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Chapter 3

# Weed Seedbank in Rice Fields

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**Abstract**

The weed seedbank in the soil is the major source of weeds in rice fields. Therefore, information on ecological aspects of weeds occurring in rice, including their potential seed production, is crucial for weed management. The size of the weed seedbank in rice fields is highly variable depending on the climate, relief position, soil moisture content, depth of sampling, history of the areas and management practices used by farmers. As a survival strategy, colonization and persistence in the communities, most common weeds in rice fields produce huge number of seeds and vegetative propagules with physical and physiological dormancy mechanisms, insuring seed viability in the soil for long periods. A large proportion of weed seedbank remains generally on or close to the soil surface after seed rain. Sampling protocols involve the use soil cores at variable soil depths. Determination of the size of the weed seedbank can be made by seed direct extraction and germination methods. The latter is more precise with respect to enumeration of viable seeds in the soil. Weed management in rice fields should focus on methods suitable to decrease the weed population in the soil seedbank.

**Keywords:** competition, biological invasion, germination, weed management, allelopathy

## 1. Introduction

Many weeds grow in association with the rice crop and their distribution and occurrence intensity are determined by a complex of climate, soils and relief and management practices. Weeds interfere with rice growth and yield by means of competition for nutrients, water, light and space. Moreover, many weed species possess allelopathy mechanisms that hinder or even prevent the growth of other species associated with them, including rice, resulting in decreased yield by up to 96% [1].

Weeds are a major biological constraint for rice farmers. Many weed species that occur in rice fields can produce a huge number of small seeds and vegetative propagules as a strategy to survive stresses imposed by control methods [2–4]. After dispersal, seeds may remain on the

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soil surface or be buried by means of biotic and abiotic agents thus forming a seedbank which becomes the main source of weeds in rice cropping fields.

As a survival strategy, colonization and persistence in the communities, the weeds have developed a number of features, for example, seed dormancy, which enables the occurrence of discontinuous germination during the rice crop growing season in addition to ensuring the viability of the seeds in the soil for long periods.

The weed seedbank in the soil is a dynamic system with inputs and outputs. The inputs occur via seed rain as a result of efficient dispersion mechanisms and the outputs by means of germination, predation [5–7] and decay or seed death [8].

Various factors affect weed seed germination including variations in soil temperature and moisture [9–13] and physiological aspects of the seeds particularly seed dormancy [14]. When favorable environmental conditions occur and physiological constraints are overcome, seeds germinate; weeds grow and produce new propagules enriching the soil seedbank.

Research on identification and quantification of weed species germinated in the soil seedbank from rice fields were carried out by numerous authors [9, 15–20]. However, due to its ecological and economic importance, the status of the weed seedbank in rice cropping fields needs to be further investigated. Studies on weed seedbank ecology are crucial for improving weed control practices in rice fields.

Field and greenhouse studies are needed in order to understand the soil weed seedbank germination dynamics and its relationship with the weed flora on rice fields. These studies can contribute to predict infestations and could lead to improved management practices to decrease the negative effects of weed interference with rice crop growth and yield.

The goal of this chapter is to discuss general aspects of weed seedbank ecology including weeds associated with rice agroecosystems, types, sizes and major characteristics of the weed seedbank in rice fields, including seed dormancy, research methodology, factors affecting germination dynamics and some aspects of weed seedbank management in rice fields.

## 2. Major weeds in rice fields

### 2.1. South and Southeast Asia

Many weeds are associated with rice agroecosystems in different parts of the world. In South and Southeast Asia, 64 weeds were reported as the most important in upland rice [21]. These occur in 18 families; 37 are broadleaves, 20 are grasses and 7 are sedges. Twenty-seven of the cited weeds are primarily annuals, 20 are perennials and 17 are classified as annual or perennial [21]. Ninety weed species were reported competing with rice under aerobic systems [22]. In contrast [23] reported 47 weed species in the rice crop and [24] cited more than 1800 weed species reported in 15 South and Southeast Asian countries. *Cyperus iria* L., *Cyperus difformis* L., *Echinochloa colona* (L.) Link, *Ischaemum rugosum* Salisb. *Leptochloa chinensis* Nees, *Ludwigia hyssopifolia* (G. Don) Excel, *Oryza sativa* L., *Schoenoplectus juncoides* (Roxb.) Palla, *Sphenochlea zeylanica* Gaertn. are the 12 most troublesome weeds of rice in Asia [25].

### 2.2. Africa

One hundred and thirty weed species are reported to occur in rice-based cropping systems in Africa [26]. Major weed species of upland rice areas are *Rottboellia cochinchinensis* (Lour.) W. Clayton, *Digitaria horizontalis* Willd., *Ageratum conyzoides* L. and *Tridax procumbens* L., while *A. conyzoides* and *Panicum laxum* Sw. which were more cited in the hydromorphic areas and *Cyperus difformis* L., *Sphenoclea zeylanica* Gaertn., *Fimbristylis littoralis* Gaudich, *Oryza longistaminata* A. Chev. & Roehr., *Echinochloa colona* (L.) Link and *Echinochloa crus-pavonis* (Kunth) Schult. dominates the lowland rice fields. Poaceae (43%) and Cyperaceae (37%) are the most prevalent families in lowland rice while, in the uplands, weed species composition tends to be more diverse with Poaceae (36%) and Asteraceae (16%) most prevalent [26].

### 2.3. Latin America

In Latin America [27] reported 13,892 individuals belonging to 20 families, 40 genera and 60 species in the soil weed seedbank germination studies *in situ* and *ex situ* in which there were 11,530 individuals and 50 species *ex situ* and 2362 individuals and 34 species *in situ*. Total density was 3859 plants $m^{-2}$ [27].

The families with the highest species richness were Cyperaceae with sixteen, Poaceae with ten and Fabaceae-Faboideae with six species each. These families contributed with 53.3% of total species. In contrast, ten families: Amaranthaceae, Euphorbiaceae, Lamiaceae, Loganiaceae, Marantaceae, Nyctaginaceae, Plantaginaceae, Portulacaceae, Solanaceae, Thelypteridaceae and Turneraceae had only one species each. These correspond to 50% of the total of all recorded families [27]. Similar results were observed by [15] who reported that that 86% of species present in seedbank from 22 rice fields in Camboja were Cyperaceae family. In Nepal, Ref. [28] also reported that 37% of the species present in the weed seedbank belonged to this family.

In the tropics, about 80% of seeds germinate until the 60th day of the study in the greenhouse. Germination peak is generally observed at 25 days after the beginning of the study which coincides with the period of the start of the rainy season in the region leading to an increase in weed germination and emergence in weed soil seedbank. Germination stabilization generally occurs at 115 days after start of study [16] (**Figure 1**).

Floristic diversity, based on Shannon Diversity Index, generally is greater *ex situ* study with $H' = 2.66$ nats $ind^{-1}$, against $H' = 2.53$ nats $ind^{-1}$ *in situ*. The highest number of individuals and species found *ex situ* contribute for the greatest floristic diversity *ex situ* [16].

The most important species in the weed seedbank in Latin America based on the importance value were *Ludwigia octovalvis* (Jacq.) P. H. Raven, *Schoenoplectus juncoides* (Roxb.) Palla, *Lindernia crustacea* (L.) F. Muell, *Cyperus sphacelatus* Roth, *Cyperus iria* L., *Fimbristylis dichotoma* (L.) Vahl, *Boerhavia erecta* L., *Rhynchospora nervosa* (Vahl) Boeck, *Scleria lithosperma* (L.) Sw. and *Sida rhombifolia* L. [16]. In Latin America, species of the family Cyperaceae largely dominates the weed seedbank in the soil of rice fields [16]. Forrmation of a seedbank represents an important regeneration component for many species of this family [2].

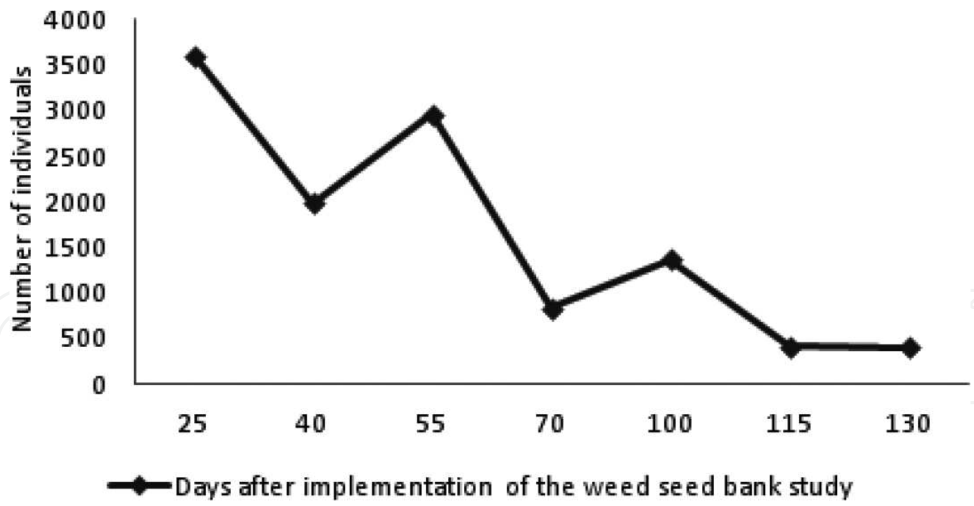


**Figure 1.** Germination curve of weed of the weed seedbank from a rice field, in Maranhão State, Northeast Brazil, Latin America.

The species dominance in weed seedbank in rice fields might be related not only to cultural practices and crop history but also to the reproductive capacity of the weed species. All species cited here are propagated exclusively by seeds, except for *F. dichotoma* and *S. lithosperma* (Cyperaceae), which also propagate asexually, by rhizomes [29].

The ability to produce a very high number of seeds is one of the main features developed by weeds that occur in rice fields. This is a strategy to escape the stress imposed by the control methods and ensure the species survival.

In the Philippines, for example, see [25], among the weed species occurring in paddy fields, one of the species *Ludwigia octovalvis* (L.) F. Muell (Onagraceae) is capable of producing 250,000 seeds, while *Echinochloa colona* (L.) Link and *Echinochloa crus-galli* (L.) P. Beauv both from the Poacae family can produce 3100 and 2900 seeds per plant, respectively [5].

*Schoenoplectus* spp. (Cyperaceae) are able to produce on average 82,098 seeds.m$^{-2}$ [2]. Other species of the same family, among which, *Fimbristylis miliaceae* (L.) Vahl, *Fimbristylis dichotoma* (L.) Vahl, can produce 10,000 and 6500 seeds per plant, respectively [29], while *Cyperus iria* (L.) can produce 5000 seeds per plant [30].

After dispersal, weed seeds are deposited on the soil forming the seedbank that becomes the main source of weeds in rice fields.

## 3. Weed seedbank types

Soil seedbanks vary according to the duration their seeds remain viable in the soil [30]. Weed scientists distinguished between transient seedbanks for species that have viable seeds present for less than 1 year, such as seeds from grasses, for example, and short-term persistent seedbanks for species with viable seeds that remain for at least 1 but less than 5 years and

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long-term persistent, when seeds persist in the soil for at least 5 years [30]. Seeds of many weed species of the Malvaceae and Fabaceae families have long persistence in the soil because of their tegument impermeability to water and gases [14].

Seed persistence in the soil has been attributed to variation in fungal activity, soil fertility, particularly the presence of nitrates, oxygen supply, vegetation cover, burial depth via biotic and abiotic agents, seed density and predator pressure [31].

## 4. Characteristics of the weed seedbanks

### 4.1. Seed dormancy

Dormancy is the failure of the weed seeds to germinate under favorable environmental conditions. There are two types of seed dormancy. The first is known as primary or innate dormancy which occurs when seeds are dormant at the time of maturity and the second, as secondary dormancy which is when weed seeds can cycle in and out of a dormancy state due to variation on environmental conditions [14]. Seed dormancy in the soil is important because it maintains the weed seedbank over time and thus helps to ensure that for most weed species only a small proportion of buried weed seeds is recruited as seedlings from the soil seedbank in any given year [14].

The main dormancy mechanisms are physiological, by means of hormones, phytochromes and inhibitors; physical, due to impermeable seed coat to water and gases; and morphological, due to immature embryo [14].

In temperate climate regions, the weed seedbank declines 32% a year [32]. In contrast, in tropical regions, the weed seedbank is generally smaller and the decline tends to be faster because (a) there is a high seedling recruitment rate due to favorable climate conditions for seed germination, which persist for longer periods than in temperate regions; (b) high seed mortality due to attack of predators; (c) high relative humidity and higher temperatures, which favor biotic agents; (d) seedling mortality due to seed germination in short, hot dry periods that can occur during the rainy season; (e) a shorter duration or even the absence of seed dormancy in many weed species; and (f) low seed viability [33].

In post-dispersal weed seedbank studies carried out in rice fields in the Philippines, it was noted that in a period of only 14 days, the fire ants (*Solenopsis geminata*) were the main predators and responsible for the removal of 98%, 88% and 75% of *Digitaria ciliaris* (Retz.) Koeler, *Eleusine indica* (L.) and *Echinochloa colona* (L.) Link seeds, respectively, previously placed on soil surface [5].

Generally higher germination rates observed in the soil weed seedbank in rice fields in the first 60 days [27] is probably due to dormancy breaking because of greater sunlight exposition and temperature variation as observed by many authors [34–35]. This is corroborated by studies carried out in the Philippines where 50% of weed soil seedbank in rice fields germinated in first six weeks [36] and in rice field in Malaysia where it was noted that the highest germination peak occurred at 30 days [9].

### 4.2. Weed seedbank size in rice fields

The magnitude of weed seedbanks in rice fields is highly variable. Using the direct seed extraction method Ref. [17] found 260,000 seeds $m^{-2}$ in Vietnã, Ref. [19] reported that the number of weed seeds in the soil ranged from 17,300 to 646,000 $m^{-2}$ in New South Wales, Australia, Ref. [15] reported that in the top 5 cm of soil ranged from 52.1 to 167,000 seeds $m^{-2}$ with overall mean of 8,500 seeds $m^{-2}$ in Cambodian rice fields, Ref. [37] found from 116,812 to 294,761 seeds $m^{-2}$ in China. In contrast, using the germination method Ref. [38] found from 1700 to 4000 seedlings $m^{-2}$ in Northern Laos, Ref. [39] counted 878 seedlings $m^{-2}$ and Ref. [18] found 4953 seedlings $m^{-2}$ in weed seedbank in rice fields in Latin America.

Differences in the number of seeds or weed seedling density in the seedbank can be explained by several factors, including climate, relief position, soil moisture content, depth of sampling, history of the areas and management practices used by rice farmer [40].

### 4.3. Seed distribution in the soil profile

In cropping systems where there is no soil disturbance and no tillage, as is the case for subsistence farming, weed seeds tend to remain on the soil surface, where they are easier to control [42].

The seed location is an important feature because only those situated on or near the soil surface are able to germinate, which can lead to greater short-term germination flows accelerating the reduction of the seedbank. Moreover, the permanence of seeds at the soil surface favors predation [43].

Studies on the movement of weed seeds in a no-till soil have shown that after 1 year, the seeds reached deeper in sandy soils (10% > 6 mm) than in clayey soils (2% > 6 mm). It was also noted that the vertical movement is very small and is conditioned by soil texture, the cumulative rainfall and the seed size, weight and shape [43].

The smaller and lighter seed concentrate at the soil surface. With respect to the seed shape, those flattened are more difficult to penetrate the soil than spherical, discoidal or pyramidal [43].

## 5. Weed seedbank research methodology

### 5.1. Sampling

Weed scientists advocate the use of 5 cm diameter cores to sample weed seedbanks in the soil. They state that this size core is large enough to detect seeds, but small enough not to burden the researcher with too much soil [44]. The number of cores to be sampled and the depth to which soil cores should be taken depends upon the research objectives. If the research is to determine the seedbank size and composition or to relate seedbanks to aboveground weed flora, then seedbanks should be sampled at times that follow seed shed but precede seed germination [44].

### 5.2. Determination of the size and floristic composition of the weed seedbank

There are two methods to enumerate the number of seeds in the soil: Direct seed extraction and germination method

#### *5.2.1. Direct seed extraction*

In the direct seed extraction technique, seeds are separated from soil by washing or flotation. Initially the soil sample is placed on a screen with a mesh size smaller than the smallest expected seed. A mesh size of about 0.2 mm is enough to catch most small seeds [44].

The flotation method is often used after the soil sample has been washed. The objective is to separate seed from soil particles so that they will float in a solution made with water and potassium carbonate. After the seeds are separated using the direct seed extraction method, they must be identified. Identification is made under magnification using proper literature [44].

#### *5.2.2. Germination method*

The second technique for enumerating seeds in the soil seedbank is the germination method [44]. This technique is used to enumerate the density of nondormant seeds in the seedbank. Twenty cores are recommended from an experimental treatment [44]. The cores are mixed, composed, inserted in trays and placed in greenhouse. The most suitable soil depth in the trays should be within 2–3 cm with a maximum of 5 cm so that all seeds can germinate. Trays should be perforated in order to facilitate drainage. In case of sandy soils, water retention can be improved by lining the trays with vermiculite (**Figure 2**).

**Figure 2.** Germination method.

In recent years, research on seedbanks has focused more on the germination method instead of the direct seed extraction. The main reason for this is that the germination method is more accurate because it enables to estimate the actual weed seedbank size considering that all viable seeds will germinate even if it takes several months of work. Furthermore, the seedlings are easier to identify than the seeds.

## 6. Weed seedbank management in rice fields

The weed seedbank in rice fields is an indicator of weed community resulting from the present and past weed control practices and can provide valuable information for the development of ecologically friendly practices such as, for example, the reduction of herbicide application.

In the past few years, several authors have recommended that the weed management should integrate the different control methods in order to decrease weed population in the soil seedbank [45–48].

A reduction in the weed seedbank germination means minor problem with weeds and hence savings for rice farmers. Moreover, it can provide a healthier environment with less use of chemicals, creating the necessary conditions for the development of more efficient and environmentally acceptable weed management.

Therefore, it is important to limit the current contribution to the weed seedbank to reduce the population size and facilitate the use of future weed control practices.

### 6.1. Land preparation

Soil disturbance with tillage can promote weed seed germination by several mechanisms including exposition of weed seeds to light which releases seeds of some species from dormancy but can also bury some seeds that are on the soil surface [41]. Tillage prior to rice crop establishment may result in nitrogen mineralization which can promote some seed germination. On the other hand, off-season dry soil tillage at sufficient depth may help breaking and drying vegetative propagules including stolons, bulbs and subsoil rhizomes of perennial weeds. However, tillage may cause soil erosion and increase costs for the rice farmer [36]. Patterns of weed emergence as affected by tillage in upland and lowland rice soils have shown that 40–50% occurred within 6 weeks after tillage in both sites. A significant weed emergence was observed within 3 weeks in both soils but very little emergence occurred in lowland soil [36].

### 6.2. Mulching

Soil mulching reduces weed seed germination by 90% [49]. The reduction in seed germination in the weed seedbank occur because the mulch prevents the penetration of light or blocks certain spectrum of light wavelengths which are necessary for most of the weed seeds to germinate [50–52]. This is the case for the weed species that produce seeds that are photoblastic positive, that is, need light to germinate, such as *Amaranthus retroflexus* [53],

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*Eclipta alba* [54], *Hyptis suaveolens* [55], *Digitaria* spp. [56], *Urtica dioica* [57], *Ageratum conyzoides* [23, 58], *Fimbristylis autumnalis* [23] and *Cyperus aggregatus* [59].

Moreover, the physical barrier formed by straw must contributes to the death of germinated seedlings from seeds located on the soil surface, whose reserves were not enough to overcome the mulch [60, 61] and provides cover for predators that feed on weed seeds. In addition, residues have a moderating effect on temperature fluctuations in the soil, which in turn can impact seed dormancy of many weed species.

In India, for example, see Ref. [62], the use wheat straw as mulch resulted in 54% reduction in weed density at 30 days after rice seeding. In Vietnam, the herbaceous legume *Tephrosia candida* (Roxb.) D.C. used as mulch caused a reduction in the weed growth and a significant increase in rice yield [63].

### 6.3. Herbicides

Herbicides are widely used in rice cropping systems all over the world and may be economically attractive in some cases as it requires less overall weeding times. In Africa, 26 herbicides as single application or mixtures are being used in upland and lowland rice [26]. They are effective in reducing weed populations and hence the number of seeds added to the soil seedbank. However, their use is sharply decreasing due to social and environmental concerns and major negative impacts on soil biology aside from promoting the appearance of herbicide resistance in 51 weeds in rice fields [64].

### 6.4. Interaction between weeds and ducks

In China, a form of organic rice farming called rice-duck farming (RDF) has proven to be very successful in controlling weeds and decreasing the weed bank size in rice fields [65]. Interaction between weeds and ducks after 9 years under RDF, resulted in a decline from 38 to 21 in the number of weed species and the density of both the weed seedbank and aboveground weed flora decreased by more than 90%. After 9 years of interaction between weeds and ducks, RDF resulted in a more uniform vertical distribution of the weed seedbank both quantitatively and qualitatively. The ecological indices point to a gradual change towards fewer species, lower density and lower diversity following continued RDF. The dominant species in the weed seedbank shifted [65].

## 7. Conclusions

In recent years, there is growing interest in the adoption of conservation practices in rice agricultural production. This involves reducing soil disturbance along with maintaining crop residues on the surface, reducing weed seed inputs and promoting seed depletion in the weed seedbank in the soil. The technology of no-till or minimum tillage and also the growing interest in the practice of organic agriculture and agroecology to develop more balanced rice production systems are current trends that converge to a healthy environmentally and economically sustainable agricultural model.

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