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Dynamics of weed seed bank and its management for sustainable crop production

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Abstract
The seed bank is the resting place of weed seeds and is an important component of the life cycle of weeds. Seed banks are the sole source of future weed populations of the weed species both annuals and perennials that reproduce only by seeds. For this reason, understanding fate of 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 soil weed seed bank and can thus be used to manage seed longevity and germination behavior of weed seeds. Among the factors responsible for low crop production, weeds are considered as the major limiting factors. Therefore, weed control with minimum cost and less adverse effect on environment is of prime importance. Weed infestation reduces the grain yield; this reduction can be accomplished by managing the soil weed seed bank

Keywords: Annuals, environment, distribution, dormant, weed seed bank

Introduction
Weed is the competitive nutrient absorbing destructive pest of crops (Laxminarayan and Mishra 2001) [9]. Among the factors responsible for low crop production, weeds are considered as the major limiting factors (Kalyanasundaram *et al*. 2006) [7]. Weed infestation reduces the grain yield by 70-80% in aus rice (early summer), 30-40% for transplanted aman rice (late summer) and 22-36% for modern boro rice cultivars (winter rice) (BRRI, 2006; Khan and Ashraf, 2006; Sarker, 1996) [8]. Subsistence farmers of the tropics spend more time, energy and money on weed control than on any other aspects of crop production (Kassasian, 1971). Poor weed control is the major factors responsible for reduction in yield (Amarjit *et al*., 1994). Therefore, weed control with minimum cost and less adverse effect on environment is of prime importance. One of the most important, yet often neglected, weed management strategies is to reduce the number of weed seeds present in the field. This reduction can be accomplished by managing the soil weed seed bank.

The weed seed bank is the reserve of viable weed seeds present on the soil surface and scattered in the soil profile (Singh *et al*., 2012) [14] It consists of both new weed seeds recently shed and older seeds that have persisted in the soil for several years. In practice, the soil's weed seed bank also includes the tubers, bulbs, rhizomes, and other vegetative structures through which most serious perennial weeds propagate themselves,. Agricultural soils can contain thousands of weed seeds per square foot and understanding the factors impacting the dynamics of weed seed banks can help in the development of integrated weed management (IWM) programs. The weed seed bank not only serves as a physical history of the past successes and failures of cropping systems, it can also help producers predict the degree to which crop-weed competition will affect crop yield and quality. Weed seed banks are particularly critical in farming systems, which rely on cultivation as a primary means of weed control. Because a cultivation pass generally kills a fixed proportion of weed seedlings present, a high initial population will result in a high density of weeds surviving cultivation and competing with the crop. Initial weed population is directly related to the density of seeds in the seed bank (Brainard *et al*., 2008; Teasdale *et al*., 2004) [2, 15]; thus, effective cultivation-based weed control requires either a low seed bank density (Forcella *et al*., 2003) [5] or multiple cultivation passes to achieve adequate weed control.

Weed seeds can reach the soil surface and become part of the soil seed bank through several avenues. The main source of weed seeds in the seed bank is from local matured weeds that set seed. Agricultural weed seeds can also enter a field by animals, wind, water and human activities, like cultivation and harvesting. How far weed seeds can travel depends on the dispersal process and the weed species. Understanding the importance of these dispersal mechanisms is vital in the development of preventive weed management strategies. Weed seeds can have numerous fates after they are dispersed into a field. While a few of these weed seeds will germinate, emerge, grow and produce more seeds, a large proportion of them will germinate and die (also known as fatal germination), decay in the soil, or fall to predation by insects, birds or mammals. Many weed seeds will remain dormant in the soil and not germinate under any set of environmental conditions. When a weed seed is dormant it will not germinate regardless of the environmental condition. This dormancy state is not permanent and weed seeds can change from a state of dormancy to non-dormancy, where they can germinate over a wide range of environmental conditions. Because dormancy can create future weed problems, weed scientists think about dormancy as a dispersal mechanism through time.

Management practices affect weeds seed distribution in the soil profile

Weed seeds disperse both horizontally and vertically in the soil profile. While the horizontal distribution of weed seeds in the seed bank generally follows the direction of crop rows, type of tillage is the main factor determining the vertical distribution of weed seeds within the soil profile. In plowed fields, the majority of weed seeds are buried four to six inches below the surface. Under reduced tillage systems such as chisel plowing, approximately 80 to 90 percent of the weed seeds are distributed in the top four inches of the soil profile. In no-till fields, the majority of weed seeds remain at or near the soil surface. Although very few studies have assessed the effect of tillage systems on the vertical distribution of weed seeds in different soil types, evidence exists that soil characteristics influence weed seed distribution.

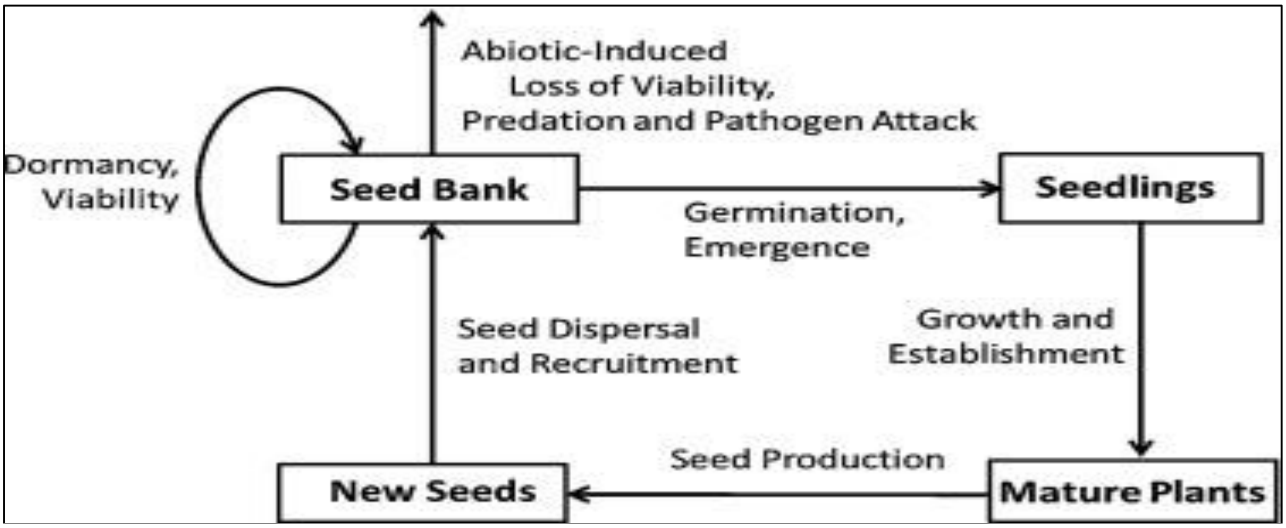

Fig 1: Simplified conceptual representation of transitions among annual weed states

Purpose 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 *Taraxacum officinale* Weber which reproduce by seed only (Gulden and Shirtliffe, 2009) [6]. 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. 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 (Gulden and Shirtliffe, 2009) [6].

Fate of weed seeds in the seed bank

Weed seeds can have numerous fates after they are dispersed into a field (Fig. 2). Of the many seeds 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 (Menalled, 2013) [12]. 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% (White *et al*., 2007) [17]. Larger animals such as rodents and birds can also consume significant amounts of weed seeds.

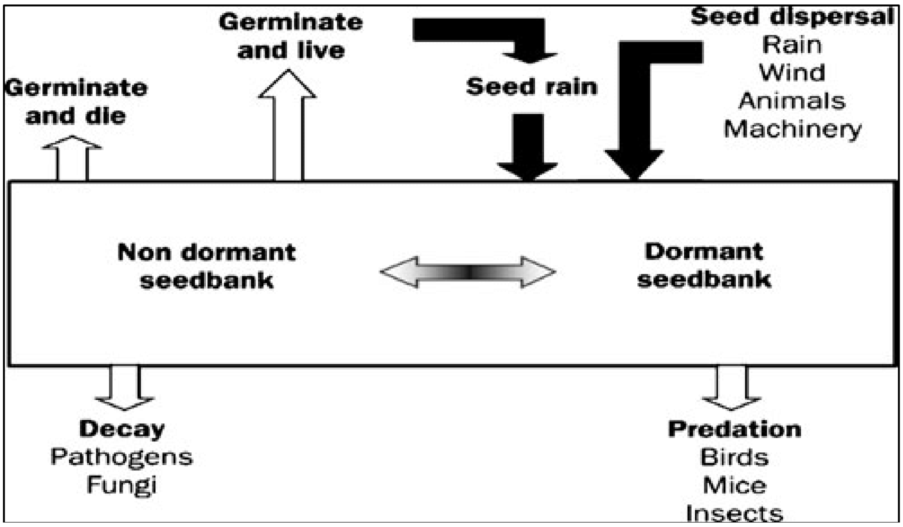

Fig 2: Fate of weed seeds: Inputs to the seedbank are shown with black arrows and losses with white arrows. (Source: Menalled, 2013) [13].

The attack of the A. fatua seeds by soil pathogens was suspected to be the main reason for increase in seed mortality with higher soil moisture contents. With *Setaria viridis* seeds less than 1% of seeds buried in bags were viable after six years (Thomas *et al*., 1986). 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 scoparia* (L.) can sense their depth of burial to limit lethal germination. Seed desiccation is also another important mechanism where 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 (Gulden and Shirtliffe, 2009) [6].

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 related (Thompson *et al*., 2003) [16]. 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. The actual seed longevity in the soil depends on an interaction of many factors, including intrinsic dormancy of the seed population, depth of seed burial, frequency of disturbance, environmental conditions (light, moisture, temperature), and biological processes such as predation, allelopathy, and microbial attack (Davis *et al*., 2005; Liebman *et al*., 2001) [4, 10]. Understanding how management practices or soil conditions can modify the residence time of viable seeds can help producers minimize future weed problems. For example, seeds of 20 weed species that were mixed into the top 6 inches of soil persisted longer in untilled soil than in soil tilled four times annually (Mohler, 2001a) [13], which likely reflects greater germination losses in the disturbed treatment.

Table 1: Number of years required for 50 percent and 99 percent reduction in seed number in the seedbank of ten common agricultural weeds. (Davis *et al*. 2005) [4]

	Years required for 50% reduction	Years required for 99% reduction
Common lambsquarters (*Chenopodium album*)	12	78
Field pennycress (*Thlaspi arvense*)	6	38
Common cocklebur (*Xanthium strumarium*)	6	37
Yellow foxtail (*Setaria glauca*)	5	30
Prostrate knotweed (*Polygonum aviculare*)	4	30
Shepherd’s purse (*Capsella bursa-pastoris*)	3	11
Giant foxtail (*Setaria faberi*)	less than 1	5
Common sunflower (*Helianthus annuus*)	less than ½	2
Kochia (*Kochia scoparia*)	less than ½	2

Evaluating the weed seed bank

One way to estimate a field's weed seed bank is to wait and see what weeds emerge during the first season. However, knowing something about seed bank content before the season starts can help the farmer prevent severe weed problems before they develop. Davis (2004) [3] recommended the following simple procedure for scouting the weed seed bank: A little effort in understanding weed seed bank can give valuable information about what weeds to expect in a given growing season, weed density, and when most weed germination will take place. To get a weed preview, germinate of weeds is the best. For summer annual weeds, March–April is a good time to sample weed seed banks. Using a soil probe or a garden trowel, 20 samples to a 2” depth in a ‘W’ pattern need to be collected from the field. Soil should be placed in a dish, in a warm place (> 65 º F) and kept moist. Within one to two weeks, weed seedlings will be emerged and need to be identified (Davis, 2004) [3]. For a more representative sampling, sufficient soil samples should be collected to fill several dishes, or seedling flat. The larger the sample, the more closely the observed weed emergence will reflect field weed seed bank status.

Why is it important to prevent weed seed production?

Limiting current contributions to the weed seed bank is the best approach to ease future weed management. Over a five-year period in Nebraska, broadleaf and grass weed seed bank was reduced to 5 percent of the original density when weeds were not allowed to produce seeds. However, in the sixth year, weeds were not controlled and the seed bank density increased to 90 percent of the original level (Burnside *et al*., 1984)!

In a six-year study conducted in Canada, Beckie and collaborators (2005) observed that when standard weed management practices were combined with weed seed shed prevention, weed patches expanded in size by 35 percent. However, when only standard weed management approaches were applied, weed patch expansion reached 330 percent.

These studies illustrate three important points. First, seed bank abundance declines rapidly when no new weed seed are allowed to enter to soil. Second, management failures can translate into a rapid increase in weed seed bank abundance. Finally, preventing weed seed production not only helps reducing weed seed banks, it prevents the spread of weeds across the field. Therefore, efforts should be made every year to reduce seed production and weed seed bank abundance as a few seeds are capable of infesting the fields.

Weed Seed Bank Management Practices

Strategies to minimize annual inputs (deposits) to the weed seed bank

- Kill weeds before they set seed-before flowering to be safe, because some weeds (such as hairy galinsoga) can mature seeds from flowers that are pollinated before the weeds are pulled or severed. If in doubt, attempt to thresh the seeds from the fruits or flowers of flowering weeds; dough-consistency and firm seeds can be considered mature and should be removed from the field if possible.
- Control creeping perennial weeds before they can form new rhizomes, tubers, or other propagules.
- Keep crops ahead of the weeds—small weeds overshadowed by a good crop canopy may have less than 1% of the seed forming capacity of vigorous individuals growing in full sun.
- Walk fields to remove large weed escapes before they flower. Getting the largest 10% of individuals can reduce seed production by 90% or better.
- Mow field margins to minimize seed set by weed species that have the potential to invade fields. (Balance this with the potential role of field margins as beneficial insect habitat).
- Mow or graze fields promptly after harvest to interrupt weed seed production.
- Utilize good sanitation practices to prevent introduction of new weed species into the field, and remove new invaders before they propagate.

Another measure that can help contain seed bank populations is to increase the diversity of crop rotations. Although data on the effects of crop rotations on weed seed banks in organic systems have not been consistent, there is some evidence suggesting that more diverse rotations, especially those that include one or more years in red clover, alfalfa, or other perennial sod crops, can help reduce seed inputs from velvetleaf and other annual weeds, and promote seed bank declines through seed predation and decay (Davis *et al*., 2005; Teasdale *et al*., 2004) [4, 15].

Strategies to maximize losses (withdrawals) from the weed seed bank

- Till or cultivate to stimulate weed seed germination at a time when the seedlings can be easily knocked out by additional cultivation or flaming (stale seedbed), or will be freeze-killed before they can reproduce. Rolling after tillage can further enhance germination by improving seed–soil contact.
- If practical, time this tillage or cultivation to take place when seeds of the major weeds present are least dormant, and/or during the season of the weeds' peak emergence, in order to maximize the seed bank withdrawal.
- Time crop planting to facilitate destruction of flushes of weed seedling emergence. For example, if the major weeds in a given field are known to reach their peak emergence in mid-May, delay corn planting until end of May to allow time to remove this flush prior to planting.
- Maintain habitat for weed seed predators—vegetation or mulch cover—in at least part of the field for as much of the year as practical.
- Reduce or avoid tillage during critical times for weed seed predator activity. If a significant weed seed rain has occurred, leave weed seeds at the surface for a period of time before tilling to maximize weed seed predation.

Because soil microorganisms can play a role in weed seed decay, maintaining a high level of soil biological activity through good organic soil management might be expected to shorten the half-life of weed seed banks. In addition, incorporation of a succulent legume or other cover crop may either stimulate weed seed germination by enhancing soil nitrate N levels, or promote weed seed or seedling decay as a result of the "feeding frenzy" of soil microorganisms on the green manure residues. However, the potential of these practices as weed seed bank management tools requires verification through further research.

While it is sometimes advantageous to cause weed seeds to germinate, it is important at other times to keep them quiescent long enough for the crop to get well established. Several practices can help reduce the number of weeds emerging in the crop.

- Cultivate at night or with light shields over the cultivation implement to minimize the light stimulus to weed seeds.
- Leave a loose soil surface after planting or cultivation to reduce seed–soil contact for near-surface weed seeds, thereby deterring germination. If practical, cover newly seeded rows with loose soil to reduce within-row weed emergence.
- Minimize soil disturbance at or near the time of planting. Do major tillage in fall or very early spring several weeks before planting. Use flame or very shallow cultivation to prepare the seedbed.
- Avoid practices that result in early pulses of nitrogen that may stimulate weed emergence. Use split N fertilizer applications and slow releasing forms of N, such as compost and legume–grass cover crop mixtures) to make N availability patterns over the season match N needs of the crop rather than the weeds.
- Avoid planting crops in fields with heavy populations of weeds with similar life cycles. For example, fields dominated by late emerging summer annual weeds might best be planted in early crops like peas.

- Time crop planting to take place well before the most abundant weed species in the field are expected to emerge.
- Time crop planting to take place after the expected major weed seedling flushes, and remove the latter by shallow cultivation or flame weeding.
- Invert the soil to a depth from which weed seeds cannot emerge (most effective for weeds with small, short-lived seeds).

Incorporated green manures or surface residues of cover crops can reduce the establishment of small-seeded weeds through allelopathy and/or physical hindrance. Thus, these practices can provide a measure of selective weed control for transplanted or large-seeded crops, which are tolerant to the stresses imposed by cover crop residues. This selectivity does not apply to small-seeded, direct sown vegetables like carrots and salad greens, which are at least as sensitive to these cover crop effects as small-seeded weeds.

Conclusion

One of the most important, yet often neglected weed management strategies is to reduce the number of weed seeds present in the field, and thereby limit potential weed populations during crop production. This can be accomplished by managing the weed seed bank. There are many fates and processes that occur in the weed seed bank, many of which are not very well understood. 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 would be an important component of integrated weed management.

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