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Soil weed seed bank: Importance and management for sustainable crop production- A Review

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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.

Keywords: Weed seed bank, Deposit, Distribution, Withdrawal

Introduction

The weed seed bank is the reserve of viable weed seeds present on the soil surface and scattered throughout the soil profile (Singh *et al.,* 2012; Begum *et al.,* 2006). It consists of both new weed seeds recently shed, and older seeds that have persisted in the soil from previous years. In practice, the soil's weed seed bank also includes the tubers, bulbs, rhizomes, and other vegetative structures through which some of our most serious perennial weeds propagate themselves. Agricultural soils can contain thousands of weed seeds and a dozen or more vegetative weed propagules per square foot (Menalled, 2013).

The weed seed bank serves as a physical history of the past successes and failures of cropping systems, and knowledge of its content (size and species composition) can help producers both anticipate and ameliorate potential impacts of crop weed competition on crop yield and quality. Eliminating "deposits" to the weed seed bank also called seed rain-is the best approach to ease future weed management (Menalled, 2008).

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); thus, effective cultivation-based weed control requires either a low seed bank density (Forcella *et al.,* 2003) or multiple cultivation passes to achieve adequate weed control.

Types of seed bank

This review focuses on soil seed banks which are the most common and important in 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. *Arctium minus* Bernh and *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., *Kochiascoparia* L.). Aerial seed banks tend to be of greater importance in pasture, orchard, or natural settings than in agricultural fields (Gulden and Shirtliffe, 2009).

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 *Kochiascoparia* (L.) and *Taraxacumofficinale* (Weber). Seed banks of these species require almost annual renewal, while other species such as *Amaranthusretroflexus* (L.) and *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 to choose appropriate practices to manage the seed banks.

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 *Taraxacumofficinale* Weber which reproduce by seed only (Gulden and Shirtliffe, 2009). 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).

Fate of weed seeds in the seed bank

Weed seeds can have numerous fates after they are dispersed into a field (Fig. 1). 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). 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). Larger animals such as rodents and birds can also consume significant amounts of weed seeds.

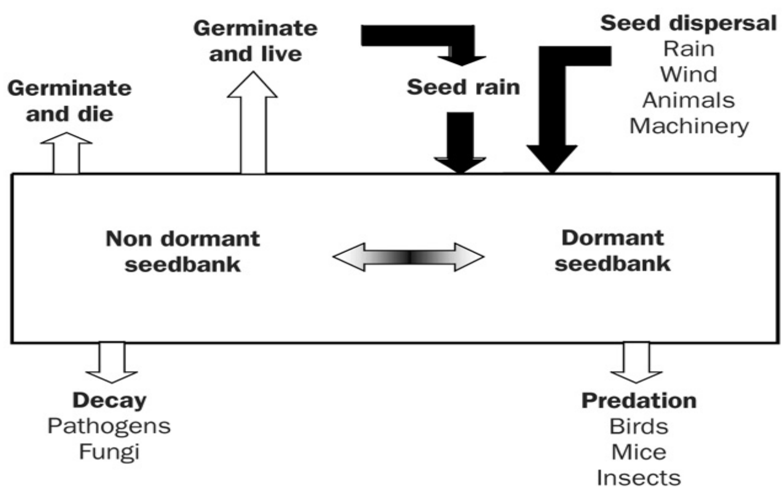

Fig. 1. Fate of weed seeds. Inputs to the seed bank are shown with black arrows and losses with white arrows (Source: Menalled, 2013).

When buried and not available to predators, attack by pathogens is more common. Mortality of *Avenafatua* (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 study (Mickelson and Grey, 2006). 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 *Setariaviridis* 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 *Kochiascoparia* (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).

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 seeds (Baskin and Baskin, 1998). 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 *A. fatua* (Gulden and Shirtliffe, 2009). 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., *Abutilon thoephrasti* (L.) and members of the goosefoot family such as *Chenopodium album* (L.). Seeds from these species can readily survive several decades in the soil seed bank (Radosevich *et al.,* 1997). 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 factors (Baskin and Baskin, 1998).

Secondary seed dormancy is controlled by factors like temperature, light, oxygen, and certain bio-chemicals. Light and temperature are capable of both inducing and breaking secondary seed dormancy (Gulden *et al.,* 2003) 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 *A. retroflexus*, a flash of white light (as faint as full moon light) is often sufficient in breaking seed dormancy as the seed is close to the surface. This is one mechanism by which day-time cultivation increases seed germination. In other species such as *A. fatua* 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 operation (Sexsmith and Piman, 1967). 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 success(Thornton *et al.,* 1998); 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 related (Thompson *et al.,* 2003). 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.

Table 1. Longevity of different weed species in the seed bank (Source: Conn *et al.,* 2006)

Weed species	Maximum longevity (years)
Calamagrostiscanadensis (Michx.) Beauv.	8-14
Hordeumjubatum L.	7-8
Elytrigiarepens (L.) Nevski	4-6
Avenafatua L.	4-6
Dracocephalumparviflorum Nutt.	> 20*
Stellaria media (L.) Vill.	> 20
Galeopsistetrahit L	2-3
Chenopodium album L.	> 20
Spergulaarvensis L.	18-20
Descurainiasophia (L.) Webb ex Prantl.	16
Polygonumpensylvanicum L.	14-18
P. aviculare L.	10-14
P. convolvulus L.	6-8
Matricariamatricarioides (Less.) C.L. Porter	> 20
Potentillanorvegica L.	12-14
Capsella bursa-pastoris (L.) Medicus	> 20

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

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). 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), which likely reflects greater germination losses in the disturbed treatment.

Distribution of weed seed in the seed bank

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 (Cousens and Moss, 1990). Under reduced tillage systems such as chisel plowing, approximately 80 to 90 percent of the weed seeds are distributed in the top four inches. In no-till fields, the majority of weed seeds remain at or near the soil surface. Clements *et al.* (1996) have shown that soil texture may influence weed seed distribution in the soil profile under these different tillage systems (Fig. 2).

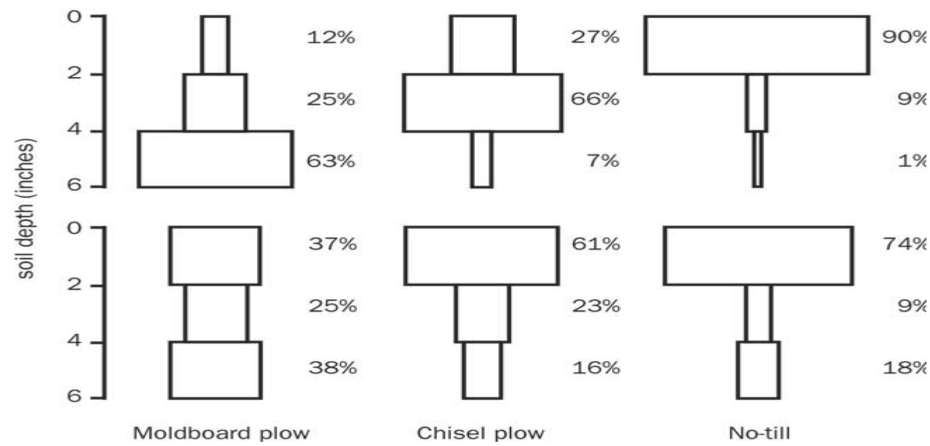

Fig. 2. Vertical distribution of weed seeds in a loamy sand soil (top) and a silty loam soil (bottom) (Source: Clements *et al.,* 1996)

Understanding the impact of management practices on the vertical distribution of seeds is important because it can help us predict weed emergence patterns. For example, in most soils small-seeded weeds such as *Kochiascoparia* (L.), *Cirsiumarvense* (L.), and *Chenopodium album* (L.) germinate at very shallow depths (less than 0.5 inch). Large seeded weeds such as *Helianthus annus* (L.) have more seed reserves and may germinate from greater depths.

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) 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). 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.

Management of weed seed bank

Soil and crop management: 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 effect on the weed seed bank, only a few key methods directly affect weed seed input, seed bank persistence and germination from the 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 (Hossain *et al.* 2014c). 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 m^{-2} (Blackshaw *et al.,* 2004a; Clements *et al.,* 1996). 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}) (Archibold, 1981). Weed seed bank additions are high in fallow fields in part due to incomplete weed control by tillage and the absence of a competitive crop (Archibold and Hume, 1983).

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 operation (Shirtliffe and Entz, 2005).

Tillage: Tillage was the main method for managing weeds, until the introduction of herbicides. 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, 37% of the viable weed seed bank was found in the top 5 cm of the soil profile and 74% under no-till(Clements *et al.,* 1996). 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-till (Gulden *et al.,* 2004). Canola seed could only have persisted for three years if it was buried (Liebman *et al*., 2001); 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 management (Fenner and Thompson, 2005). In general, lower weed populations were reported by farmers that practice no-till in western Canada, which is indicative of lower weed seed banks (Blackshaw *et al.,* 2008). In Ontario, weed seed banks were almost two times greater under chisel plow management compared to no-till (duCroixSissons *et al.,* 2000).

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 levels (Mickelson and Grey, 2006).

Surface accumulation of seeds under reduced tillage would increase predator access to seeds and therefore could increase their removal rates. Lack of soil disturbance via tillage could also encourage higher predator populations. No till fields increase the number, diversity, or activity of seed-consuming fauna as compared to conventionally tilled fields (Blubaugh and Kaplan, 2015) may be due to increased habitat (Baraibar *et al.,* 2009) or decreased mortality rate (Shearin *et al.,* 2007).

Mulching: The mulch of dead plant residue (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 (*Secalecereale* L.), clover (*Trifolium*s pp. L.) and recently incorporated canola contain allelopathic chemicals which inhibit seed germination (Moyer *et al.,* 2000; Vera *et al.,* 1987). The effectiveness of allelopathic chemicals diminishes over time as the chemicals are leached form 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 allele-chemicals 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 (Blackshaw*et al.,* 2003; Blackshaw*et al.,*2004b). 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 system (O'Donovan *et al.,* 1997). 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. Composting manures before application reduces the viability of weed seeds, minimizing weed seed inputs into the seed bank (Menalled, 2008).

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. 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 would be an important component of integrated weed management.

References

Archibold, O.W. 1981. Buried viable propagules in native prairie and adjacent agricultural sites in central Saskatchewan. *Can. J. Bot*. 59: 701-706.

Archibold, O.W. and Hume, L. 1983. A preliminary survey of weed input into fallow fields in Saskatchewan. *Can. J. Bot*. 61: 1216-1221.

Baraibar, B., Westerman, P.R., Carrión, E. and Recasens, J. 2009. Effects of tillage and irrigation in cereal fields on weed seed removal by seed predators. J. Appl. Ecol. 460: 380–387.

Baskin C.C. and Baskin, J.M. 1998. *Seeds: Ecology, biogeography, and evolution of dormancy and germination*. San Diego: Academic Press. 666p.

Begum, M., Juraimi, A.S., Rastan, S.O.B.S., Amartalingam, R. and Man, A.B. 2006.Seedbank and seedling emergence characteristics of weeds in rice field soils of the muda granary area in north-west peninsular Malaysia. BIOTROPIA. 13 (1): 11 – 21.

Blackshaw R.E., Brandt, R.N., Janzen, H.H. and Entz, T. 2004b. *Weed species response to phosphorous fertilization*. Weed Sci. 52: 406-412.

Blackshaw R.E., Brandt, R.N., Janzen, H.H., Entz T., Grant, C. and Derksen, D.A. 2003. Differential response of weed species to added nitrogen. Weed Sci. 51: 532-539.

Blackshaw R.E., Harker, K.N., O'Donovan, J.T., Beckie, H.J. and Smith, E.G. 2008.Ongoing development of integrated weed management systems on the Canadian Prairies. Weed Sci. 56: 146-150.

Blackshaw R.E., Molnar, L.J. and Janzen, H.H. 2004a. Nitrogen fertilizer timing and application method affect weed growth and competition. Weed Sci. 52:614-622.

Blubaugh, C.K. and Kaplan, I. 2015. Tillage compromises weed seed predator activity across developmental stages. Biol. Control 81: 76–82.

Brainard, D.C., Bellinder, R.R., Hahn, R.R. and Shah, D.A. 2008.Crop rotation, cover crop and weed management effects on weed seedbanks and yields in snap bean, sweet corn and cabbage. Weed Science. 56: 434–441.

Clements, D.R., Benoit, D.L., Murphy, S.D. and Swanton, C.J. 1996. Tillage effects on weed seed return and seedbank composition. Weed Sci. 44: 314-322.

Conn, J.S., Beattie, K.L. and Blanchard, A. 2006. Seed viability and dormancy of 17 weed species after 19.7 years of burial in Alaska. Weed Sci. 54: 464-470.

Cousens, R. and Moss, S.R. 1990. A model of the effects of cultivations on the vertical distribution of weed seeds within the soil. Weed Res. 30: 61–70.

Davis, A.S. 2004.Managing weed seedbanks throughout the growing season [Online].New Agriculture Network Vol. 1 No. 2.

Davis, A.S., Renner, K.A. and Gross, K.L. 2005. Weed seedbank and community shifts in a long-term cropping systems experiment. Weed Sci. 53: 296–306.

duCroixSissons M.J., van Acker, R.C., Derksen, D.A. and Thomas, A.G. 2000. Depth of seedling recruitment of five weed species measured in situ in conventional- and zero-tillage fields. Weed Sci. 48:327-332.

Fenner, M. and Thompson, K. 2005.The ecology of seeds. Cambridge, UK: Cambridge University Press. 250 p.

Forcella, F. 2003. Debiting the seedbank: Priorities and predictions. p. 151–162. *In*Bekker*et al.* (eds.) Seedbanks: Determination, dynamics and management. Aspects of Applied Biology 69.Association of Applied Biologists, Welles Bourne, UK.

Gulden R.H., Thomas, A.G. and Shirtliffe, S.J. 2003 Secondary seed dormancy prolongs persistence of volunteer canola (*Brassica napus*) in western Canada. Weed Sci. 51: 904-913.

Gulden R.H., Thomas, A.G. and Shirtliffe, S.J. 2004. Secondary dormancy, temperature, and seed burial depth regulate seedbank dynamics in *Brassica napus*. Weed Sci. 52: 382-388.

Gulden, R.H. and Shirtliffe, S.J. 2009. Weed Seed Banks: Biology and Management. Prairie Soils & Crops J. 2: 46-52.

Hossain, M.M., Begum, M., Hashem, A, Rahman, M.M., Bell, R.W. Haque, M.E. 2014c. Yield response of mustard as influenced by weed management practice under conservation agriculture system. Bangladesh J. Weed Sci. 4 & 5, 87-92.

Liebman, M., Mohler, C.L. and Staver, C.P. 2001 Ecological management of agricultural weeds. Cambridge, UK: Cambridge University Press. 532 p.

Menalled, F.D. 2008. Weed Seedbank Dynamics & Integrated Management of Agricultural Weeds. Agriculture and Natural Resources (Weeds), 200-708SA

Menalled, F.D. 2013. Manage the Weed Seed Bank—Minimize "Deposits" and Maximize "Withdrawals". Available at: extension.org http://www.extension.org/pages/18527/manage-the-weed-seed bankminimize-deposits-andmaximize-withdrawals#. VkG6 Xl53C1t

Mickelson, J.A. and Grey, W.E. 2006.Effect of soil water content on wild oat (*Avenafatua* L.) seed mortality and seedling emergence. Weed Sci. 54: 255-262.

Mohler, C.L. 2001a. Weed life history: identifying vulnerabilities. Cambridge University Press, New York. p.40–98.

Moyer J.R., Blackshaw, R.E., Smith, E.G. and McGinn, S.M. 2000. Cereal cover crops for weed suppression in a summer fallow-wheat cropping sequence. Can. J. Plant Sci. 80: 441-449.

O' Donovan, J.T., McAndrew, D.W. and Thomas, A.G. 1997. Tillage and nitrogen influence weed population dynamics in barley (*Hordeumvulgare* L.). Weed Technol. 11: 502-509.

Radosevich, S., Holt, J. and Ghersa, C. 1997. *Weed ecology: Implications for management.* New York: John Wiley & Sons, Inc. 589p.

Sexsmith J.T. and Piman, V.J. 1967.Effect of nitrogen fertilization on germination and stand of wild oats. Weed Res. 11: 99-101.

Shearin, A., Reberg-Horton, S. and Gallandt, E. 2007. Direct effects of tillage on the activity and density of ground beetle (Coleoptera: Carabidae) weed seed predators. Environ. Entomol. 36: 1140–1146.

Shirtliffe S.J. and Entz, M.H. 2005 *Chaff collection reduces seed dispersal of wild oat (Avenafatua) by a combine harvester*. Weed Sci. 53: 465-470.

Singh, A., Kaur, R., Kang, J.S. and Singh, G. 2012.Weed dynamics in rice-wheat cropping system. Global *J. Biol. Heal. Sci*., 1(1): 7-16.

Teasdale, J.R., Magnum, R.W., Radhakrishnan, J. and Cavigelli, M.A. 2004. Weed seedbank dynamics in three organic farming crop rotations. *Agronomy J.* 96: 1429–1435.

Thomas, A.G., Banting, J.D. and Bowes, G. 1986. Longevity of green foxtail seeds in a Canadian prairie soil. Can. *J. Plant Sci*. 66: 189-192.

Thompson K., Ceriani, R.M., Bakker, J.P., and Bekker, R.M. 2003. Are seed dormancy and persistence in soil related? Seed Sci. Res. 13: 97-100.

Thornton, M.A., Peters, N.B.C., West, T.M. and Thomas, T.H. 1998. A novel way to control volunteer oilseed rape (*Brassica napus*).Asp. Appl. Biol. 51: 191–196.

Vera, C.L., McGregor, D.I. and Downey, R.K. 1987. Detrimental effects of volunteer Brassica on production of certain cereal and oilseed crops. *Can. J. Plant Sci*. 67: 983-995.

White S.S., Renner, K.A., Menalled, F.D. and Landis, D.A. 2007. Feeding preferences of weed seed predators and effect on weed emergence. Weed Sci. 55: 606-612.