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Weed seed bank diversity and community shift in a four-decade-old fertilization experiment in rice–rice system

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ABSTRACT

The development of management practices that allow the prediction of timing and extent of weed emergence is essential for planning more effective weed control strategies as well as maintenance of biodiversity in agricultural systems. A better understanding of the seed bank could provide useful insights into the long-term effects of organic and chemical fertilization for maintaining diversity. The effects of organic and inorganic fertilization on weed seed bank composition, density and diversity were studied in the soil of a long-term fertilizer experiment established four decades ago in CRRI, Cuttack, India. Weed seed density was lowest for *Paspalidium flavidum* (22 individuals per m^2) and highest for *Ammania baccifera* (11,616 individuals per m^2) irrespective of the treatments. Highest weed seed density was observed in farm yard manure (FYM) treatment whereas, lowest was in NK treatment, which was 232% higher in FYM over NK treatment. Weed seedling emergence was higher in *kharif* flushes and lowest in *rabi*. Principal component analysis ordination indicated little similarity in the weed community composition particularly among NP, NPK and NPK + FYM, while application of N alone was quite distant. Weed species diversity was reduced significantly with application of inorganic N either applied with K or alone; therefore, lowest diversity and species richness was observed in NK treatment followed by N alone. The results of the study may contribute to the development of effective weed management strategies as well as maintenance of weed diversity which leads to transition from an herbicide-dependent cropping system to a more environmentally friendly cropping system.

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1. Introduction

The production of a huge number of small seeds is an important survival strategy developed by weeds to counter control methods in agro ecosystems. After dispersal, the seeds remain on the soil surface or are buried through the actions of various biotic and abiotic agents, thus forming a seed bank, which becomes the main source of weeds in the ecosystem. Soil weed seed bank is the general term for the vital weed seeds existing in topsoil (Roberts, 1981; Qiang, 2001). The seed bank consists of new seeds recently shed by weeds and older seeds that have persisted in the soil for several years. Changes in agricultural management practices alter the pattern of disturbance and produce changes in seed bank characteristics. Changes in these seed bank characteristics often lead to changes in the size and species composition of the weed flora (Clements et al., 1996). Species composition of the flora may be sometimes more important than total number of seeds (Roberts and Ricketts, 1979; Begum et al., 2006). However, weed seed populations in cultivated soils are generally composed of a few dominant species that are present in high numbers, a few others present at moderate levels, and a large variety of species present in the soil at low levels (Wilson and Furrer, 1996). Knowledge of the size and species composition of this seed bank would be useful in predicting future weed infestations (Carretero, 1977; Mcfarland and Shafer, 2011).

The fate of seeds in the soil is difficult to determine and comprehensive information on the seed pool dynamics of most species is sparse. High weed seed populations occur in tropical soils, but limited data is available on emergence patterns (Zimdahl et al., 1988). Practical knowledge of periodicity of germination is of significant importance, since it is a major factor in determining the association of weeds with cropping systems and to enable a degree of forecasting as to which weed species may occur in a seedbed.

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Predicting potential weed emergence is fundamental in the development of integrated pest management strategies for weed control. Predictions of emerged seedling densities allow estimations of weed competition, crop yield loss, need for herbicides, financial returns and weed seed production at the end of the growing season (Forcella, 1992; Begum et al., 2006). Furthermore, the remaining seeds in the soil are also a major concern to understand the soil seed bank status (Cardina and Sparrow, 1996). It has been suggested that estimates of seed bank populations in arable soils could be used to predict weed infestation, which could improve decision making for the management of specific weed problems (Ball and Miller, 1989). The control of weed populations through the manipulation of the weed seed bank is an important weed management option (Sago, 2000).

In the pursuit of more sustainable approaches to agricultural management, there is an obvious need to integrate knowledge of ecology and the agricultural sciences. Several factors affect weed seed germination, chief among which are variations in soil temperature and moisture; light intensity; and the physiological aspects of seeds, particularly seed dormancy. When favorable conditions occur, seeds germinate; seedlings are recruited and produce new propagules, enriching the soil seed bank and future weed populations. The methods that have been proposed for weed seedbank analysis can be ascribed to two main categories: (1) direct seed extraction methods including various sieving techniques (Smutny and Kren, 2002), elutriation (Kovach et al., 1988; Wiles et al., 1996) or flotation (Malone, 1967; Tsuyuzaki, 1994; Goro and Tsuyuzaki, 2004) and (2) germination methods by which the seedbank is assessed *via* identification and enumeration of seedlings emerged from the soils under controlled conditions (Cardina and Sparrow, 1996; Swanton et al., 2000; Bàrberi and Lo Cascio, 2001).

Our purpose is to use weed seed bank diversity and weed community shift as a framework to discuss the impact of shifting weed diversity in organic and inorganic fertilizer management practices as well as the impact of this shift on future weed management practices. Both inorganic and organic fertilizers had significant effects on weed communities; organic fertilizers could reduce weed density and increase weed-community species diversity and evenness (Everaarts, 1992; Major et al., 2005; Lal et al., 2014). These findings provide a basis for the study of soil weed seedbanks in different fertilizer-management conditions. This might contribute to predicting infestations and could lead to improved management strategies to minimize the negative impact that invasive plants have on crop development and yield even in long term. The aim of this study was to find out that how does fertilization influence the development of the weed seed bank and is there any relation between soil nutrients and species composition of the soil weed-seed bank. The present study was conducted to assess the impact of long term organic and inorganic fertilization on soil weed seed bank in a tropical rice–rice system.

2. Materials and methods

2.1. Description of experiment

A long-term fertilization field experiment was initiated in 1969 at Central Rice Research Institute, Cuttack, India (20°25′ N, 85°55′ E; elevation 24 m above mean sea level). This site is a tropical flooded shallow lowland ecology and falls under a tropical climate that has annual precipitation of 1333.6 mm of which 75–80% was received during June to September. Mean annual maximum and minimum temperatures were 31.6 and 22.1 °C, respectively, and the mean annual temperature was 25.5 °C. The soil of the experimental site was classified as Aeric Endoaquept with sandy clay loam texture (30.9% clay, 16.6% silt, 52.5% sand), having bulk density 1.40 $Mg\,m^{-3}$, pH (using 1:2.5, soil:water suspension) 6.6, cation exchange capacity 15.2 c mol (p+) kg^{-1}, electrical conductivity (EC) 0.5 $dS\,m^{-1}$, total C 0.78%, total N 0.08 $g\,kg^{-1}$, exchangeable K 0.26 c mol (p+) kg^{-1} and available P 13.0 $mg\,kg^{-1}$.

A rice–rice cropping system has been carried out since its inception, *kharif* season rice was transplanted in June and *rabi* season rice was transplanted in January every year. The design of experiment was randomized complete block design with three replications. Seven treatments were included in the present investigation: (i) control (non-fertilization), (ii) inorganic nitrogen fertilization (N) (iii) inorganic nitrogen and phosphorus (P) fertilization (NP), (iv) inorganic nitrogen and potassium fertilization (NK) (v) inorganic N, P and K combination (NPK) (vi) farm yard manure application (FYM) (vii) inorganic NPK application combined with FYM (NPK + FYM). The wastes from the Institute's dairy farm were used to prepare the FYM which contained 171–189 g total organic C and 4–16 g total N kg^{-1}. The FYM (5 $Mg\,ha^{-1}$) was applied uniformly as per the treatments at the time of final puddling every year in wet season. The chemical fertilizers were applied as per the recommended dose, *i.e.* 60-40-40 and 80-40-40 N-P_2O_5-K_2O $kg\,ha^{-1}$ for wet and dry seasons, respectively. Full dose of P and K and one split of nitrogen were applied as basal before transplanting of rice, remaining splits of nitrogen were applied as top dressing, as per the treatments. Since establishment of the experiment only hand weeding was performed as weed control measures in both the seasons at active tillering and panicle initiation stage.

Six soil cores of 5 cm in diameter and 10 cm depth were sampled from each treatment in a *W* shaped pattern. Samples from each individual treatment from 0 to 5 and 5 to 15 cm soil depth were bulked and air-dried in the net house. Subsequently, the soil samples were passed through a 4-mm sieve to remove large debris and break up soil clods. Samples from each treatment were placed in 38 cm × 25 cm × 10 cm plastic trays. Each plastic tray was filled with 8.0 kg of soil. The trays were placed on a bench in a green house where they were kept well watered under natural light. The positions of the trays were randomized every 1–2 week during the study period. Trays were daily sprinkled with water as needed in order to keep them moist for germination.

In this study, we utilized data from the direct germination study because the direct germination study requires a considerable amount of time and space but provides a more complete listing of species present in the seed bank than elutriation (Gross, 1990) and we were interested in quantifying the soil weed seed bank of long-term experiment. Weed seedlings that emerged were identified, counted, and removed, initial flush of weed seedlings were censused at monthly intervals but the censused interval was increased later as fewer new weed seedlings were emerged. After the removal of each flush of weed seedlings, soils were air dried for 3 days and puddled, thoroughly mixed in order to expose the weed seeds to the upper layer of the soil, and rewetted to permit further germination. This process was repeated for 10 times from 2012 to 2014.

2.2. Data processing and analysis

Data from the 2012 to 2014 germination studies were expressed as number of emerged weed seedlings per square meter, weed species density (number of species per sample). Phytosociological structure was assessed by common parameters such as absolute and relative values of frequency, density, abundance and importance value for each species (Mueller-Dombois and

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