growth and reproductive capacity over long periods and is difficult to control with herbicides in a cotton crop.

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