

Weed Seed Banks: Biology and Management

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Summary

The seed bank refers to the resting place of weed seeds and forms an important component of the life cycle of weeds. In annual and some perennial weed species that reproduce by seed only, seed banks are the sole source of future weed populations. Because of this, understanding what happens to seeds in the seed bank can be an important component of overall weed control. When weed seeds enter the seed bank, several factors influence the duration for which seeds persist. Seeds can sense the surrounding environment in the seed bank and use these stimuli to become dormant or initiate germination. Soil and crop management practices can directly influence the environment of seeds in the seed bank and can thus be used to manage seed longevity and germination behaviour.

Biology of Weed Seed Banks

Purpose and types of seed bank

Weed seeds are an important component of the weed life cycle as they are the origin of future populations, and are particularly important in annual and simple perennial species like dandelion (*Taraxacum officinale* Weber) which reproduce by seed only. As a rule perennial species usually rely on seeds to establish new colonies some distance away from the mother plant. Around the mother plant, colony expansion is the result of vegetative reproduction.

The term seed bank simply refers to places where seeds collect or remain until germination. Seed banks serve many purposes. They allow species such as annual weeds to survive the harsh environmental conditions of winter. They enhance the survival of a species by buffering against harsh environmental conditions or highly effective control methods and allowing them to germinate over a period of many years. This ability slows the genetic shift of a weed population exposed to intense selection pressures by ensuring that all the seedlings that germinate in any one year are not all from similar genetic backgrounds. This review focuses on soil seed banks which are the most common and important in prairie agricultural systems, although aerial seed banks also exist. Aerial seed banks are those where the seeds remain on the mother plant for some time after maturation allowing for more dispersal strategies. Some of these strategies includes dispersal by weeds seeds clinging to the fur of animals [e.g. common burdock (*Arctium minus* Bernh.) and common cocklebur (*Xanthium strumarium* L.)] or relying on passage through the digestive tract as is the case for many fruit bearing shrubs and trees, or shake off the mother plant as it is blown away from its point of origin by wind (e.g., kochia (*Kochia scoparia* L.). Aerial seed banks tend to be of greater importance in pasture, orchard, or natural settings than in agricultural fields.

Soil seed banks are typically characterized by their longevity and are determined by how long an individual seed may reside within it in a viable state. This longevity depends primarily on plant species. Transient seed banks are those where seeds only survive for a short time in the seed bank (no more than a couple of years) as is the case with kochia and dandelion. Seed banks of these species require almost annual renewal, while other species such as redroot pigweed (*Amaranthus retroflexus* L.) and lambsquarters (*Chenopodium album* L.) form a persistent seed bank with the ability to remain viable in the soil for many decades. It is important to understand the seed bank characteristics of a species as these provide clues as to how to choose appropriate practices to manage the seed banks.

What happens to weed seeds in the seed bank?

Of the many seeds that are in the seed bank, very few will actually emerge and produce a plant. Most seeds will die, decompose or be eaten before ever germinating. Of those that do germinate, some will die before a mature plant is produced. Seed predation is typically greatest when weed seeds remain on the surface and there is sufficient residue cover for predators (i.e. no-till). Generalist predators such as common ground beetles or crickets can reduce weed seed emergence by 5 to 15%²⁵. Larger animals such as rodents and birds can also consume significant amounts of weed seeds.

When buried and not available to predators, attack by pathogens is more common. In a recent study in Montana, mortality of wild oat (*Avena fatua* L.) seed increased as soil moisture content increased from 6 to 24% with maximum mortality values reaching 55 and 88% after two years of the study¹⁵. The attack of the wild oat seeds by soil pathogens was suspected to be the main reason for increase in seed mortality with higher soil moisture contents. With green foxtail seeds less than 1% of seeds buried in bags were viable after six years²¹.

Two other mechanisms of seed mortality in the seed bank are lethal germination and desiccation. Lethal germination occurs when seeds germinate from a deep depth and seedlings exhaust their seed reserves and die before reaching the soil surface. Many weed seeds such as kochia can sense their depth of burial to limit lethal germination. Seed desiccation is also another important mechanism in western Canada due to the extreme environmental conditions in summer and winter. Dry seeds by design are very resistant to desiccation and can remain viable for up to 2000 years. However, desiccation tolerance is lost quickly when seeds are subjected to frequent and short-term wetting and drying conditions before germination is complete. The end result is higher seed mortality.

Seed dormancy

Seed dormancy prevents germination during conditions that would otherwise be ideal for germination. Most weed seeds are dormant at the time of maturity which is referred to as primary dormancy. However, seeds can cycle in and out of a dormant state because of environmental conditions. This process is referred to as secondary dormancy and regulates seasonal germination in weed seeds³. Secondary seed dormancy prevents germination at a time of year when the life cycle of a plant could not be completed and this ensures that summer annual species germinate primarily in the spring and winter annual weeds germinate primarily in the fall. This process is regulated by seasonal changes in soil temperatures. For most summer annual weeds that germinate in the spring, the cold of winter will break dormancy and allow the seed to germinate in the spring. On the other hand, winter annual weeds such as stinkweed and shepherd's purse require the heat of summer to break dormancy. This allows them to germinate in the early fall and form a rosette before winter.

Types of seed dormancy

Seed dormancy is controlled by several mechanisms. An immature embryo at the time of seed maturation will not allow germination. This is a form of primary dormancy and occurs in wild oat. A period of 'after ripening' is required before seeds are able to germinate. Another mechanism for seed dormancy is physical dormancy where a hard seed coat prevents uptake of water. This is an important mechanism for extended persistence in the soil seed bank. Weed families with high levels of seeds with impermeable coats include the pea family (e.g., black medic (*Medicago lupulina* L.)), the mallow family (round leaved mallow (*Malva pusilla* L.), velvetleaf (*Abutilon theophrasti* L.)) and members of the goosefoot family such as lambsquarters. Seeds from these species can readily survive several decades in the soil seed bank¹⁸. Finally, seed dormancy may also be due to physiological changes. This is the mechanism for secondary or cyclical seed dormancy and this mechanism is regulated by many factors³.

Secondary seed dormancy is controlled by factors like temperature, light, oxygen, and certain bio-chemicals. Factors such as light and temperature are capable of both inducing and breaking secondary seed dormancy. Light quality and temperature also convey information about the presence of other plants and the burial depth of weed seeds. In small seeded species like redroot pigweed, a flash of white light (as faint as full moon light) is often sufficient in breaking

seed dormancy by telling the seed it is close to the surface. This is one mechanism by which day-time cultivation increases seed germination. In other species such as wild oat for example, high levels of white light prevent germination as this indicates that the seed is not buried sufficiently deep for optimum seedling establishment. Light only penetrates a few millimeters into the soil profile. In some small seeded species, the fluctuations in daily temperature which decrease into the soil profile provide an indication of depth of burial. Temperature variations are particularly important in small seeded weeds that can emerge successfully only from shallow depths. Low oxygen concentrations are also indicative of burial depth and induce seed dormancy in many species. In addition, there are also a number of chemicals that remove seed dormancy. Most notably, nitrate nitrogen and some chemicals that are found in smoke. When these chemical signals are released by dead vegetation and during a fire, they indicate niche availability. In the 1960s research was conducted that attempted to regulate germination in the wild by adding nitrate-nitrogen fertilizer. The idea was that nitrate-nitrogen added to the soil would cause wild oat seeds to germinate which could then be killed with a tillage operation¹⁹. Ultimately this technique failed because of the large amount of nitrate-nitrogen fertilizer required and the inconsistency of the effect. The plant hormone gibberellic acid also removes seed dormancy and this compound has been used to induce germination in dormant volunteer canola (*Brassica napus* L.) seed in soil in the greenhouse with some success²³; however, the high cost of producing this compound make this method unpractical under field situations.

Dormancy is a complex mechanism that controls when a seed will germinate. However, seed dormancy characteristics and the persistence of the seed in the seed bank (Table 1) are not always related²². One reason for this is that seed dormancy can only regulate germination when the conditions necessary for germination are present. In many cases, however, ideal conditions do not exist and seeds that are not dormant cannot germinate. Although seed dormancy is an important mechanism for most weed species, there are important weed species such as kochia and dandelion that essentially possess no seed dormancy.

Seed characteristics such as dormancy vary greatly among seeds from an individual plant and among years. Because the seed coat is made from plant tissue that the mother plant produces, the environment under which the seed develops will affect seed dormancy. Environmental conditions during seed maturation can impact seed coat hardness in weeds like black medic (*Medicago lupulina* L.) or the effect of temperature on dormancy in wild oat¹¹. In addition, seed quality characteristics vary depending on the time of maturation during the season. This is particularly important for weeds with long flowering periods.

Table 1. Time at which seed bank decline curves in soil approach zero. Data adapted from a recent study conducted in Alaska over a period of 20 years⁹.

Species	Max. longevity (yrs)
Grasses	
Bluejoint Reedgrass (<i>Calamagrostis canadensis</i> (Michx.) Beauv.)	8-14
Foxtail barley (<i>Hordeum jubatum</i> L.)	7-8
Quackgrass (<i>Elytrigia repens</i> (L.) Nevski)	4-6
Wild oat (<i>Avena fatua</i> L.)	4-6
Broadleaved species	
American dragonhead (<i>Dracocephalum parviflorum</i> Nutt.)	> 20*
Common chickweed (<i>Stellaria media</i> (L.) Vill.)	> 20

Common hempnettle (<i>Galeopsis tetrahit</i> L.)	2-3
Common lambsquarters (<i>Chenopodium album</i> L.)	> 20
Corn spurry (<i>Spergula arvensis</i> L.)	18-20
Flixweed (<i>Descurainia sophia</i> (L.) Webb ex Prantl)	16
Pennsylvania Smartweed (<i>Polygonum pennsylvanicum</i> L.)	14-18
Pineapple weed (<i>Matricaria matricarioides</i> (Less.) C.L. Porter)	> 20
Prostrate knotweed (<i>Polygonum aviculare</i> L.)	10-14
Rough cinquefoil (<i>Potentilla norvegica</i> L.)	12-14
Shepherd's-purse (<i>Capsella bursa-pastoris</i> (L.) Medicus)	> 20
Wild buckwheat (<i>Polygonum convolvulus</i> L.)	6-8

* about 60% of the seed were still viable after 20 years.

How can soil and crop management reduce the size of the weed seed bank?

Reducing the input of seeds into seed bank is the most obvious way to reduce the weed seed bank. Any method that reduces the size and number of weeds producing seed will also reduce the number of seeds “deposited” into the seed bank. Of course, the weed seed bank can be managed by using other methods that increase the death of the seeds in it, or encourage germination when the weeds can then be easily controlled. Although most agronomic practices have an indirect affect on the weed seed bank, only a few key methods directly affect weed seed input, seed bank persistence and germination from the seed bank.

Reducing seed inputs into the soil-seed bank

Herbicides - Herbicides have, and continue to be, the most effective weed management tool of the 20th century. Herbicides are very effective at reducing weed populations and at the same time the number of seeds added to the soil seed bank. Weed seed bank densities tend to be greater in organic management systems than in systems reliant on herbicides, although this is not always the case as other factors such as crop rotation also strongly influence weed seed production. In production systems that use herbicides as the principal tool to manage weeds, seed bank densities are typically between 1000 and 4000 seeds/m²^{5,8}. When herbicide-tolerant crops are used extensively in cropping systems, weed seed banks will be near the low end of this range, however, despite lower weed seed bank densities in these systems, weed seedling emergence still remains significant in following years. Pre-harvest applications of glyphosate can decrease seed production and impact seed viability in late flowering weeds. However, the slow action of glyphosate means that weeds must be managed well before the plant sheds its seed near maturity.

Crop rotation – Crop rotation is also an effective means of managing the weed seed bank. Introducing perennial crops in annual cropping systems tends to deplete the soil seed bank of annual species over time. This method is more effective on weed species which have low levels of longevity such as kochia and many of the grassy weeds like wild oat and green foxtail. Likewise, crop competition is also important for decreasing weed seeds being recruited to the seed bank. Studies near Saskatoon, SK conducted in the late 1970s showed that seed bank populations were greatest in summer fallow (about 1600 seeds m⁻²) versus wheat stubble (about 500 viable seeds m⁻²)¹. Weed seed bank additions are high in fallow fields in part due to incomplete weed control by tillage and the absence of a competitive crop²

Chaff collection – Chaff collection is an effective method for reducing inputs into the weed seed bank. Weed seeds generally weigh less than crop seeds and therefore end up in the chaff fraction which is typically spread evenly across the field. Even for large weed seeds such as wild oat, chaff collection can prevent upwards of 90% of the weed seed numbers added to the seed bank during the harvest operation²⁰.



Figure 1. Harvest losses also contribute to the seed bank. With small seeded crops such as canola, even small harvest losses contribute large numbers of seeds to the weed seed bank. Photo credit: Robert Gulden

Direct management of the weed seed bank

Tillage - Until the introduction of herbicides, tillage was the main method for managing weeds. The degree of soil inversion and depth of tillage, strongly affected the vertical distribution of weed seeds in the soil seed bank. When using a moldboard plow, for example, 37% of the viable weed seed bank was found in the top 5 cm of the soil profile and 74% under no-till⁸. Using a chisel plow resulted in 61% of the seed near the soil surface. Deep buried seeds that remain undisturbed can persist in the soil seed bank for decades as they avoid some of the seed viability hazards previously described. Therefore, tillage slows the rate of turnover of the seed bank. In practical terms this could impact the rate of development of herbicide-resistant weed populations, with a slower shift in conventional tillage situations than under no-till. However, experimental evidence of this is lacking.

Some soil inversion and burial of weed seeds occurs during the seeding operation in no-till. Since disc openers reduce the amount of soil disturbance compared to hoe openers, one would therefore expect a reduction in seed burial. However a study conducted in Saskatchewan found that the seed bank persistence of volunteer canola was similar after three years under conventional and no-till¹³. Canola seed could only have persisted for three years if it was buried¹⁴; therefore, these results suggest that even a single pass with a low disturbance disc opener resulted in some seed burial, even in the no-till system. There are few studies that compare the degree of seed bank burial with different types of seed openers. A study in Manitoba showed that average seedling emergence of all weed species studied was from a greater depth in conventional-till than no-till management¹¹. In general, lower weed populations were reported by

farmers that practice no-till in western Canada, which is indicative of lower weed seed banks⁷. In Ontario, weed seed banks were almost two times greater under chisel plow management compared to no-till¹⁰.

Tillage can promote weed seed germination by several mechanisms. Soil disturbance with tillage will expose weed seeds to a flash of light that releases seeds from dormancy. Furthermore, soil disturbance through tillage also results in nitrogen mineralization which can promote some seed germination. To reduce the impact of tillage on weed seed germination, tillage in the dark or using a cultivator covered with light impermeable material has been tried but with variable success because of the inherent variability in weed seed populations for germination. This method depends on the actual placement of the seed after tillage and other factors such as nitrogen mineralization which can promote germination independent of light because of the presence of high nitrate levels¹⁵.

Mulching - The mulch of dead plant residue (what farmers often call “trash”) on the soil surface also impacts the seed bank in no-till systems. Crop residues create micro-environments that provide cover for animals that feed on them. In addition, residues have a moderating effect on temperature fluctuations in the soil, which in turn can impact seed dormancy of many of the smaller seeded broadleaf weeds that use daily temperature fluctuations to gauge burial depth. Crop residues of plant species such as rye (*Secale cereale* L.), clover (*Trifolium spp.* L.) and recently incorporated canola contain allelopathic chemicals which inhibit seed germination^{16,24}. The effectiveness of allelopathic chemicals diminishes over time as the chemicals are leached from the crop residue and degrade due to soil moisture, light and microbial activity. Large-seeded weed species tend to be less susceptible to allelopathic compounds than small-seeded species. It is not clear whether this is due to the lower surface area to volume ratio of larger seeds or whether it is due to reduced concentrations of allelochemicals at the deeper depths from which large seeded weed species tend to germinate.

Fertilization – Similar to crops, weeds also respond well to inorganic fertilizers fertilization^{4,5}. Over the long-term, weed seed banks of many species can be reduced by up to 50% by correct timing and placement of nitrogen fertilizer with spring banding at time of seeding being most effective⁶. Interestingly banding nitrogen fertilizer greatly reduced green foxtail and stinkweed populations, especially under a no-tillage cropping system¹⁷. Fall-applied nitrogen that is broadcast on the surface maximizes the competitive ability of weeds by allowing more access to the fertilizer which enhances weed populations and the weed seed bank.

Conclusions

Weed seed banks are an important component of the weed life cycle. There are many fates and processes that occur in the weed seed bank, many of which are not very well understood. The sheer difficulty of monitoring a process that occurs mostly underground has deterred weed scientists from gaining a full understanding of the weed seed bank. Nevertheless, current knowledge about weed seed banks has shown some potential management options. Reducing inputs to the seed bank is an important component of seed bank management, while other strategies like using a no-till cropping system can be used to directly affect germination, persistence and mortality of weed seeds. Managing weed seed banks should be an important component of integrated weed management, but more often than not, seed bank management is not being exploited to its fullest potential.

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