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How long do seeds of the invasive tree, *Ailanthus altissima* remain viable?

Joanne Rebbeck*, Joan Jolliff

USDA Forest Service, Northern Research Station, 359 Main Road, Delaware, OH 43015, United States

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ABSTRACT

The non-native invasive tree, *Ailanthus altissima* is an increasing threat to the diversity and health of temperate forests. Female trees are prolific producers of wind-dispersed seeds. It is not known if *Ailanthus* seeds remain viable in natural growing conditions beyond two years. We collected *Ailanthus* seeds from eleven sources in fall 2010 and incubated outdoors in either mixed oak leaf litter or mineral soil (10 cm depth) for five years to assess seed viability. Each May sets of seeds were retrieved, counted and sown in a greenhouse to measure germination. Initially germination rates averaged 87%, however in year 5 (2016), germination rates of seeds incubated outdoors in oak leaf litter, fell to 1.9%, while those incubated in mineral soil averaged 75%. Germination rates of soil-incubated seeds ranged from 48 to 95% among the eleven seed sources after five years. These findings demonstrate that the common practice to eliminate *Ailanthus* seed sources two years prior to a timber harvest is insufficient to deplete its seed bank. We propose that managers remove seed sources at minimum of six years in advance of a scheduled timber harvest. Ideally, it would be most advantageous to incorporate removal of females *Ailanthus* as a routine management practice.

1. Introduction

Native to northeastern China, *Ailanthus altissima* (*Ailanthus*, tree-of-heaven, Chinese sumac, stink tree), is widely distributed throughout many temperate regions of the world including all continents with the exception of Antarctica (Kowarik and Säumel, 2007). It has been present in North American landscapes since being introduced into Philadelphia, PA USA in 1784 (Kasson et al., 2013). *Ailanthus* is often considered a forest edge species, but its presence within interior forest sites is common (Ellenwood et al., 2015; Rebbeck et al., 2017). It is fast growing, reaching heights of 18–21 m in 10 years (Knapp and Canham, 2000; Kowarik and Säumel, 2007). *Ailanthus*'s tendency of aggressive clonal spread, creates dense thickets which can out-compete native trees, increasing its infamous invasive potential.

This dioecious tree is a prolific seeder with average annual seed production estimates of 325,000 per tree (Bory and Clair-Maczulajtys, 1980). Wickert et al. (2017) reported seed production is positively related to tree diameter, with *Ailanthus* trees exceeding 20 cm dbh capable of producing > 1 million seeds in a single year. Seeds are found singly in oblong, papery thin, 33–48 mm long spirally-twisted samaras lacking endosperm (Zasada and Little, 2008). Seeds develop as numerous dense clusters in the summer, mature in early fall and typically persist on the tree until spring. Wind-dispersed seeds can travel in excess of 200 m (Landenberger et al., 2007) with the potential of invading newly disturbed sites. Secondary dispersal is common on the ground as well as along streams and rivers (Säumel and Kowarik, 2010).

Few experimental studies have monitored native seed survival viability in forested ecosystems (Marquis, 1975, Granström, 1987). Clark and Boyce (1964) found yellow-poplar, *Liriodendron tulipifera* seeds, a native species with a similar life history and ecological niche to *Ailanthus* remained viable for four years under forest litter. Globally, non-native invasive species often have large and persistent seed banks (D'Antonio and Meyerson, 2002). However, North American studies on the seed bank persistence and viability of non-native woody plant species have been limited primarily to herbaceous non-natives (Blaney and Kotanen, 2001; Huebner, 2011). The persistence of *Ailanthus* seeds in soil seed banks has not been studied beyond two years (Kowarik and Säumel, 2007). Seeds do not appear to require stratification to germinate, but germination rates can increase to 96% following cold stratification (Graves, 1990). *Ailanthus* seeds are not dependent on high light conditions for germination and can germinate and persist in closed canopy forests (Kota et al., 2007; Martin et al., 2010). Kaproth and McGraw (2008) reported that *Ailanthus* seeds submerged in water for five months retained high germination rates (94%). These traits verify its potential for high fecundity in unfavorable growing environments. There are many factors that lead to increased *Ailanthus* regeneration including prescribed fire, herbicide use and timber harvesting.

It is important to understand how forest management practices

* Corresponding author.
E-mail address: jrebbeck@fs.fed.us (J. Rebbeck).

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influence the dissemination of vegetation and seed propagules of *Ailanthus* and other non-native invasive plants to minimize their human-facilitated spread. We found that timber harvests within 20 years predicted the presence of *Ailanthus* in southeastern Ohio mixed oak forests while recent prescribed burns (≤8 years) did not (Rebbeck et al., 2017). Anecdotally, forest managers in the eastern United States have reported increases in *Ailanthus* seedlings immediately following prescribed fires. It may be that fire, by reducing leaf litter and increasing available light, creates improved conditions for *Ailanthus* seedling establishment as observed for native species such as yellow-poplar (Hutchinson et al., 2005). In addition, herbicide to control interfering vegetation may alter forest floor light conditions and stimulate germination of native and non-native seed banks (Horsley, 1994). Soil disturbances resulting from the use of heavy equipment such as dozers and skidders for timber harvesting and prescribed fire may also facilitate *Ailanthus* seed germination and dispersal of vegetative fragments capable of rooting (Rebbeck et al., 2017).

Understanding the basic biology of non-natives such as *Ailanthus* is crucial to choosing appropriate forest management practices that do not facilitate dispersal. Current proactive control recommendations include the removal of *Ailanthus* seed sources more than 200 m from a planned timber harvest (Landenberger et al., 2007). Unfortunately we do not know how long in advance of a disturbance managers should wait for the *Ailanthus* seed bank to be exhausted because its seed longevity has not been studied beyond two years (Kowarik and Säumel, 2007). Our objective is to determine if *Ailanthus* seeds remain viable when maintained in either forest litter or buried in mineral soil for five years.

2. Methods

2.1. Study design

A repeated measures nested factorial design tested the effect of three factors on the germination of retrieved *Ailanthus* seeds: (1) seed incubation location, either under natural forest leaf litter (soil depth = 0 cm) or burial (soil depth = 10 cm); (2) seed source (11 mother trees from central and southeastern Ohio) and (3) length of incubation (1–5 years). The incubation locations were chosen to simulate two possible seed dispersal scenarios which might occur within forests: (1) where no active management occurred as represented by leaf litter incubations, and (2) within actively managed forests where seeds are buried by harvesting or road-building equipment.

Ailanthus seeds were collected in October 2010. Sites locations of seed trees were georeferenced using a hand-held GARMIN GPSmap 76CSx unit (Table 1). In November 2010, lots of 50 seeds were counted and placed into 20 × 20 cm, 5 mm plastic mesh litter bags for each of the 11 seed sources. The LG10 and LG11 sources had 30 seeds per bag because fewer seeds were collected. Each litter bag was uniquely identified with a metal numbered tag.

The two incubation locations were established at the USDA Forest Service Laboratory, Delaware Ohio (40°21′21″N, 83°03′52″W) in early November 2010. Seeds were incubated in either a closed canopy 50 year-old hardwood stand dominated by northern red oak (*Quercus rubra* L.) stems (30–40 cm dbh) or within a nearby (< 100 m) open and regularly mowed area. Both areas were underlain by Morley silt loam found on till plains and moraines of Wisconsin age in glaciated regions of Ohio. Within the hardwood stand, three rows of six 50 × 50 cm incubation plots each were setup within a 20 × 50 m area as complete replicates for leaf litter incubations. Each plot contained a 20 × 20 cm seed bag folded in half with 50 seeds from each of the 11 seed sources which were randomly positioned within each plot. Litter bags were secured to the forest floor or soil with steel pins and then covered with anchored 12 × 24-mm opening hardware cloth to minimize disturbance by wildlife. Leaf litter depth within the site averaged 3 cm.

A duplicate set of seeds were buried to a depth of 10 cm within 18 50 × 50-cm plots within a mowed turf grass area immediately west of a 15-year-old yellow-poplar plantation. This area was cleared of grass and rototilled to a depth of 15 cm. To minimize seed loss and improve seed bag retrieval, a single layer of fiberglass mesh window screen was placed between the bare soil and the seed bags. Soil was placed over the hardware anchored seed bags to a depth of 10 cm, then burial locations were covered with oak leaf litter collected from the hardwood stand to a depth that simulated annual leaf litter deposition. To minimize wind displacement of oak leaf litter, plots were covered with anchored plastic deer-fence. Each autumn, fresh oak leaf litter was added to the buried seed plots. Each seed source by time of incubation combination was replicated three times at the two seed incubation locations. A total of 396 L bags (11 seed sources × 6 collections × 3 replicates × 2 incubation locations) holding a total of 18,360 seeds were deployed.

Hourly air and bare soil (5 cm depth) temperatures were collected at an onsite weather station, cooperatively managed by USDA Forest Service, Delaware, OH and Ohio Agricultural Research and Development Center, The Ohio State University, Wooster, OH. Soil (10-cm depth) and air temperatures were also monitored hourly using an Onset HOBO thermocouple probe/datalogger within the center of the hardwood plantation incubation site.

The daily mean air and soil temperatures recorded at the weather station are summarized in Fig. 1. Monthly air and bare soil temperatures at 5 cm averaged −0.35 °C and 1.45 °C in January, respectively and 23 °C and 25 °C in July, respectively during the study. Because of intermittent equipment failures, temperature data was missing from January 26, 2011 to May 30, 2011, February 8, 2012 to March 2012 and July 9, 2013 to June 5, 2014. Rainfall data were collected onsite at the National Atmospheric Deposition Program National Trends Network OH17 Site station (NADP National Trends Network 2018). Annual mean rainfall was 1111 mm from 2011 to 2016. The highest observed annual precipitation of 1445 mm was measured in 2011, while the lowest (951 mm) was measured the following year. June was the wettest month most frequently (≥120 mm rainfall) while November was the driest month (≤50 mm rainfall) observed during the study

Table 1
Locations of 11 seed-bearing *Ailanthus* trees in central and southeastern Ohio and percent seed germination from 2011 to 2016.

Tree ID	Ohio City, County	Latitude, longitude	Seed collection date	Percent germination	Percent germination[a] minimum – maximum
DE01	Delaware, Delaware	40°17′59″N, 83°03′45″W	10/05/2010	46.2 ± 5.5 de	36.4 (2015) – 66.3
DE02	Delaware, Delaware	40°18′01″N, 83°04′59″W	10/24/2010	55.9 ± 5.3bcde	39.0 (2013) – 86.6
DE03	Delaware, Delaware	40°18′02″N, 83°04′01″W	10/24/2010	55.0 ± 5.8 bcde	47.3 (2015) – 79.8
DE04	Delaware, Delaware	40°18′11″N, 83°04′10″W	10/24/2010	66.4 ± 5.7 ab	52.3 (2013) – 95.1
DU05	Dublin, Franklin	40°06′07″N, 83°06′37″W	10/22/2010	63.9 ± 5.5 abc	51.6 (2016) – 87.6
DU06	Dublin, Franklin	40°06′09″N, 83°06′35″W	10/22/2010	56.9 ± 5.4 bcd	49.5 (2014) – 84.4
SB07	South Bloomfield, Pickaway	39°46′22″N, 82°59′22″W	10/23/2010	61.2 ± 5.1 abcd	49.0 (2016) – 85.0
LD08	Londonderry, Ross	39°16′04″N, 82°47′32″W	10/23/2010	70.8 ± 5.5 a	56.8 (2016) – 96.6
LD09	Londonderry, Ross	39°16′06″N, 82°47′24″W	10/23/2010	49.6 ± 5.0 cde	37.4 (2016) – 76.36
LG10	Logan, Hocking	39°32′31″N, 82°25′12″W	10/25/2010	38.8 ± 5.0 e	25.9 (2015) – 56.3
LG11	Logan, Hocking	39°32′04″N, 82°24′47″W	10/25/2010	64.8 ± 6.2 ab	49.7 (2016) – 87.6

[a] Year of observed minimum annual percent germination is shown in parenthesis; maximum values were all observed in 2011.