Seasonal emergence of selected summer annual weed species in dependence on soil temperature

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ABSTRACT

This study aimed to describe emergence cycles of selected weed species under Central European conditions in relation to cumulative soil temperatures from the start of the vegetation season. Emergence of *Chenopodium album*, *Echinochloa crus-galli*, *Galinsoga ciliata,* and *Abutilon theophrasti* was observed from March to October during the period 2001–2006 at two locations. The beginning of main field emergence was determined as the day when the sum of effective hour temperatures was achieved, and was detected from the second decade of April to early May for *C. album*, in the second decade of May for *E. crus-galli*, from late April to the beginning of May for *G. ciliata*, and from the end of April to mid-May for *A. theophrasti*. The relationship between cumulative soil surface layer temperature and weed mass field emergence at the beginning of the growing season is very direct (differences ± 7 days) – but only when soil moisture is sufficient. In a drier spring, the beginning of mass field emergence occurs with 1–4 weeks of delay and field emergence is usually slower and protracted.

Keywords: weed biology; emergence; germination; SET; *Chenopodium album*; *Galinsoga ciliate*; *Echinochloa crus-galli*; *Abutilon theophrasti*

Seeds of the majority of weed species persist in soil, creating a soil seed bank (with species-related differences in seed longevity) and emerge in periodical annual cycles (Hakansson 1986, Bouwmeester and Karssen 1992). The cycles of field emergence are specified above, all being influenced by secondary seed dormancy (Popay et al. 1995), which is induced especially by hydrothermal conditions. In general, secondary seed dormancy of spring and summer annual weeds is induced by high soil temperature during summer. Dormant seeds of this group of weeds cannot germinate in late summer and in autumn. On the contrary, low temperatures during winter interrupt the dormancy (Baskin and Baskin 1985). Secondary dormancy of winter annual weeds is induced by low soil temperatures during winter and high soil moisture; hence this weed group does not emerge in spring. High soil temperatures during summer break down seed dormancy of these weeds and they can intensively germinate during late summer and autumn (Baskin and Baskin 1986). Seed dormancy of some weed species is not controlled by soil temperature alone, which is typical for the majority of species from the Asteraceae family (Andersson and Milberg 1996). In temperate regions, soil temperature is probably the most distinct and recognizable factor governing emergence (Forcella et al. 2000). There are numerous articles describing temperature effects on seed germination, whereas descriptions of temperature effects on emergence and initial seedling elongation are less abundant. According to Ekeleme et al. (2005), an increase of field emergence of *Ageratum conyzoides* (a tropical weed) is strongly dependent (r^2 = 0.83) on increasing soil temperature and moisture in the 20 mm soil surface layer.

Weed field emergence is strongly influenced by soil moisture as well as soil aeration – oxygen content (Benvenuti and Macchia 1995). Therefore, weeds emerge in intensive waves after intensive rainfall and after soil cultivation (Doohan et al.

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1991). Soil moisture was rather difficult to measure, and its cumulative effects on dormancy, germination, and emergence are difficult to specify (Forcella et al. 2000). Integration of the cumulative effects of water deficits was encapsulated in the 'hydrotime' concept (Gummerson 1986, Bradford 1995). To date, this has been used primarily to describe seed germination in laboratory settings rather than seedling emergence under field conditions.

However, the process and intensity of weed emergence cycles are influenced also by other environmental factors and by biological characteristic of seeds. A significant characteristic is especially sensitivity to light conditions during germination (Borriss 1967, Jensen 1995). Seeds of many weed species germinate better in light; mainly far-red radiation – ca 650 nm – is important. These positively photoblastic seeds are usually small and emerge in large quantities from the soil surface, where soil moisture is a limiting factor for germination. By contrast, large seeds, which usually do not need light for germination, emerge better from deeper soil layers, with better moisture conditions for germination (Jursík et al. 2002). Therefore weeds that produce positively photoblastic seeds react to soil cultivation by intensive emergence. The aim of this study was to describe emergence cycles of selected weed species under the conditions of Central Europe. We also tested the hypothesis that the start of these weed species' emergence at the beginning of the growing season is dependent on cumulative soil temperature.

MATERIALS AND METHODS

Field trials were carried out in Eastern Bohemia (Parizov) during the period 2001–2006 and in Central Bohemia (Prague) in 2005–2006. Two years before the experiment started, the experimental field had been kept as fallow ground (by tilling and applying glyphosate). More details about the experimental fields are presented in Table 1. The experimental area at each location was 100 m^2. Soil temperature was recorded every hour during the experiment with data-logger (20 mm under the soil surface). Field emergence of *Chenopodium album* (L.), *Echinochloa crus-galli* (L.), *Galinsoga ciliata* (Blake), and *Abutilon theophrasti* (Med.) was monitored during the growing season (from March to October). All emerged weed seedlings were recorded from 1 m^2 (4 replications) in 3–4 week intervals. The experimental plots were cultivated by tiller (0.1 m depth) after each weed counting; removal was done to create favorable conditions for the emergence of new weed seedlings. More frequent weed counting was not possible because the emergence of new weeds after soil tilling was usually slow. Sowing of new weed seeds was carried out by hand after the last recording of weeds (November) and 10 000 seeds/m^2 of every weed species were sown. Seeds were collected from plants growing near the experimental sites.

Laboratory experiments were carried out in climatic chambers in years 2000–2003 using non-dormant seeds of the weed species cited above. Germination proceeded in Petri dishes on 3 water-soaked filter papers. Seeds of *C. album* were separated from tunics that could inhibit germination (Holm et al. 1977). Germination was observed at constant temperatures of 5, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, and 30°C (14/10 h light period, 1000 lx) and was evaluated after 14 days. Germination energy (speed of germination) was studied at constant temperatures of 15, 20, and 30°C (14/10 h light period, 1000 lx) and was evaluated daily. Germinated seeds were removed during the tests. Each treatment (temperature) contained 50 seeds of each weed species in 4 replications and experiments were repeated 3 times (seeds matured in 1999, 2000 and 2001).

The results of laboratory experiments were used for calculating the concrete sum of effective hour temperatures (SET, reported as H) for each weed at which 90% of total germination was achieved, as well as t_{min} and y_{max}. The following formula was used for calculating dependence of the beginning of weed emergence on soil temperature:

$$x_k = \sum_{i=1} y_i$$

Where: k = serial number of the hour and day counted from the start of measurements of hour soil temperature (1 March); soil temperatures at 20 mm under soil surface were lower then t_{min};

Table 1. Description of experimental locations and soil properties

	Prague	Parizov
Altitude (m)	290	380
Average air temperature (°C)	9.0	8.2
Average annual precipitation (mm)	500	700
Soil type	Chernozem	Cambisol
Content of clay in soil (%)	45	35
Soil pH (KCl)	7.5	6.2

y_i = effective temperature (°C);

$y_i = t_i - t_{\min}$

Where: $t_{\min}$ = minimum soil temperature (°C) needed for germination determined under laboratory conditions for specific weed species (temperature at which 10% of non-dormant seeds were germinating); t_i = measured hour soil temperature (°C); when $t_i < t_{\min}$, then $y_i = 0$); and $y_{\max}$ = maximum effective soil temperature (°C) which evokes increasing germination energy as determined in laboratory conditions for specific weed species; when $y_i > y_{\max}$, then $y_i = y_{\max}$.

The beginning of main field emergence was designated by the value of the last serial number (k) for which x_k > SET was first accepted.

Differences in emergence rate (number of weed seedlings) among periods of the growing season (May, June, July, August, September) were statistically evaluated by the Statgraphics Plus software-package using analysis of variance. The contrasts between treatments were tested by the Tukey HSD test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

The results of laboratory experiments were used for calculating $t_{\min}$, $y_{\max}$, and SET (Table 2). Detailed results of laboratory experiments are presented in Jursík et al. (2003). Days when SETs were achieved for tested weeds in all monitored years are shown in Table 3.

Table 2. Values of SET (sum of effective hour temperatures), $t_{\min}$ and $y_{\max}$ for studied weed species based on results of laboratory experiments

Weeds	SET (°H)	$t_{\min}$	$y_{\max}$
		(°C)	
G. ciliata	780	10	21
C. album	1600	8	20
E. crus-galli	1940	14	31
A. theophrasti	1800	8	28

Chenopodium album. Depending on soil temperature (20 mm under soil surface), the start of main field emergence of *C. album* occurred from the second decade of April to early May (Table 3). Only in Prague in 2005, which was a combination of a more arid location and very dry spring, the beginning of main field emergence occurred in the middle of May (Tables 4 and 5). The beginnings of main field emergence corresponded with dates of achieving SET (± 7 days). Only in 2005 (Prague) SET was achieved 2 weeks before main field emergence (extremely dry spring), although, according to Berés (1993), seeds of *C. album* germinate well also under water stress.

Subsequently, field emergence of *C. album* decreased significantly during June. Minimum field emergence was recorded in July but there were significant differences among experimental years. A certain increase of field emergence was recorded during August and September, with distinct differences among experimental years. This second wave of field emergence was significantly less intensive than the spring wave (Table 6) and the increase of emergence was not statistically significant ($\alpha = 0.05$). Seasonal field emergence cycles of *C. album* were similar at both locations during all experimental years (Figure 1). Similar seasonal cycles of field emergence for *C. album* were observed also by Roberts and Neilson (1980) and Grundy (2002).

Echinochloa crus-galli. The start of main field emergence for *E. crus-galli* occurred most often during the second decade of May (11–22 May), depending on soil temperature (20 mm beneath soil surface). The beginning of main field emergence corresponded with the date of achieving SET

Table 3. Real dates of achieving SET (measured 20 mm under soil surface) for monitored weeds and differences of real time for beginning of main field emergence (days)

Weeds	Parizov					Prague	
	2001	2002	2003	2005	2006	2005	2006
G. ciliata	01.05/0	24.04/–3	19.04/+14	14.04/+32	24.04/+12	–	–
C. album	03.05/–2	26.04/–4	25.04/+5	17.04/+7	27.04/+6	01.05/+14	26.04/0
E. crus-galli	24.05/–4	13.05/–2	08.05/+14	15.05/+7	13.05/+7	13.05/+10	08.05/+3
A. theophrasti	–	–	–	–	–	02.05/+13	25.04/+1

Table 4. Monthly precipitation totals at both locations (mm)

Month	Parizov					Prague	
	2001	2002	2003	2005	2006	2005	2006
January	31.0	17.7	39.1	34.8	37.1	29.1	8.3
February	30.1	56.6	3.8	46.9	22.7	38.4	21.1
March	37.7	15.6	8.0	13.1	67.0	12.2	37.8
April	77.0	39.7	38.7	37.1	44.7	13.8	58.3
May	98.3	36.4	96.9	79.8	89.7	82.6	97.0
June	94.5	88.8	14.6	30.6	97.3	65.2	58.9
July	113.3	109.8	119.3	165.3	22.7	124.9	28.7
August	116.8	155.3	47.0	113.2	147.7	55.1	92.4
September	105.9	74.1	36.3	38.8	4.1	29.4	10.7
October	29.2	67.7	47.3	9.7	45.6	10.9	28.5
November	48.7	62.9	13.9	15.1	19.6	11.2	7.3
December	44.2	49.9	45.6	50.5	20.1	26.7	14.2
Total	826.7	774.5	510.5	634.9	617.3	498.5	463.2

(± 7 days). Only in 2003 and 2005 (drier spring, Tables 4 and 5), SET was achieved 7–14 days before the main field emergence at both locations (Table 3). This may have been caused by relatively high sensitivity of *E. crus-galli* seeds to water stress during germination, which is, however, partially compensated by the ability of the seeds to emerge from deeper soil layers (Abdallah 1991).

A rapid decline in the field emergence of *E. crus-galli* was recorded during June (Figure 1) and zero field emergence was recorded from mid-July at both locations in all experimental years (Table 6). However, Torma and Hódi (2002) recorded small waves of field emergence during July in Hungary. Martinková and Honěk (2000) found that a decrease in the germination rate of *E. crus-galli* seeds (in summer) is accelerated by higher soil moisture in July, as expressed by the ratio of the sum of July precipitation and average July temperature.

Galinsoga ciliate. Field emergence of *G. ciliata* was monitored only in Parizov. The start of main field emergence for *G. ciliata* occurred from late April to the beginning of May, depending on soil temperature (20 mm under soil surface). The beginning of main field emergence corresponded with the date of achieving SET (± 3 days) only in 2001 and 2002 (wet spring, Tables 4 and 5). In other experimental years, SET was achieved 12–32 days before main field emergence (Table 3). This could be caused by strong dependence of *G. ciliata* field emergence on soil surface moisture, because seeds of this species show significant positive photoblasticity and germinate especially from the soil surface (Jursík et al. 2003).

Later development in field emergence of *G. ciliata* was also markedly influenced by rainfall during the growing season. Field emergence of *G. ciliata* fluctuated (Figure 1) depending on the amount of

Table 5. P/T ratio (month precipitation totals/month-average temperature) at the beginning of growing seasons at both locations (very dry months was written bolt) (mm/°C)

Month	Parizov					Prague	
	2001	2002	2003	2005	2006	2005	2006
March	7.85	2.79	**1.63**	4.68	30.45	6.1	31.50
April	9.63	4.46	4.66	**3.53**	4.38	**1.36**	6.55

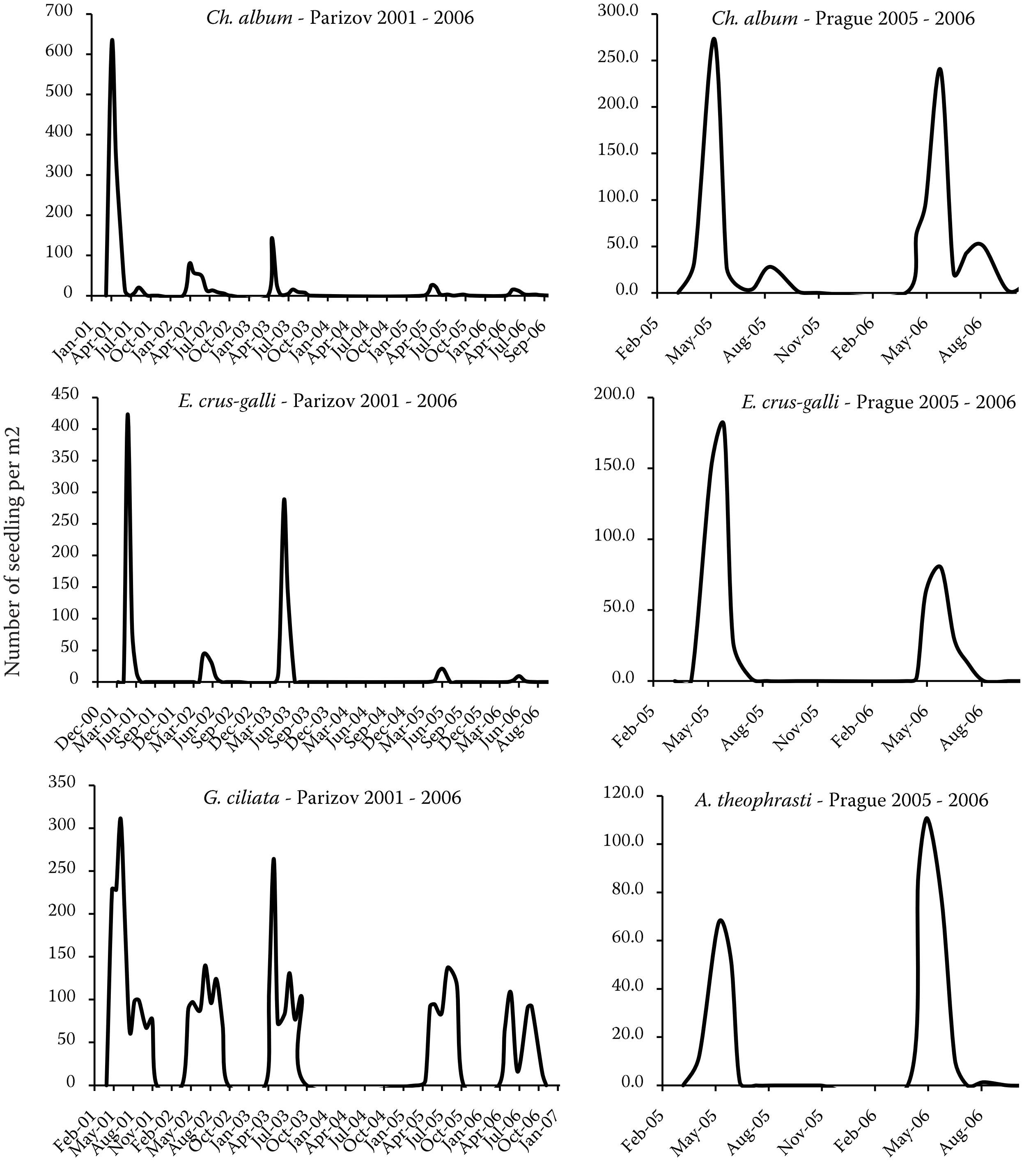

Figure 1. Cycles of field emergence of monitored weeds on both locations

precipitation, but field emergence was relatively high during the entire vegetation period in comparison with other monitored weeds (Table 6).

Abutilon theophrasti. Field emergence of *A. theophrasti* was monitored only in Prague. The start of main field emergence for *A. theophrasti* occurred in the middle of May in 2005 and during the third decade of April in 2006. This relatively high variation was evidently caused by extremely dry conditions in 2005 (Tables 4 and 5). The beginning of main field emergence corresponded with the date of SET achievement only in 2006. In 2005, SET was achieved 12 days before main field emergence (Table 3).

There was a rapid decline in field emergence of *A. theophrasti* (Figure 1) after the first wave of emergence and nearly no seedlings of *A. theophrasti* were found from July (Table 6).

Table 6. Field emergence of monitored weeds during growing season (data from all experimental years at both locations) ANOVA by Tukey HSD

Months	Number of seedlings per m^2			
	G. ciliata	*C. album*	*E. crus-galli*	*A. theophrasti*
May	149.60^a	152.67^a	143.62^a	89.00^a
June	134.93^{ab}	40.00^b	70.67^b	31.33^b
July	77.47^b	9.90^b	3.62^c	0.00^b
August	110.53^{ab}	16.57^b	0.00^c	0.67^b
September	96.27^{ab}	5.71^b	0.00^c	0.00^b
D_{min} ($\alpha = 0.05$)	66.81	58.44	64.63	34.79

In all experimental years and at both locations, the beginning of *C. album* emergence was detected before the beginning of *E. crus-galli* emergence. This is very useful information for the precise timing of weed control in many crops, especially in sugar beet, maize, sunflower, some vegetables, and others which have relatively low competitive ability and need a very long weed-free period (Jursík et al. 2008).

With respect to the results of this work, we can conclude that the relationships described above between cumulative temperature of soil surface layer (expressed as SET) and the beginning of main field emergence of weeds at the beginning of the growing season is very strong (differences in experimental years ± 7 days), but only when sufficient soil moisture is available. Soil moisture is a limiting factor for germination of seeds, and especially for species with seeds germinating mainly from the upper soil layer (0–20 mm). In a drier spring, the beginning of main field emergence is usually achieved with 1–4 weeks delay and the increase of field emergence is usually slower and protracted. This work can be useful for creating a model for predicting cycles of field emergence and for the exact timing of weed control.

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