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Morphological differences between the seedlings and the suckers of *Ailanthus altissima*

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Mit 8 Abbildungen
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Zusammenfassung: Morphologische Unterschiede von Sämlingen und Wurzelsprossen von *Ailanthus altissima*. – In diesem Artikel werden Sämlinge und Wurzelsprosse von *Ailanthus altissima* verglichen. Ausgehend von einer Keimrate von 35 % in einem Keimungstest wurde versucht, eindeutige morphologische Unterschiede zwischen Sämlingen und Wurzelsprossen von *Ailanthus altissima* zu ermitteln. Dies soll dabei helfen, beide Vermehrungstypen voneinander zu unterscheiden, ohne die Pflanzen ausgraben zu müssen. Als ein signifikanter Unterschied stellte sich der Unterschied in der Form der einjährigen Sprossachse dar, welcher bei Sämlingen mehr konisch, bei Wurzelschösslingen mehr zylindrisch ausgebildet ist.

Abstract: In this article, the seedlings and saplings of *Ailanthus altissima* will be compared with one another. The germination test showed a germination rate of 35 %. We tried to establish/determine clear morphological differences between seedlings and root suckers of *Ailanthus altissima* that might be helpful in identifying both propagule types without needing to dig the plants out of the ground. One particularly significant difference between seedlings and suckers that we observed was in the shape of the one-year-old shoots, which were conical in the case of seedlings and cylindrical in the case of suckers.

Keywords: *Ailanthus altissima*, neophyte, alien species, invasion, germination, saplings, seedlings, suckers

1. Introduction

The human-mediated invasion of different kinds of habitats by alien species is rapidly becoming a global phenomenon (SEEBENS et al. 2017, WAGNER et al. 2017) exerting an increasingly negative influence on biodiversity (VILÀ et al. 2010). Central European lowland habitats including forests are being especially adversely affected by increasing abundancies of alien tree species (CHYTRÝ et al. 2009). Alien tree species are often highly invasive and competitive, and can act as habitat transformers (RICHARDSON et al. 2000). In addition to research involving *Acer negundo* and *Robinia pseudoacacia,* more recent research in Central Europe, has been focused on *Ailanthus altissima* (Mill.) Swingle, the tree of heaven (BERG et al. 2017, WICKERT et al. 2017).

Ailanthus altissima was introduced from China to Europe in the middle of the 18th century, and has since been successfully naturalized all over the southern temperate and meridional zones (HU 1979). In its synanthropic range the species is a typical fast growing and light-demanding woody pioneer of disturbed areas. The large amount of

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wind-dispersed fruits from female individuals (up to 1 million seeds per mother plant, Wickert et al. 2017) promotes the invasion success of *Ailanthus altissima* in new habitats. Seedlings develop a nutrient-storing taproot and several lateral roots (Dubroca & Bory 1981). Roots in upper soil layers show macroscopically visible primordia or suppressed buds, which can form root suckers for clonal reproduction (Kowarik 1995), a feature rare in native European tree flora. This characteristic enables the tree to persist in the habitat by forming dominant stands (Berg et al. 2017), and ultimately to change the species composition in sense of declining the floristic richness (Motard et al. 2011). Until now, *Ailanthus altissima* has been rarely found in shaded, dense forests in Austria. Only in warmer climate, it has been able to invade woodland habitats (Knüsel et al. 2017). This supports predictions that invasion of this species will be promoted by global warming (Stevens et al. 2015).

The task of investigating the reproduction, dispersal and invasion strategies of alien species is important for deepening the understanding of the invasion process, both for model-based predictions and for planning management activities. Berg et al. 2017 payed attention to ecological differences between young and older individuals of tree species for invasion studies. It may therefore be important to distinguish between the different reproduction types, between generative seedlings and vegetative root-borne suckers of *Ailanthus altissima*. Both can be found mixed within the habitats of *A. altissima*. According to Motard et al. 2011, root suckers should have a particular morphology: large leaves, long internodes, and brownish bark. According to our field experiences, we could not confirm these differences. Useful was only the morphology of the underground parts, and for reasons related to nature conservation, it may be advantageous to remove all *Ailanthus*-saplings. However, to investigate the ongoing invasion process of *Ailanthus altissima* without influencing the sampling plot, it is important to distinguish seedlings and suckers using only aboveground-characters. In this study, we try to find features for the successful distinction between one-year-old individuals following differences in shoot morphology.

2. Material and Methods

2.1 Origin of material and germination test

We collected *Ailanthus altissima* fruits (one-seed samaras) at 23. February 2017 from ten female trees at the Wildoner Berg south of Graz (N46.8705 E15.505), one of the locations in Styria greatly affected by the *Ailanthus* invasion. We stored the fruits under room temperature conditions. We took 10 fruits of every tree and mixed them. To produce doubtless seedlings and for germination testing, we sowed these 100 mixed fruits in four replicate approaches with 25 random selected seeds in standard garden soil, starting on the 6^{th} of May in 2017. In order to study their morphological features, seedlings were cultivated for five months until October in the Botanical Garden of Graz. We collected 31 suckers from this year in the field including underground parts at Admonter Kogel north of Graz (N47.11238 E 15.39746), Rosenhain in Graz-Mariatrost (N47.08794 E15.44806), and Wildoner Berg south of Graz (N46.8705 E15.505).

2.2 Measurements of morphological features

The measurements were taken using a Vernier caliper for the stem diameters. Diameters were measured at the ground level (base) and at the top under the second highest leaf bud. We used a tape measure for the height, internode length and leaf size. Heights we measured from the soil-ground level to the top of the stem. We measured the length of the youngest fife internodes and the uppermost fife leaves of one-year old saplings.

All photos, except Figure 7 and 8 are by Christian Berg.

3. Results

3.1 Germination test and seedling production

After 12 days, the first seedlings appeared, followed by a 10 day period of vivid germination (Fig. 1). After the 23rd day, the rate of germination slowed down and terminated with a germination of 35 % of the seeds after 35 days.

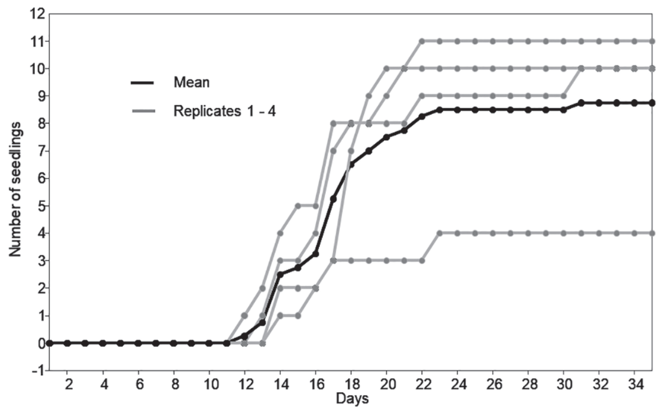

Figure 1: *Ailanthus altissima* germination test of four replicates á 25 seeds (gray, mean black) in standard garden soil (6th of May to the 8th of June, 2017). In total, 35 % of the seeds germinate.
Abb. 1: *Ailanthus altissima* Keimtest in vierfacher Wiederholung je 25 Samen (grau, Mittelwert schwarz) in normaler Gartenerde (6. Mai bis 8. Juni 2017). Keimungsrate: 35 %.

Ailanthus altissima performs an epigeal germination. In some cases remains of the pericarp of the samara lifted up around the cotyledons after germination (Fig. 2a). The opposite cotyledons are simple ovals (Fig. 2b). The following leaves show a reduced number of leaflets (Fig. 3).

Figure 2: *Ailanthus altissima* after the first two days of germination. 2a (left): Seedling with remains of the samara on the top. 2b (right): Seedling with well-developed cotyledons .
Abb. 2: *Ailanthus altissima* in den ersten zwei Tagen nach der Keimung. 2a (links): Sämling mit Resten der Flügelnuss an der Spitze. 2b (rechts): Sämling mit voll entwickelten Keimblättern.

Figure 3: *Ailanthus altissima* seedlings with primary (3a, left) and following (3b, right) leaves.
Abb. 3: *Ailanthus altissima*-Sämlinge mit Primärblättern (3a, links) und Folgeblättern (3b, rechts).

3.2 Morphological differences of seedlings and suckers

The aboveground parts of seedlings and suckers are quite similar, especially late in the growing season. Saplings older than one vegetation period do not seem to be distinguishable any more. Very young seedlings can be recognized by the presence of the opposite cotyledons (Fig. 3, Fig. 6). When a couple of following pinnate leaves developed, the cotyledons got wilt and fall off. Later, the early following leaves also fell off during the growing season (Fig. 4a). The arrangement of the following leaves on the stem can be opposite or alternate with short internodes. Sometimes, opposite leaf scars from first leaves are visible at the basal stem (Fig. 4b). They are smaller than leaf scars of normal developed leaves and a certain sign for a seedling, but sometimes even the first leaves are alternate and the scars are harder to see.

Figure 4: Opposite following leaves of a half-year old *Ailanthus altissima* seedling just before they fall off (4a, left). Opposite leaf scars at the stem base of the same seedling (4b, right).
Abb. 4: Gegenständige Folgeblätter eines 6 Monate alten *Ailanthus altissima*-Sämlings kurz vor dem Abfallen (4a, links). Gegenständige Blattnarben an der Basis der Sprossachse desselben Sämlings (4b, rechts).

As it is well known, the most striking differences between seedlings and vegetative root-suckers are exhibited in the form of the underground parts. Suckers emerge from more or less horizontal roots of a mother-plant (Fig. 5a, Fig. 8). Seedlings produce a branched root system, with fine roots tapering to filiform ends (Fig. 5b, Fig. 7). These roots have different diameters and can be rather thin. The sucker does not develop quickly its own fine root system. When pulled out of the soil, suckers give a distinct tearing sound, and show a noticeable scar from tearing.

Figure 5: Differences in the root system of suckers (5a, left) and seedlings (5b, right).
Abb. 5: Unterschiede im Wurzelsystem von Wurzelsprossen (5a, links) und Sämlingen (5b, rechts).

The aim of this study was to find aboveground differences. We compared the color of the shoots, and measured parameters of the stem and leaves to establish clear differences between seedlings and suckers, but the variability of most characters was too high, especially with regard to the leaves. Significant differences we found only in some shoot features. The shoots of seedlings are more conical than the shoots of vegetative sprouts coming from root systems. The comparable opulent root system found immediately beneath the soil surface lead to tangible thickening at the stem base by active secondary growth of the hypocotyl (Fig. 5b, Fig. 6). To the top, shoots tapering and get comparably thin up to the apex, because seedlings use their own source of nutrients (Fig. 7). Shoots of suckers are more cylindrical and often originate from deeper soil horizons (Fig. 5a, Fig. 6). A hypocotyl does not exist. Suckers grow up relative to the strength of a mother-plant, the establishment of an own root system is of lesser importance for their survival in the first year, in terms of nutritional source and structural stability, and the shoots are stronger up to the top.

Figure 6: Differences in the shape of the basal shoot: suckers cylindrical, (left) and seedlings conical, (right).
Abb. 6: Unterschiede in der Form der Sprossbasis: Wurzelspross (zylindrisch, links) und Sämling (konisch, rechts).

Figure 7: Herbarium voucher of a one-month-old seedling of *Ailanthus altissima*. Cotyledons are visible. Photo provided thanks to the courtesy of Astrid Scharfetter, Herbarium GZU.

Abb. 7: Herbarbeleg eines ein Monat alten Sämlings von *Ailanthus altissima*. Kotyledonen sind sichtbar. Foto Astrid Scharfetter, Herbarium GZU.

Figure 8: Herbarium voucher of approximately one-month-old suckers of *Ailanthus altissima*. Cotyledons are lacking. Photo provided thanks to the courtesy of Astrid Scharfetter, Herbarium GZU.

Abb. 8: Herbarbeleg eines ungefähr einen Monat alten Wurzelschösslings von *Ailanthus altissima*. Kotyledonen fehlen. Foto: Astrid Scharfetter, Herbarium GZU.

This morphology resulted in significant differences between the relationship of the basal and the top diameter of the shoots (quotient of top and basal diameter, Table 1). The values overlap to some extent, but the medians are clearly separated, making this the most distinctive character of the aboveground parts.

Table 1: Results of the measurements of seedlings and suckers of *Ailanthus altissima* for some aboveground parameters in October 2017. Differences in medians are tested with Mann-Whitney-test (*** means p=0.001). All values in centimeters.

Tab. 1: Ergebnisse der Messungen einiger oberirdischer Parameter von Sämlingen und Wurzelsprossen von *Ailanthus altissima* im Oktober 2017. Signifikanzen in den Medianen wurden mit dem Mann-Whitney-Test ermittelt (*** bedeutet p=0.001). Alle Werte in Zentimeter.

	Basal diameter		Top diameter		Top/Basal diam.		Plant size		Internode size		Leaf size	
	seedlings	suckers	seedlings	suckers	seedlings	suckers	seedlings	suckers	seedlings	suckers	seedlings	suckers
N	23	31	23	31	23	31	23	31	50	50	49	43
Min	0.42	0.43	0.31	0.36	1.35	1.09	10.5	32	1.0	1.0	12.0	14.0
Max	1.2	3.2	0.71	1.8	2.65	1.89	82	157	7.7	8.0	55.0	60.0
Mean	0.84	1.27	0.51	0.85	1.68	1.47	40.70	77.61	3.5	3.8	36.9	40.4
Median	**0.79*** **	**1.1*** **	**0.51*** **	**0.79*** **	**1.66*** **	**1.44*** **	**34.5*** **	**77*** **	3.5	3.8	38.0	40.0
25 prcntil	0.71	0.93	0.39	0.6	1.53	1.32	31.5	56	2.3	2.5	31.0	34.0
75 prcntil	1.02	1.62	0.62	1.07	1.74	1.63	49.5	92	4.5	5.0	44.0	48.0

The color (green vs. light brown) was mixed between seedlings and suckers. The color depends on the creation of woody tissue and bark, which correlates with the age of the plant (start of growing during the season), its resource availability (nutrients, water and light) and therefore its growth rate. Smaller, slow growing plants are longer herbaceous and green, while fast-growing plants under optimal conditions gets woody and brown quite early, regardless of whether it is a seedling or sucker.

Seedlings were generally smaller than suckers. We found general differences in shoot diameter as well as in plant heights. No differences we found in the length of the internodes and the length of the leaves (Table 1). Both is highly variable even in the same habitat, and depends, as the color of the shoot, on the growing conditions.

4. Discussion

Germination rates of *Ailanthus altissima* seemed to be highly variable, depending on individuals as well as age and other factors, reaching up to 78% (Wickert et al. 2017). The experimental determined rate of 35% in our tests seemed to be a medium rate, showing a good generative reproduction potential of trees at the sampling location.

Seedlings and vegetative suckers were found together at the same stand.

Motard et al. 2011 found clear differences, because root suckers should have larger leaves and longer internodes than seedlings, and a brownish bark.

For the Austrian populations, we could not confirm these differences. It is true that suckers are generally larger and more robust than seedlings. This confirmed former similar findings by Kowarik & Säumel 2007 and Knüsel et al. 2017. However, suckers from thin roots or from cut root-pieces could be rather thin, and such quantitative characters are less suitable to create a general rule.

For us, the rate of sexual reproduction was hard to estimate in the field, since seedlings and suckers were rather similar and not easy to distinguish without checking the underground parts by digging. Only very young seedlings could be easily recognized by opposite cotyledons and primary leaves. Our measurements showed that the most reliable characteristic for distinction of the one-year aboveground parts is the shape of the shoot (conical or cylindrical), calculating the quotient between top diameter and basal diameter. Since the results overlap to some extent, they can only be used as clear evidence in a statistical context. It will not be possible to distinguish seedlings and suckers in every single case without accessing the underground parts. In rocky substrates, even digging could fail to provide useful data because of atypically shaped or non-harvestable root systems. It is difficult to distinguish between the root system structure of a seedling which repeatedly sprouts from its base, and a root sucker. It is especially difficult to make distinctions on sites where the plants are periodically removed or mowing has occured, or in habitats where young seedlings have suffered from late frosts.

We conclude that the ratio between basal and top stem diameter is somewhat independent from the general size of the plants and can help to distinguish between individuals of the two different strategies of reproduction.

Most *Ailanthus*-offspring in Austria may be vegetative root-suckers, even at distances of ten meters away from potential mother plants. It was observed that root systems from felled trees produce many suckers in the following vegetation periods (Liess & Drescher 2008), even if the main root is fragmented into small pieces (Inverso & Bellani 1991).

The ratio of seedlings and suckers of *Ailanthus*-stands in Central European forests should be more considered in future investigations to better understand the dynamics of invasion, colonization and adaption.

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