Phenology of velvetleaf (*Abutilon theophrasti* Medic.) populations grown in northern Germany

Phänologie von Samtpappel (Abutilon theophrasti Medic.)-Populationen in Norddeutschland

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Summary

Velvetleaf, *Abutilon theophrasti* Medic., is an important arable weed worldwide. It is currently not present in the northern regions of Europe, but there are reasons why it may move northwards: 1) The weed has not reached the northern edge of its climatic range, 2) increasing temperatures, caused by climate change, will create more suitable growing conditions in northern areas, or 3) the weed will adapt to cooler habitats. Velvetleaf has an indeterminate growth, meaning that the reproductive output largely depends on the length of the growing season, which is determined by the timing of emergence and seed production. The purposes of this preliminary study were: 1) To evaluate the growth potential of *A. theophrasti* in the Northern German state of Mecklenburg-Vorpommern and 2) to compare the phenology of populations from different European origins to evaluate the degree of adaptation to local climatic conditions.

Forty 5 L pots were buried in the soil flush with the soil surface, 10 velvetleaf seeds of one of four populations from Spain, the Czech Republic, southern Germany or France were seeded in spring 2010 and subsequent emergence was recorded. In summer, plants were thinned to one seedling per pot and subsequent capsule production was recorded until the first frost.

French and Spanish velvetleaf populations germinated earlier, produced capsules later, and tended to produce fewer capsules per plant than did populations from southern Germany or the Czech Republic. In addition, French and Spanish populations had a lower percentage of dormant seeds. These differences are in agreement with observations and predictions made for the northward expansion of velvetleaf in North America.

Velvetleaf could grow and reproduce in northern Germany but further phenological changes, in particular a shorter growing season, a higher reproductive output and a higher level of physical dormancy, are to be expected as adaptations to local climatic conditions.

Keywords: Northward expansion, timing of emergence, timing of reproduction

Zusammenfassung

Die Samtpappel, *Abutilon theophrasti* Medic,. ist weltweit ein wichtiges Ackerunkraut. Zur Zeit kommt es nicht in den nördlichen Regionen Europas vor, aber es gibt Gründe, weshalb es sich in den Norden ausbreiten könnte: 1) Das Unkraut mag seine klimatischen Grenzen im Norden noch nicht erreicht haben, 2) durch steigende Temperaturen, verursacht durch den Klimawandel, könnten sich die nördlichen Gebiete besser zum Wachstum eignen, oder 3) das Unkraut könnte sich an die kälteren Lebensräume anpassen. Das Wachstum der Samtpappel ist indeterminiert, d. h., dass die Vermehrungsrate hauptsächlich von der Dauer der Vegetationsperiode abhängt, welche vom Zeitpunkt der Keimung und der Samenproduktion bestimmt wird. Die Ziele dieser Vorstudie waren: 1) Erfassung des Wachstumspotentials von *A. theophrasti* in Mecklenburg-Vorpommern, Norddeutschland und 2) Vergleich der Phänologie von Populationen verschiedener Herkünfte Europas um die Anpassung an die lokalen Klimabedingungen zu beurteilen.

Vierzig 5 L-Töpfe wurden eben zur Bodenoberfläche eingegraben. Im Frühjahr 2010 wurden je 10 Samtpappelsamen von einer der vier Populationen aus Spanien, der Tschechischen Republik, Süddeutschland oder Frankreich ausgesät und der anschließende Keimungszeitpunkt erhoben. Im Sommer wurde auf einen Sämling pro Topf ausgedünnt und die folgende Fruchtentwicklung wurde bis zum ersten Frost aufgezeichnet.

Die französischen und spanischen Populationen keimten früher, fruchteten später und neigten dazu, weniger Kapseln pro Pflanze auszubilden als die deutschen oder tschechischen Populationen. Darüber hinaus hatten die französischen und spanischen Populationen einen geringeren Anteil an dormanten Samen. Diese Unterschiede stimmen mit den in Nordamerika gemachten Beobachtungen und Vorhersagen zur nördlichen Ausbreitung der Samtpappel überein.

Die Samtpappel könnte sich in Norddeutschland etablieren, doch weitere phänologische Veränderungen, insbesondere eine kürzere Wachstumsperiode, eine höhere Vermehrungsrate und ein höherer Grad der physikalischen Keimruhe können als Anpassungen an die lokalen Klimabedingungen erwartet werden.

Stichwörter: Nördliche Ausbreitung, Zeitlicher Ablauf der Vermehrung, Zeitpunkt der Keimung

1. Introduction

Velvetleaf, *Abutilon theophrasti* Medic., is an important arable weed worldwide. It is present in southern and middle European countries, but not in northern regions. There are three reasons why velvetleaf may move further northward: 1) the weed hasn't reached the northern edge of its climatic range yet because of a slow expansion rate, 2) the weed is at the edge of its climatic range but increasing temperatures, caused by climate change, will make northern areas more suitable to the weed, or 3) the weed is at the edge of its climatic range but can adapt to cooler habitats.

Velvetleaf is on the short-list of species that are expected to exhibit range expansions in North America (CLEMENTS and DITOMMASO, 2011), mainly because of its association with grain maize which cultivation is moving northward thanks to breeding efforts (co-adaptation). Although the weed is already present in many locations, populations are too small to cause economic damage. However, MCDONALD et al. (2009) estimated that the so-called 'damage niche' could advance 200-650 km northward in North America because populations of velvetleaf tend to evolve rapidly. In southern Germany, the weed is mainly associated with sugar beets (MEINLSCHMIDT, 2006).

Weeds have the potential to adapt rapidly to changing environments, either through phenotypic plasticity or evolution, and there is increasing evidence that climate change may be an important driver for these adaptations (e.g., CLEMENTS and DITOMMASO, 2011). *Abutilon theophrasti* grows indeterminately, meaning that the reproductive output largely depends on the length of the growing season. Weed characteristics associated with adaptations under climate change and northward expansion include a high growth rate and a short generation time (CLEMENTS and DITOMMASO, 2011). WARWICK and BLACK (1986) found large differences among populations of velvetleaf in morphometric and life-history traits that were correlated with latitude and climate. They found, for example, a negative correlation between growing degree days (GDD) and the number of capsules per plant or the percentage dormant seeds, and a positive correlation with seed weight, indicating that populations from more northern locations produced more but lighter seeds that were more dormant than those from more southern locations.

Comparing the projected climate for the years 2071-2100 with that for 1961-1990, SCHUCHARDT et al. (2008) predict a 1.5-3.7 °C increase in the average daytime temperature, a decrease in the number of frost days and a 30 % decrease in summer precipitation for Germany. These changes have resulted in a lengthening of the growing season by 0.11-0.49 days per year over the 1951-2000 period (MENZEL et al., 2003). The greatest changes result from the lengthening of the frost-free period. *Abutilon theophrasti* may benefit from these changes.

The purposes of this preliminary study were: 1) To evaluate the growth potential of *A. theophrasti* in the northern German state of Mecklenburg-Vorpommern and 2) to compare the phenology of populations from different European origins to evaluate the degree of adaptation to local climatic conditions.

2. Materials and methods

Seeds of local velvetleaf populations were obtained from Spain (collected: Lleida, 2008), the Czech Republic (Prague, 2008), southern Germany (Dresden, 2003) and France (Dijon, 2006). Seed viability and hardseededness were determined for three samples of 100 seeds of each population (N), using a germination test in 9 cm Petri-dishes lined with moist filter paper at 35/25 °C (14/10 h) for 7 days, followed by a viability stain with triphenyl tetrazolium chloride (0.1 % TTC; 3 ml/dish) at 30 °C for 24 h. Prior to exposure to TTC, the seed coat was carefully cut to allow imbibition. The proportion of viable seeds, P_v, was calculated as $(N-N_d)/N$, with N_d the number of non-viable seeds, identified as non-germinated, non-stained seeds. The proportion of hard-seeded seeds, P_h, was calculated as N_h/N, with

N_h, the number of hard seeds, identified as hard, non-germinated seeds at the end of the germination test but viable when stained with TTC.

In spring 2010, forty 5 L pots were filled with local soil (sandy soil, 2.1-2.2 % organic matter) and buried in the soil flush with the soil surface in a field at the Plant Experimental Station of the University of Rostock (54° 3'42.85''N; 12°5'1.07''E), Mecklenburg-Vorpommern, Germany. Ten velvetleaf seeds of one of the four populations were seeded in ten randomly selected pots on 27 April and subsequent emergence was recorded. The proportion of germinated seeds, P_g, was calculated as $N_g/10$, with N_g the cumulative number of seedlings. Because spring 2010 was very dry, pots were irrigated when required. Pots were fertilized using a granular fertilizer at a rate equivalent to 104 kg N/ha on 5 May. Early May, slug pellets (Matarex, 5 % metaldehyde, 0.02 g/pot) were added twice to protect the weed seedlings from snails and slugs. On 25 June, plants were thinned to one seedling per pot and subsequent capsule production, $\overline{S}$, was recorded until the first frost (6 October 2010). The average date of emergence, $\overline{G}$, and the average date of reproduction, $\overline{R}$, were calculated as a weighted average, with the number of emerged plants and the number of capsules as weights, respectively. The length of the season, L, was estimated as $L=\overline{R}-\overline{G}$. The number of seeds per capsule, $\overline{C}$, was counted for 10 randomly selected capsules per velvetleaf population.

Regression models with a logit link and a binomial variance function allowing for overdispersion (Genstat 11) were used to test for the effect of population origin on P_v, P_h and P_g. Regression models with a log link and a poisson variance function were used to test for the effect of population origin on the total number of capsules per plant, $\overline{S}$, and the number of seeds per capsule, $\overline{C}$. Soil temperature was recorded once per hour at 5 cm depth, using two data loggers (Lascar EL-USB-2). Air temperature and precipitation were obtained from a meteorological station on site (HENNEBERG, 2011).

3. Results

The monthly air temperature at 2 m, soil temperature at 5 cm and precipitation from April-October are summarized in Table 1.

The proportion of viable seeds, P_v, differed significantly between velvetleaf populations ($p = 0.016$; Tab. 2), caused by the fact that P_v of the German population (0.88) was lower than for the other populations. The proportion of hard seeds, P_h, differed significantly between populations ($p < 0.001$), with the lowest value for the Spanish population (0.09), followed by the French population (0.19) and the populations from Germany and the Czech Republic (0.41 and 0.38, respectively; Tab. 2). The proportion of germinated seeds in the field test, P_g, did not differ significantly between velvetleaf populations ($p = 0.494$).

Tab. 1 Monthly minimum and average air temperature at 2 m, cumulative monthly precipitation (after HENNEBERG, 2011), and monthly minimum and average soil temperature at 5 cm for the experimental field at the Plant Experimental Station of the University of Rostock, Mecklenburg-Vorpommern, Germany, from April-October 2010.

Tab. 1 *Monatliche tiefste und mittlere Lufttemperaturen in 2 m Höhe, monatlicher Gesamtniederschlag (nach Henneberg, 2011) und die monatlichen tiefste und mittlere Bodentemperaturen in 5 cm Tiefe für den Zeitraum des Feldversuchs vom April bis Oktober 2011 in der Versuchstation der Universität Rostock, Mecklenburg-Vorpommern, Deutschland.*

	Apr.	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**
Minimum air temperature [°C]	-2.6	-1.9	4.9	7.3	7.6	2.0	-3.3
Average air temperature [°C]	7.4	9.0	14.8	20.5	16.6	12.2	7.7
Precipitation [mm]	12.0	90.7	34.6	15.3	138.5	85.3	47.3
Minimum soil temperature [°C]	7.3*	4.1	10.7	14.5	11.8	8.7	7.4**
Average soil temperature [°C]	13.8*	12.4	18.4	23.8	17.8	13.6	10.9**

* started 27 April at 12:00 h.; ** terminated 6 October at 12:00 h.

Tab. 2 Characterization of four populations of *Abutilon theophrasti* in terms of the proportion of hard seeds (P_h), viable seeds (P_v), germinated seeds in the field trial, P_g, mean emergence date ($\overline{G}$), mean reproduction date ($\overline{R}$), length of the growing season (L), mean capsule production per plant ($\overline{S}$), and the mean number of seeds per capsule ($\overline{C}$). Values within a row followed by the same letter are not significantly different from each other (t-test; $\alpha = 0.05$).

Tab. 2 *Darstellung der vier* Abutilon theophrasti-*Populationen in Bezug auf den Anteil an harten Samen (P_h), lebensfähigen Samen (P_v), gekeimten Samen im Feldversuch (P_g), mittlerem Keimzeitpunkt ($\overline{G}$), mittlerem Vermehrungszeitpunkt ($\overline{R}$), Länge der Vegetationsperiode (L), durchschnittlicher Kapselproduktion pro Pflanze ($\overline{S}$), und der durchschnittlichen Samenanzahl pro Pflanze ($\overline{C}$). Die Werte einer Zeile mit denselben Buchstaben unterscheiden sich nicht signifikant voneinander (t-test; $\alpha = 0{,}05$).*

	***Abutilon theophrasti* origin**			
Parameter	**Germany**	**Czech Republic**	**France**	**Spain**
P_h [mean ± SE]	0.41 ± 0.02 c	0.38 ± 0.04 c	0.19 ± 0.03 b	0.09 ± 0.00 a
P_v [mean ± SE]	0.88 ± 0.04 a	0.94 ± 0.01 ab	0.99 ± 0.01 b	0.99 ± 0.01 b
P_g [mean ± SE]	0.29 ± 0.05	0.27 ± 0.04	0.32 ± 0.07	0.38 ± 0.04
$\overline{G}$ [date]	2-Jun	3-Jun	12-May	22-May
$\overline{R}$ [date]	25-Sep	24-Sep	25-Sep	27-Sep
L [days]	115	113	136	128
$\overline{S}$ [capsules/plant]	14.1 ± 5.1	38.5 ± 10.5	11.5 ± 2.8	22.0 ± 9.6
$\overline{C}$ [seeds/capsule]	30.1 ± 1.8 b	40.9 ± 0.9 b	28.6 ± 2.6 a	37.0 ± 2.2 b

There were subtle differences in the timing of emergence between velvetleaf populations (Fig. 1A), resulting in a 12 days difference in $\overline{G}$ between populations (Tab. 2). Capsule production increased over time (Fig. 1B) and differed between populations, resulting in a three days difference in $\overline{R}$. The length of the growing season, L, was shortest for the population from the Czech Republic (113 days) and longest for the population from France (136 days). Cumulative capsule production, $\overline{S}$, did not differ significantly between populations (p = 0.067), although $\overline{S}$ tended to be higher for the Czech population than for the other populations. Seed production per capsule, $\overline{C}$, was significantly lower for the French population than for the other populations (p = 0.002).

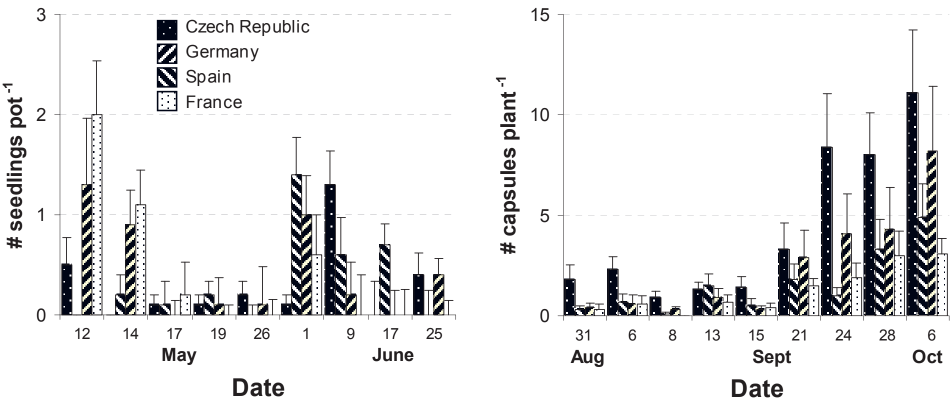

Fig. 1 Seedling emergence (A) and capsule production (B) for *Abutilon theophrasti* originating from the Czech Republic, Germany, Spain, and France and when grown in pots in Rostock, Mecklenburg-Vorpommern, Germany (N =10; mean + SE).

Abb. 1 *Keimlingsentwicklung (A) und Fruchtproduktion (B) von* Abutilon theophrasti-*Populationen aus der Tschechischen Republik, Deutschland, Spanien, und Frankreich kultiviert in Töpfen in Rostock, Mecklenburg-Vorpommern, Deutschland* (N =10; Mittelwert + Standardfehler).

4. Discussion

All four velvetleaf populations, originating from different European countries, successfully emerged, grew and reproduced in northern Germany. This would suggest that the main reason for the absence of *A. theophrasti* from fields in northern Germany is that velvetleaf has not expanded so far north yet. Once in the region, climatic conditions would then not be a constraint and populations could persist. However, that conclusion is premature. Weather conditions in 2010 were favourable for velvetleaf. For example, there was only one day of frost in spring (5 May; -1.9 °C), which occurred before seedling emergence (12 May). Minimum soil temperature was as high as 4 °C (5 May 2010). The first day of frost in autumn occurred on 6 October 2010. Consequently, the growing season was long enough (147 days) for all populations to be able to complete their life cycle and reproduce profusely. The only concession we made to the prevalent climatic conditions was irrigation. Precipitation was 24, 38 and 53 mm below the local long-term average (1976-2008; HENNEBERG, 2011), in April, June and July, respectively. Had irrigation been omitted, most seedlings would have succumbed to drought. For a true evaluation of the growth potential of southern populations of velvetleaf under the climatic conditions in northern Germany, this experiment would have to be repeated over a number of years.

The four velvetleaf populations differed with regard to their phenology and reproductive output. In general, the velvetleaf populations originating from France and Spain had a lower proportion of dormant seeds, germinated earlier and required a longer growing season than did populations from southern Germany or the Czech Republic. This is in agreement with observations by WARWICK and BLACK (1986) and predictions by CLEMENTS and DITOMMASO (2011). Although we did not specifically relate weather data in the four countries of origin to phenological characteristics, it is likely that the observed differences in *A. theophrasti* are adaptations to the local climatic conditions. In regions where a late frost in spring is unlikely, such as north-eastern Spain or mid France, the risks of population failure caused by early emergence and a low proportion of physical dormancy are low, assuming that velvetleaf seedlings are sensitive to frost. However, these risks are much higher in the Czech Republic and southern Germany, where late spring frosts are more likely. This could explain the higher proportion of hardseededness and the later date of emergence.

The Czech population combined the shortest growing season with the highest reproductive output ($\overline{S} \times \overline{C} \approx$1575 seeds/plant), which is also in agreement with WARWICK and BLACK (1986) and CLEMENTS and DITOMMASO (2011), who conducted trials in cooler regions. Additional morphological or physiological adaptations that allow higher seed production must have been involved. These could include a shifted allocation of resources in favour of reproductive organs and leaves, or a better photosynthetic efficiency. However, these growth-related traits were not investigated in this study. The southern German population performed unexpectedly poor in this respect.

Although all four tested velvetleaf populations prospered in 2010, it is unlikely that velvetleaf populations that are currently growing in more southern locations will be able to establish under prevalent climatic conditions in Northern Germany. On the North American continent, however, velvetleaf has shown a remarkable ability to adapt to cooler climates (WARWICK and BLACK, 1986), and we expect the same to happen in Europe. The higher reproductive output, higher proportion of dormant seeds and shorter growing season in populations from the Czech Republic and southern Germany may be features that allow a northward expansion.

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