Phenological and demographic behaviour of an exotic invasive weed in agroecosystems

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Abstract

An experimental work was conducted in Lleida (Spain) aiming to characterise the phenology and to quantify the demographic processes regulating the populations of *Abutilon theophrasti* Medicus in maize fields. Seedling emergence started a few days after crop sowing in early May and continued during two more months. The vegetative phase was very long due to the late seeding emergence; these later emerged plants showed a slower development, and many of them did not reach the fertility stage. A flowering peak was observed 12 weeks after emergence in late July, and fruit dehiscence and seed setting started in mid August, several weeks before crop harvest. Four different cohorts were identified, and two main peaks of emergence were determined 21 and 49 days after crop sowing nearest related with field irrigation. A functional logarithmic relationship between cumulative growing degree-days (GDD) and cumulative emergence was also described. The resulting demographic diagram reflects greater values relating to seedling survival for May cohorts (90.2 vs 7.9%), to fertility (100 vs 75%) and to fecundity (3774 vs 92 seeds pl^{-1}) than those determined for the June cohorts. The late emerged plants are subjected to a high density and are strongly affected by light competition, and their reproductive phase initiation delay is of about 10–20 days. In an assay conducted in Petri dishes, the seeds provided from plants emerged earlier were found more vigorous and germinated more than those from late emerged plants, which seem to be affected by incomplete fruit and seed ripening. Following the crop cycle without any weed control, the population rate increase was about 21.2. These values explain the high invasion capacity of this weed in the local summer irrigated fields, which consists in assuring their presence through a persistent soil seed bank and increasing the probability to spread to other fields.

Introduction

Most of the weeds in arable crops show a clear adaptation to the cultural techniques. This enables them to tolerate the proposed control strategies such as tillage, mowing, crop rotations, fallow, herbicides. The efficacy of any of these techniques therefore requires a detailed knowledge of the weed species' biology, especially referring to the phenological and demographic behaviour. The detection of the critical cycle phase, during which the main demographic regulation takes place, allows the identification of the most appropriate moment for the control method. This also allows the estimation of the expected economic benefit of weed control at short term taking into account the costs of these techniques and the infestation degree of the weed species. Each infestation situation together with the expected objectives define the correct control strategy: prevention, contention, reduction or eradication (Fernández Quintanilla 1992). The

main aspects affecting this decision are on the one hand the economic value of the crop and on the other hand the biological behaviour of the weed. The assessment of this latter aspect is generally complex as besides the degree of harm caused by the weed species other phenologial and demographic parameters are considered. The definition of a control strategy of an exotic weed is urgent and necessary but presents an additional difficulty due to the lack of information of the biological behaviour in the new geographical area and agro-ecosystem. A clear example of this situation occurred with the presence and expansion of *Abutilon theophrasti* Medicus (velvetleaf) during the 1980s in the irrigated area of Aragon and Catalonia (northeastern Spain) (Zaragoza 1982; Izquierdo 1986). Even if its presence in Spain, more concrete, in Catalonia, had been quoted several times since the XIX century as a transitory weed (Casasayas and Masalles 1981; Casasayas 1989), its invasive behaviour was not detected until the 1980s when the weed was introduced infesting maize, sorghum and soyabean imported from the USA.

This invasive process was also observed more or less at the same time in Holland, Italy and France (Häfliger 1979; Cantele et al. 1987). In Spain, the presence of *A. theophrasti* as an infesting weed started in the irrigated area of the Urgell (Lleida) where it established itself with success in the maize fields showing a great capacity of adaptation and competition. The economic losses in these first years were especially important not only due to the damage caused by the weed but also due to the lack of selective herbicides to control it (Izquierdo 1986). In 1991, around 10,000 ha of maize were affected corresponding to 44% of the cultivated maize area. This shows that the expansion is up to sixfold higher than the one observed seven years before (Calvet and Recasens 1993).

Spreading of *A. theophrasti* in crop fields in Catalonia presumably occurs through the joint harvest of weed seeds with the corn, its posterior incorporation in clamp, which is then spread as a caw manure on other fields (Izquierdo 1986). The survival capacity of these seeds in maize silage and in slurry is well known, and a similar weed spread mechanism was observed in Holland (Elema et al. 1990; Bloemhard et al. 1992).

A. theophrasti is a summer annual C_3 weed with rapid growth and high photosynthetic rates

(Regnier et al. 1988). Control is difficult due to the extremely long-living seeds (Egley and Chander 1983; Lueschen et al. 1993), which exhibit hardseededness (Horowitz and Taylorson 1984). Velvetleaf is an excellent competitor due to its rapid root growth compared to other weed species and due to its allelopathic effects on crop plants (Warwick and Black 1986). The species exhibits characteristic genetic traits of colonizers, including polyploidy, self-fertilization, and high levels of population differentiation (Warwick 1990; Warwick and Black 1986).

A better understanding of the phenological and demographic behaviour of *A. theophrasti* weed populations in Mediterranean crop fields is needed to optimise the efficacy of a control program. The objectives of this research were to characterise the phenology and demography of an *A. theophrasti* population, including the initial time of emergence, to describe the demography of different cohorts, to find the percentage of germinability of their seeds after production and to calculate the rate of increase of the weed population during a cropping season.

Materials and methods

Site description of the experimental field and general procedures

Field experiments were conducted during 1998, in a 2 ha commercial maize monocrop at El Poal (Lleida, Spain) where a natural infestation of velvetleaf was detected during the last few years. The soil was described as a Fluventic Xerochrepts with 2.9% organic matter and pH 8. The experimental field was chisel plowed in early April prior to the maize sowing, which took place on 26 April. No herbicides were applied in the experimental field plot during the trial. The experimental design consisted of a 10 × 15 m grid, within 15 permanent 1.5 × 1 m squares were randomly selected for the phenological and demographic estimations.

Daily rainfall and maximum and minimum air temperatures were obtained from a meteorology station less than 1 km away from the experimental field. Growing degree days (GDD) were calculated as the mean of the daily minimum and maximum air temperatures minus the 10 °C base

temperature (Gupta 1985; Benvenuti and Macchia 1993).

Phenology

During the crop cycle, the different phenological stages of all the *A. theophrasti* plants found in the different selected squares, were estimated following the BCCH scale (Hess et al. 1997).

Seed bank estimates

Two soil sampling dates were considered for the seed bank study. One was sampled shortly after the crop sowing and the other after the crop harvest. In each case, five soil cores measuring 5 cm in diameter and 20 cm in depth, were collected in a W-shaped pattern from each permanent square. The total soil surface area sampled was 98.72 cm^2 per quadrat. Following Dessaint et al. (1990) and Mulugeta and Stoltenberg (1997), soil core samples were stored for 2 weeks in the PVC cores at 4 °C with the aim to prevent seed germination. Later, the samples were water-cleaned and the organic fraction, containing velvetleaf seeds, placed in aluminium trays in the greenhouse. The samples were surface watered whenever necessary. Weed seedling emergence in the greenhouse was quantified periodically. Three months later, the dormant seeds remaining in the soil samples were identified and separated using a pair of binoculars. During the identification, seeds, which remained firm when pressed by fine tipped nippers, were considered viable. The amount of dormant seeds and greenhouse seedlings were summed up to obtain the viable seed count. The seed number was expressed on the basis of soil surface.

Over-ground demography

Velvetleaf seedling emergence in each square was determined by regular assessments and marking newly emerged seedlings with a coloured wire. The mean time of emergence (MTE) was calculated following the methods of Mulugeta and Stontelberg (1998), where n_i was the number of seedlings at time i and d_i was the number of days from day 0 of the experiment (the crop sowing) to time i.

$$\mathrm{MTE} = \sum n_i d_i \bigg/ \sum n_i$$

A differently coloured wire was used on each approximately weekly sampling date. Velvetleaf plants marked with the same colour belonged to the same cohort. The different initial times of seedling emergence (16 and 26 May, 13 and 20 June) were referred to as cohorts (A1, A2, A3, A4), respectively. The time of emergence was established from the soil disturbance, which happened at the crop sowing. Weed seedlings that had emerged before the crop sowing were removed by hand. Plant density counts were followed until crop harvest, and velvetleaf seed production was measured by hand-harvesting seed capsules from all plants of each quadrat as they matured.

Seed germination in Petri dishes

To estimate the seed germinability, seeds of velvetleaf were collected from the A1 and A2 cohorts, only, as insufficient seeds were obtained from the other two cohorts. Twenty seeds of each cohort were placed on filter paper in a 9 cm diameter plastic Petri dish. The seeds were watered daily with 4 ml of distilled water and maintained in a growth chamber at 12–24 °C with a 12 h photoperiod. Germination of seeds with a protruded radicle of seed length or greater were counted under a fluorescent lamp. Seed germination was determined daily for two weeks after exposure to water. Germinated seeds were removed from the Petri dishes with nippers and then counted. The experiment was conducted in a completely randomised design with 20 replications.

Statistical analysis

Cumulative emergence data of velvetleaf were analysed by least-squares regression. The functional relationship between cumulative emergence and cumulative GDD was determined. Data of soil seed bank, seedling emergence on quadrats and seed germination in Petri dishes were analysed using the ANOVA procedure, and the differences between soil sampling time or cohorts were determined using the Fisher Protected LSD test

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Results and discussion

Phenology

A. theophrasti seedling emergence started in less than two weeks after crop sowing (early May) and continued for two months until mid June (Table 1). The vegetative development phase characterized by the appearance of leaves and buds, stem elongation and of the lateral branches is normally very long so that a low percentage of plants were still at this stage even in mid September. This prolongation of the vegetative phase is due to the presence of plants, which survive until the end of summer without reaching the fertility stage. The vegetative phase lasted a little longer than two months for the first germinating plants in May even if it was not rare to observe still a low percentage of vegetative plants in August. Flowering started at the beginning of June and continued until mid-September. A flowering peak occurred 12 weeks after emergence corresponding to late July even if this maximum was not very evident due to the long lasting flowering phase. However, maximum flowering percentages were observed between mid July and mid August. Fruit dehiscence and seed setting started in mid August and continued during autumn until maize harvest. At this moment, a bit more than half of the population was already dying off. This phenological gradient means that during the summer, plants at most of the development stages can be found within the same population.

The phenological behaviour of this weed species in the present trial has been found to be similar to the one observed in the fields of southern and central USA (Hartzler et al. 1999) but a bit earlier than the one observed in eastern Canada and northern USA (Warwick and Black 1988) where the flowering starts from late August to September and seed setting occurs from September to October. On the other hand, compared with the observation made in Italy (Cantele et al. 1987; Viggiani 1995), the present population shows a slight phenological delay, especially referring to the beginning of emergence. These

Table 1. Percentage of plants of *Abutilon theophrasti* at each phenological stage during the crop season.

Date	d.a.s[b]	Phenological stages[a]							
		10	20	30	40	50–60	70	80	90
26 April	0								
9 May	13	100							
16 May	20	98	2						
23 May	27	81	19						
30 May	34	3	96	1					
6 June	41	1	52	47					
13 June	48	41	1	58					
20 June	55	20	26	54					
1 July	66		40	49	11				
5 July	70		37	50	9	3	1		
13 July	78		33	34	19	9	4		
20 July	85		28	27	2	15	8		
27 July	92		15	28	23	18	16		
3 August	99		5	24	26	13	32		
7 August	103		3	24	17	14	42		
14 August	110		1	25	11	19	44		
21 August	117		1	10	8	15	50	16	
31 August	127			5	4	6	35	49	
7 September	134			3	2	3	27	65	
14 September	141			1	1	3	17	78	
21 September	148					3	7	86	4
30 September	157						6	38	56

[a] Phenological stages: 0, germination; 10, emergence; 20, leaf and shoot development; 30, stem elongation; 40, side shoot development; 50, flowerbud development; 60, flowering; 70, fruit development; 80, seed maturity; 90, dying off.
[b] Days after crop sowing.

geographical variations in the phenological behaviour of *A. theophrasti* can be considered as normal due to the climatic variability of the compared environments on the one hand, and on the other hand, the type of crop and variety can be sown at different moments, which can oscillate within more than 4 weeks inside the same region. Besides the presence of this weed species in other Spanish areas, especially in maize and cotton fields of southern Spain (Andalucía) (Cortés et al. 1998), no phenological data are available from these populations, which would allow the analysis of possible differences between them.

In this species, flowering and seed production showed a short-day photoperiodic response (Sato et al. 1994), and its competitive ability could be influenced by the daylength. However, Steinmaus and Norris (2002) indicated that velvetleaf had a range of growth responses to a variety of light availabilities and that it should have little difficulties in becoming fully established in the irrigated agroecosystems of Mediterranean-type regions. From a climate-matching approach, it appears that the Mediterranean climate is a deterrent to the integration of velvetleaf, and that its persistence in the same Mediterranean regions is more closely linked to the use of irrigation in agriculture than to climatic factors (Holt and Boose 2000).

Seedling emergence

Initial *A. theophrasti* emergence occurred at 18 DAS (days after sowing) at the same time as the maize emergence, and reached a first peak at 21 DAS with 53% of the total emergence (Figure 1). Following 3 weeks without emergence, a second emergence event corresponding to approximately 38% of the cumulative emergence occurred 49 DAS, a few days after irrigation. A maximum
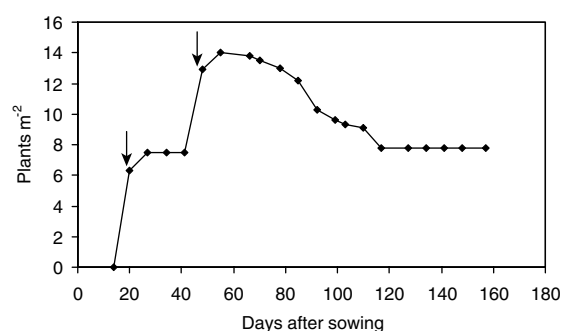

Figure 1. Changes in the total *Abutilon theophrasti* density during the crop cycle. The arrows indicate the field irrigation dates.

seedling density of 14 plants m^{-2} was observed, 56 days after crop sowing. The emergence is well identified by four different cohorts (Table 2). Plant densities of A1 and A3 cohorts were, respectively, 6.6 and 5.8 seedlings m^{-2} and were greater than that of the other cohorts (A2 and A4) which were only 1.2 and 1.0 seedlings m^{-2} respectively as estimated.

Similar dates were observed for populations growing in the USA (Cardina and Norquay 1997; Harztler et al. 1999) and Italy (Cantele et al. 1987), with two emergence peaks nearest related with soil humidity caused by rain or field irrigation. Other secondary factors, such as the soil ploughing similar to the one conducted previously in our field, specifically influence the earlier velvetleaf emergence (Mohler and Galdorf 1997). Exposure of seeds to light, improved soil aeration, increased loss of volatile inhibitors from soil and movement of seeds to more favourable germination sites have been suggested as possible causes of increased seed germination and emergence of seedlings (Egley 1986).

A mean time of emergence (MTE) value of 41.4 was estimated, which fits into the range

Table 2. Plant density and cumulative growing degree days (GDD) of four *Abutilon theophrasti* cohorts.

Cohort	Initial time of emergence	Cumulative GDD from crop sowing to weed emergence	Days from crop sowing to emergence time	Plant density at emergence time Pl m^{-2}	Significance[a]
A1	Mid-May (16/5)	120.9	21	6.6	a
A2	Late May (26/5)	204.0	31	1.2	b
A3	Mid-June (13/6)	321.7	49	5.7	a
A4	Late June (20/6)	378.8	56	1.0	b

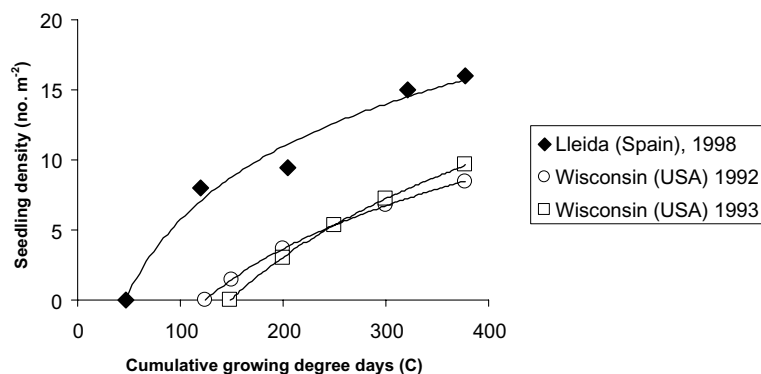[a] Values with different letters are different for $P \leq 0.05$.

Figure 2. The influence of growing degree days (GDD, base temperature 10 °C) on cumulative seedling density of *Abutilon theophrasti* in Lleida (Spain) in comparison with those estimated in Wisconsin (USA) (Mulugeta and Stoltenberg 1997). Cumulative emergence was described by $y = 7.519 \ln x - 28.892$.

(from 30 to 42) observed by Hartzler et al. (1999) for this species during three different cropping seasons.

Pattern emergence

The functional relationship between cumulative GDD and cumulative emergence was described by a logarithmic model (Figure 2). A similar logarithmic function was established by Mulugeta and Stoltenberg (1997), but our data showed an earlier and greater emergence for the same cumulated GDD in comparison with those American populations. In all cases, emergence was nearly complete after 380 GDD.

In accordance with these authors, the emergence length of this species appeared to be affected by GDD accumulation and rainfall. In our region, rainfall is very low (<400 mmm year^{-1}), and the summer is the typically driest season of the Mediterranean climate. The higher pattern of emergence of *A. theophrasti* observed in our fields seems to be promoted by the periodic field irrigation which brings the humidity needed for seeds that were in the soil.

Seedling survival

Data on velvetleaf seedling cohort survival are shown in Table 3. In the first cohort (A1), which showed a greater seedling density, a 50% mortality was observed. This cohort showed a greater plant density at crop harvest (4 plants m^{-2}). The greater survival (74%) of cohort A2 does not correspond to a significant adult plant density because a small number of seedlings emerged. Only 10% of the plants from cohort A3 reached maturity, and there was no plant survival was detected from the A4 cohort. At harvest time, the final plant density was mainly represented by the first cohort A1 with a 71%. These data show that the survival of velvetleaf in a maize field depended on the seedling emergence moment. A first approach of these results indicated that this survival reduction may be due to interspecific and intraspecific competition. This effect is magnified in the June cohorts, which had more difficult conditions to survive compared to more developed plants. Lindquist (1995) suggested a competition for light so that the late velvetleaf seedlings would be more affected due to a great canopy closure than to the present plant density.

Table 3. Plant density and seed production of four *Abutilon theophrasti* cohorts before crop harvest time.

Cohort	Cumulative GDD between crop sowing to crop harvest	Seedling survival (%)	Plan density at harvest (Pl m^{-2})	Seed production (seeds plant^{-1})	Seed production (seeds m^{-2})
A1	1506.5	50	4.0	5402	513,190
A2	1400.8	74	1.1	2177	43,540
A3	1283.1	10	0.5	92	7452
A4	1225.8	0	0.0	0	0

Seed production

Velvetleaf seed production per plant differs between A1 (5402 seeds plant^{-1}) and A2 (2177 seeds plant^{-1}) and was greater than the production at A3 (92 seeds plant^{-1}) (Table 3). Seed production per unit area did no differ among A1 (513190 seeds m^{-2}) and A2 (43540 seeds m^{-2}). By comparison, Zanin and Sattin (1988) observed an average velvetleaf seed production of 3379 seeds plant^{-1} for Italian populations when grown together with maize. Warwick and Black (1988) indicated a variable fecundity of this species ranging from 700 to 17,000 seeds depending on their origin, field crop or plant size.

As was noted, for this species, by Lindquist et al. (1995), the differences between cohort fecundity would be due to the fact that the earlier emerging plants will have an inherent advantage over later emerging individuals and therefore will be responsible for producing a greater number of seeds. These late emerged plants in a high density of other plants seem to present delayed reproduction and show a lower allocation to reproduction due to competition for light (Mabry and Wayne 1997). Under shady conditions, the plants can show a suppressed growth and seed production (Bello et al. 1995) or a time delay of about 10–20 days for the initiation of reproductive allocations (Steinmaus and Norris 2002).

Seed bank population

There was a large difference between the number of velvetleaf seeds recovered in October (after crop harvest) and the number of seeds found in the seed bank immediately before crop sowing (Table 4). The seed bank at the beginning of the trial had 215 seed m^{-2}. We do not know the amount of surviving seeds during the cropping

Table 4. Soil seed density of *Abutilon theophrasti* before crop sowing and after crop harvest.

	Seeds m^{-2}	Significance[a]
Before crop sowing	215	a
After crop harvest	4567	b

[a] Values with different letters are different for $P \le 0.05$.

cycle, but this figure should not be more than 200 seeds m^{-2}, corresponding to the value of the initial seed bank minus total emerged seeds. However, emergence is only one source of the seed loss from the seed bank and predation, disease, fatal germination corresponding to germination without emergence and seed death should be added. After the seed rain and crop harvest, the seed bank was of 4567 seeds m^{-2}. This value corresponds to a 21-fold increase of the initial seed bank. Despite the fact that these data vary from the trial to the commercial field because no control was done in the experiment, they reflect a part of the species' cycle and specifically the population increase that can be expected. The low initial seed bank density suggests that the present field had been recently infested with *A. theophrasti*. The amount found is similar to that of the velvetleaf seed bank estimated by Cardina and Norquay (1997) in a maize field at a 20 cm depth where only a single year seed production was allowed.

The percentage of seeds in the seed bank that became seedlings, i.e. the emergence rate was 6.5% (data not shown). This value is very similar to the one reported by Lindquist et al. (1995) and 2% higher than those estimated by Pacala and Silander in soybean (1990). This similarity reflects that, in the same season, the emergence of a cohort from the seed bank is independent of the number of previous cohorts, which have previously germinated and seems to be mainly promoted by the field irrigation during the late spring season.

Velvetleaf emergence increases with shallow burial and decreases at greater burial depths (Cantele et al. 1987; Mohler and Galdorf 1997). Although temperature and soil moisture conditions are probably not limiting, germination is rare in seeds buried at more than 10 cm depth (Cardina and Sparrow 1997) so that then an important source of seeds remain dormant. The main fraction of the soil seed bank estimated in October is derived from the seed rain shed by mature plants. During the next season, depending on the soil tillage and on the depth in which the seeds will be placed, the survived seeds will be able to germinate or will continue being dormant. In all cases, a permanent seed bank has been formed, and the weed infestation is guaranteed for several years.

Demographic diagrammatic model

As an annual weed, five demographic processes regulate the population dynamics of *A. theophrasti*: seedling recruitment and survival, seed production, seed dispersal, and seed survival in the soil. A schematic diagram of the annual population dynamics is shown in Figure 3. The boxes represent state variables that can be measured in the field. The valve symbols represent the five demographic processes, each of which may be influenced by a number of factors including competition, predation and migration. In Figure 3, separated data are shown for the two main flux seedling emergence observed: May cohort corresponding to A1 + A2 and June cohort corresponding to A3 + A4. For both monthly cohorts, similar rates of emergence of 3.6% and 3.2%, respectively, were observed, but great differences in seedling survival were registered: 90.2% in the May cohort and 7.9% in the June cohort. These differences are also reflected in the different plant densities. The mortality causes of the youngest cohort have been commented above and are mainly promoted by an interspecific and intraspecific competition for light. In the June cohort, it was also observed that several plants did not reach the fertility stage. The seed production was also very different for the May and June cohorts: 3774 seeds plant^{-1} and only 92 seeds plant^{-1}, respectively. No data on seed exportation with the harvest machinery or about depredation by animals were obtained. The rate of population increase during the crop cycle (Δ) was calculated as the coefficient between both soil seed bank estimates. This value is very high (>21) and shows a vigorous capacity of this species to spread in a new habitat. The absence of herbicide application and the absence of any other weeds in this experience reflect the behaviour of this species in the earlier years of their introduction in Spanish maize fields being capable to compete with the crop and to replace other weeds.
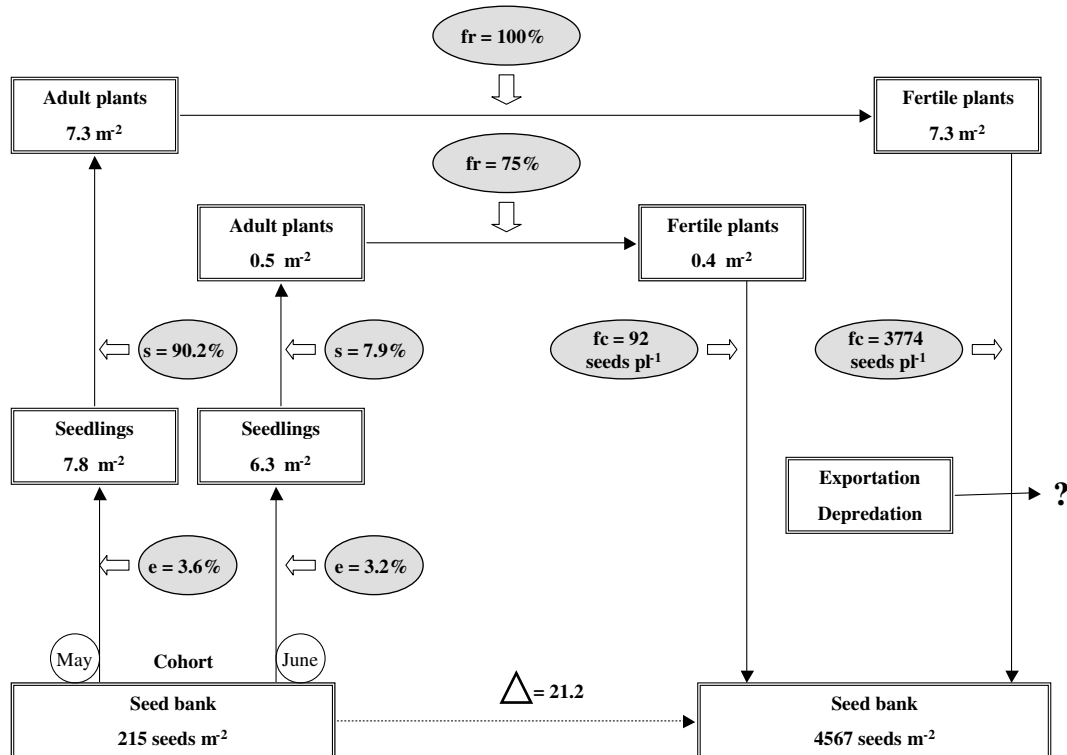

Figure 3. Demographic diagrammatic model for both monthly cohorts (May cohort and June cohort) of *Abutilon theophrasti* population present in a maize crop. e, emergence; s, seedling survival; fr, fertility; fc, fecundity; Δ, rate of population increase during the crop cycle (April–October).

Table 5. Germinability of harvested seeds of *Abutilon theophrasti* for the two earlier emerged cohorts.

Cohort	Emergence time	Germination (%)	Significance[a]
A1	Mid-May (16/5)	81.5	a
A2	Late May (26/5)	38.8	b

[a] Values with different letters are different for $P \leq 0.05$.

Seed germinability

A significant difference between the A1 and A2 cohorts on seed germinability in Petri dishes in the laboratory was found (Table 5). Big differences in the percentage of germinability of seeds from the A1 and A2 cohorts were found (81% and 37%, respectively). These results are in concordance with those of Sato et al. (1994), who noted that seeds of this species produced by earlier germinated plants were heavier and more vigorous than those which germinated later. Two causes can explain these differences: (1) a higher dormancy appears in the seeds produced by late germinated plants or (2) incomplete fruit and seed ripening in the plants occurs in these later cohorts. Velvetleaf shows a typically primary dormancy known as 'hardseededness', which is caused by the seed coat being impermeable to water (Warwick and Black 1986). This seed dormancy is shortened in shaded plants (Bello et al. 1995), but it is unclear whether the decrease in seed dormancy of shaded plants does result from the fact that few seeds have a hard seed coat or if some other dormancy mechanisms are responsible for it. If we understand that our A2 cohort is composed mainly of shaded plants, our results are not in concordance with the expected decrease in dormancy. A possible cause of these differences would be the delayed allocation observed in the late germinating plants and, as a consequence, an incomplete fruit and seed maturity. Steinmaus and Norris (2002) confirm, for this species, a time delay of about 10–20 days for the initiation of reproductive allocation in shaded plants in comparison with plants grown in full sunlight.

Implications for management

The phenological behaviour of *A. theophrasti* in our maize fields do not differ substantially from those registered in Italy or USA by other authors. The extended period of the different phenological stages, and specially the possibility to emerge over a long period of time and their ability to shed seeds several weeks before crop harvest, help to characterize their high phenotypic plasticity. The emergence time of *A. theophrasti* appeared to be affected by GDD accumulation and rainfall (Hartzler et al. 1999). In Mediterranean maize crops, the irrigation replaces the rainfall as a factor favouring the seedling emergence. Two main cohorts were well identified in concordance with time of two relevant agricultural practices: the crop sowing and the next irrigation applied to the field approximately 1 month later. Although other later emergences would be possible, only both these earlier cohorts are determinants in the persistence of the population in further years. The high fecundity levels that have been estimated in this species and the known high longevity of their seeds (Zanin and Sattin 1988) promote a 'persistent seed bank' as was defined by Thompson and Grime (1979). *A theophrasti* is in general more of a problem in monocultures, where one crop is grown year after year, than in rotational sequences, because it has a better chance of building up a seed bank in the soil.

Diverse practices are proposed to sustain effective control of *A. theophrasti* infestations, including crop rotation, multiple herbicide applications and soil tillage (Warwick and Black 1988), but their efficiency is always incomplete. Once the species becomes established in a field, it is very difficult to eradicate it, and the use of density-based weed threshold treatments may not be an appropriate or effective weed control strategy for long term management of the species in maize (Cardina and Norquay 1997). Preventive practices to reduce the chances of its introduction into an infested field should be the best strategy. This prevention will require thorough cleaning of farm equipment that has passed through infested fields. In addition, due to the spread of *A. theophrasti* in our summer irrigated crops with the caw manure, a high level of attention is required for the maize silage used as animal food. Farmers must refuse this forage if the presence of *A. theophrasti* seeds is confirmed.

Further research is needed on the control strategies of this weed. The cost and the difficulty to establish a threshold herbicide treatment,

obligated to enhance the prevention practices if their introduction in the field would be possible, or apply an efficient eradication programme, hand weeding included, if this species is already present in the field.

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