Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231-6345 (Online)
An Online International Journal Available at http://www.cibtech.org/jls.htm
2012 Vol. 2 (1) January- March, pp.30 -37 /Rajani srivastava
Research Article

DIVERSITY OF WEED SOIL SEED BANK IN INDIAN DRYLAND AND IRRIGATED AGROECOSYSTEMS

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ABSTRACT

This study evaluated the integrated effect of dryland and irrigated crop production systems on diversity of soil seed bank in rice based Indian tropical agroecosystems. During the winter season 10 species were common to both agroecosystems, 4 species were exclusive to the dryland agroecosystem and 2 species were exclusive to the irrigated agroecosystem. In the rainy season also 7 species were common, 5 species exclusive to dryland and 6 species were exclusive to the irrigated agroecosystem. Weed diversity was greater in dryland agroecosystem compared to irrigated agroecosystem. Considerably smaller size of soil seed bank in the irrigated agroecosystem (cf. dryland) is related to lowered weed seed production (365-397 x 10^3 m^{-2} in dryland, 253-262 x 10^3 m^{-2} in irrigated agroecosystem), particularly during the winter. Dryland agroecosystem showed greater accumulation of seeds of broad leaved weeds in soil whereas irrigated agroecosystem accumulated more seeds of grasses/sedges. About three-fourth of soil seed bank during winter season was accounted by *Anagallis arvensis* and *Chenopodium album* in dryland agroecosystem, and by *Chenopodium album* and *Melilotus indica* in irrigated agroecosystem; however, during rainy season *Ammannia baccifera, Echinochloa colona* and *Cyperus rotundus* dominated in both agroecosystems**.** Build up of very large seed bank of *Echinochloa colona* and *Cyperus rotundus* in the irrigated agroecosystem indicated that in future these species may become predominant weeds with the spread of irrigation. Continuously increasing irrigated crop area will have major detrimental impact on existing weed flora, and lead to the invasion of new weed species in agroecosystems.

Key Words: *Dryland Agroecosystem,Irrigated Agroecosystem,Soil Seed Bank, Weeds, Seed Production.*

INTRODUCTION

The success of weeds in agroecosystems is mainly due to their high diversity and enormous capacity to produce seeds for the propagation of offsprings (Dekker, 1997). Accurate predictions of future weed populations based on seed production, soil seed bank and seedling emergence pattern would be required for developing bio-economic weed management models to minimize the losses in agronomic yield due to weeds (Buhler *et al.,* 1997). The soil seed bank, an ever-present component of agroecosystems (Forcella *et al.*, 1997), is the primary source of future weed populations, serving as a unique resource for predictive management purposes. Varying management practices like organic input, tillage conditions, water control, crop rotation, fertilizer application and herbicide use have been reported to affect significantly weed communities in a range of agroecosystems (Lesson *et al.*, 2000; Liebman and Davis, 2000). According to Harbuck *et al.* (2009) yearly fluctuation in environmental factors have significant impact on the weed seed bank. The soil seed bank is a better indicator of the long-term influence of agronomic practices on weeds than the aboveground vegetation .Various diversity indices serve as useful tools to evaluate the effect of different management practices on floristic diversity (Waldhardt *et al.*, 2003). While concern about the loss of species diversity has mainly been focused on the natural habitat, the diversity of weed species and soil seed bank occupying agroecosystem has received much less attention.

Most studies on weed community and seed bank changes due to different management practices or under different agroecological conditions are restricted to temperate countries (Liebman and Davis, 2000 Lesson et al., 2000, Gallandt et al., 2004) and few in tropical countries (Rahman *et al.*, 1998). In Indian tropical region, except few (Srivastava and Singh, 2005) scant information available on comparative evaluation of weed and soil seed bank diversity in different cropping systems. In India, out of total arable land about 65% land functions under dryland conditions (rainfed only, no irrigation resulting in moisture deficit), and remaining 35% arable land is under irrigation (rainfall augmented with irrigation). Two agroecosystems represent widely differing agroecological conditions, showing different soil properties (Srivastava and Singh, 2002), which may affect the composition and dynamics of soil seed bank.

The present study, carried out in Indian dry tropics, was focused on comparative analysis of two contrasting agroecosystems (dryland and irrigated), both located in close vicinity with the objective is to evaluate the differences in species composition, seed production and soil seed bank between two agroecosystems.

MATERIALS AND METHODS

Study site

This study was carried out in the dryland and irrigated Farm of the Institute of Agricultural Sciences located within the campus of the Banaras Hindu University, Varanasi (25° 18' N lat. and 83° 1' E long., 76 m above mean sea level). Both of these Farms are established before more than 50 years. A part of the Farm area has been set-aside since 1958 for research on dryland (rainfed) agriculture. In adjoining area irrigated agriculture is practiced, creating two contrasting adjacent agroecosystems on the same soil type. First, dryland agroecosystem and second irrigated agroecosystem. This region has a tropical sub-humid climate, characterized by strong seasonality with respect to temperature and rainfall. The long-term average annual rainfall is about 1100 mm. The soil of the study sites belongs to the order Inceptisols, and sub-order orchrepts, showing thin, pale brown surface horizon, and neutral to slightly alkaline reaction. These soils belong to the sub-group udic ustocrepts, and are fine loamy, mixed, hyperthermic. The top 10 cm soil in dryland and irrigated agroecosystems, is neutral in reaction, with 0.72% and 0.81% organic C and 0.07% and 0.08% total N, respectively (Srivastava & Singh, 2002).

Three permanent plots (10 m X 9 m each) were established in two agroecosystems. Six subplots (2 sub-plots per plot, each 50 cm X 50 cm) were permanently demarcated at each site for weed analysis. Crops grown were rice (*Oryza sativa* var. NDR 118) in rainy season alternated in winter with lentil (*Lens esculentus* var. Pant 639) in the dryland; rice (*Oryza sativa* var. HUR 36) and wheat (*Triticum aestivum* var. HUW 234) alternated in the irrigated agroecosystem. Fertilizer doses were: N, P and K 80, 40 and 30 kg ha^{-1}, respectively, in dryland and 120, 80 and 60 kg ha^{-1} in irrigated agroecosystem. Wheat crop received 2-3 supplemental irrigations. No herbicide treatment was given to any cropping site.

During winter and rainy crop periods at monthly interval composition and density of weeds in agroecosystems were recorded, beginning 30 days after crop transplanting/sowing. In this study species composition and density of weeds recorded during mid cropping season (60 days after crop transplanting/sowing) are presented.

For seed production estimation, 30 individuals (10 from each permanent plot) of each weed species were tagged. Number of fruits per individual (including scars of dehisced fruits) and seeds per fruit (30 fruits per species) were counted at monthly interval. The seed production of a species was estimated as: seeds per fruits x fruits per individual x individuals per unit area. Total seeds produced per species during the cropping season were derived as the sum of seeds estimated at different sampling dates.

Within each sub-plot, soil was excavated from a 20 cm x 20 cm area in three successive 10 cm depths, twice during the annual cycle, once after the rainy season harvest (November-December) and again after the winter harvest (April-May). Depth samples of soil (6 sub-plots x 3 depths per site; each corresponding to 20 x 20 cm, 10 cm depth) were air dried and weighed. The seed losses due to germination during the air-drying period were also quantified. The size of seed bank was estimated in depth samples by seedlings emergence method. All eight counts were made at 15 days intervals during both cropping seasons.

The following species diversity coefficients were calculated from the weed density values:

Shannon–Wiener index, $H' = -\sum pi \log pi$ (Shannon and Weaver, 1963).

Simpson index, $D = 1- \sum pi^2$ (modified by Berger and Parker, 1970).

Species richness, $d = (S-1) / \ln N$ (Margalef, 1958).

where S = total number of species in the sample, N = total number of individuals of all species, pi = proportion of all individuals which belong to species I (number of individuals of each species i/N),
The similarity (IS_{sp}) between sites A and B was calculated (using maximum number of species occurring during the two cropping seasons) as follows:

$$IS_{sp} = \frac{\sum(Mw/Mg)}{a+b+c} \times \frac{100 \times Mc}{Ma + Mb + Mc}$$

(Mueller-Dombois and Ellenberg, 1974), where Mw = the smaller quantity of a species common to stands A and B, Mg = the greater quantity of a species common to stands A and B, a = number of species occurring in stand A only, b = number of species occurring in stand B only, c = number of species common to both stands A and B, Mc = sum of quantittities of species common to stands A and B, Ma = the sum of quantities of species unique to stand A,
Mb = the sum of quantities of species unique to stand B.

RESULTS

Species composition and density

Comparable number of weed species (12-14), mostly annuals, was recorded in the two agroecosystems during both cropping seasons (Table 1). Weed species composition differed with agroecosystems and with seasons. During the winter season 10 species were common to both agroecosystems, 4 species (*Alternanthera sessilis, Gnaphalium indicum, Solanum nigrum* and *Sporobolus diander*) were exclusive to the dryland agroecosystem, and two species (*Melilotus indica* and *Melilotus alba)* were exclusive to the irrigated agroecosystem. In the rainy season also 7 species were common, 5 species (*Alternanthera sessilis, Cynodon dactylon, Lindernia ciliata, Lindernia crustacea* and *Sphaeranthus indicus*) exclusive to dryland, and 6 species to the irrigated agroecosystem.
Several aquatic/moist habitat species (*Commelina benghalensis, Ipomoea aquatica, Polygonum hydropiper, Marsilea minuta, Ludwigia parviflora* and *Eclipta alba*) occurred in irrigated agroecosystem. Both agroecosystems were compared by using Spatz similarity index, which is based on differences in total number and total individuals of these species (Table 1). Dryland and irrigated agroecosystems had only 25% and 38% similarity with each other during winter and rainy cropping seasons, respectively.
During mid season (after 60 days of crop sowing/transplanting), *Anagallis arvensis* and *Chenopodium album* were the dominant forbs in dryland agroecosystem, contributing 89% shoots during winter season (Table 1). In the irrigated agroecosystem, *Chenopodium album* and *Melilotus indica* were the dominant forbs (contributing 83% forb density); *Phalaris minor* was the dominant grass (78% grasses/sedges shoots). Densities of *Anagallis arvensis* and *Chenopodium album*, especially of the former, were greater in the dryland agroecosystem, whereas density of *Phalaris minor* substantially exceeded in the irrigated agroecosystem. *Melilotus indica*, showing high shoots density, occurred only in the irrigated agroecosystem. In the dryland agroecosystem, *Ammannia baccifera*, the dominant species, and *Corchorus acutangulus*, the codominant, together contributed 78% forbs shoots during the rainy season. *Echinochloa colona* and *Cyperus* spp. (*C. iria* and *C. rotundus*), the dominant and codominant species, respectively, together contributed 90% to grasses/sedges shoots. In irrigated agroecosystem 62% forb shoots were contributed by *Ammannia baccifera* and *Corchorus acutangulus* and 94% grasses/sedges shoots by *Echinochloa colona* and *Cyperus* spp. Shoot densities of *Ammannia baccifera* and *Echinochloa colona* were distinctly greater in the dryland agroecosystem, whereas *Corchorus acutangulus* and *Cyperus* spp. showed comparable densities in both agroecosystem (Table 1).
The estimated annual seed production by all species in the dryland agroecosystem (365-397 x 10^3 m^{-2}) significantly exceeded ($p<0.05$) the seed production in the irrigated agroecosystem (252 -261 x 10^3 m^{-2}) during both annual cycles (Table 2). The difference was more marked during the winter season ($p<0.001$) when approximately two and half time greater seeds were produced in the dryland agroecosystem. The seed production did not differ significantly between the two agroecosystems in the rainy season. Major

contributors in seed production during winter season is *Anagallis arvensis* and *Chenopodium album* in dryland agroecosystem and in irrigated agroecosystem *Chenopodium album* and *Melilotus indica* whereas respective contribution in rainy season by *Ammania baccifera* and *Cyperus* spp in both agroecosystems.

Table 1: Total number of species and similarity index recorded in dryland and irrigated agroecosystems with mid season (60 days after crop sowing/transplanting) weed composition and density in two agroecosystems.

Species	**Winter season**		**Rainy season**	
	Dryland	Irrigated	Dryland	Irrigated
Total species	14 (11)	12 (10)	12 (8)	13 (10)
Common species	10		7	
Similarity index	38%		25%	
Exclusive species	4	2	5	6
Broad-leaved weeds (no. of individual m^{-2})				
Alternanthera sessilis (L.) R. Br. ex. Dc	5		4	
Gnaphalium indicum auct.	1			
Solanum nigrum L.	1			
Anagallis arvensis L.	153	16		
Chenopodium album L.	106	74		
Lathyrus aphaca L.	4	2		
Lathyrus sativa L.	7	3		
Polygonum plebejum R. Br.	6	3		
Rumex crispus L.	7	4		
Melilotus alba Desr.		7		
Melilotus indica All.		93		
Lindernia ciliata (colsm.) Pannell			8	
Lindernia crustaceae (L.) F.V. Muell			3	
Sphaeranthus indicus L.			3	
Ammannia baccifera L.			46	33
Corchorus acutangulus Lamk.			16	16
Eclipta alba (L.) Hassk				1
Ipomoea aquatica Forsk				10
Ludwigia parviflora Roxb.				5
Polygonum hydropiper L.				14
Sub-total	**290**	**202**	**80**	**79**
Grasses/sedges (no. of individual m^{-2})				
Sporobolus diander (Retz.) P. Beauv.	12			
Phalaris minor L.	13	104		
Cynodon dactylon (L.) Pers.	8	10	9	
Dichanthiun annulatum (Forsk.) stapf.	8	11	8	4
Cyperus spp* L.	12	9	52	48
Echinochloa colona (L.) Link			133	98
Cyanotis axillaries D. Don			3	2
Commelina benghalensis L.				2
Marsilea minuta L.**				2
Sub-total	**53**	**134**	**205**	**156**
Total (broad-leaved+grasses/sedges)	**343**	**336**	**285**	**235**

*Sum of *Cyperus iria* L. and *Cyperus rotundus* L., **Pteridophyte.

Values in parenthesis show the number of annual species. The names of species and authorities as in Verma et al. (1985).

Table 2: Seed production (no.± SE x 10^3 m^{-2}) and its percent species contribution (of only first year data shown here, same trend in second year) in dryland and irrigated agroecosystems during the two annual cycles.

	Dryland		Irrigated	
	Winter	Rainy	Winter	Rainy
Broad leaved weeds (%)				
Anagallis arvensis	48		11	
Chenopodium album	40		40	
Rumex crispus	3		1	
Melilotus indica			30	
Melilotus alba			1	
Ammannia baccifera		60		77
Corchorous acutangulus		1		1
Grasses/Sedges (%)				
Sporobolus diander	3			
Phalaris minor	2		7	
Cyperus iria		20	8	7
Echinochloa colona		7		6
Cyperus rotundus		9		9
Others (%)	3	5	2	1
Total seed production (1998-1999)	194.2±8.3**	171.2±31.4^{NS}	52.7±5.5**	171.2±42.8^{NS}
Annual seed production	365.5±40.19*		252.9±50.66*	
Total seed production (1999-2000)	212.3±30.9**	185.2±28.9^{NS}	82.7±9.3**	179.0±47.5^{NS}
Annual seed production	397.5±57.39*		261.8±51.05*	

*Significant at p<0.05, **Significant at p<0.001, ^{NS} Non significant

Diversity of weed and soil seed bank

Variations in richness, evenness and diversity of species and soil seed bank are shown in Table 3. The irrigated agroecosystem exhibited higher aboveground weed species diversity (*H'*) than dryland agroecosystem in the rainy season ($p < 0.01$); during the winter difference was smaller ($p < 0.1$).

While diversity (*H'*) varied significantly ($p < 0.001$) between cropping seasons in the irrigated agroecosystem, the seasonal variation in dryland was small ($p < 0.10$). The seasonal trends of species diversity and species evenness were broadly similar in both agroecosystem (as reported by Srivastava and Singh, 2005).

In case of soil seed bank diversity, with the increase of depths diversity increases in dryland agroecosystem whereas in irrigated agroecosystem reverse trend have seen. Mean diversity values are slightly greater in irrigated agroecosystem in post rainy season (1.90 and 0.79 c.a. 1.82 and 0.73) as well as post winter soil seed bank (1.66 and 0.74 c.a. 1.53 and 0.68) compared to dryland agroecosystem. Species diversity and species richness in both agroecosystem soil seed bank was greater in soil collected after rainy season whereas it was lower in soil that collected after winter season.

Statistical analysis

Seed production estimates (winter, rainy, annual) in dryland and irrigated agroecosystems were compared on the basis of t-test.

Table :3 Species diversity (Shannon-Weiner: H'; Simpson: D) and species richness (d) of soil seed bank at 0-10, 10-20 and 20-30 cm depth in dryland and irrigated agroecosystems. Values in parenthesis show range of respective indices of above ground weeds. Values are mean of two annual cycle.

Depth (cm)	Species diversity				Species richness	
	H'		**D**		**D**	
	Dryland	Irrigated	Dryland	Irrigated	Dryland	Irrigated
	Post rainy season soil seed bank					
0-10	1.70	2.01	0.70	0.82	1.64	1.80
10-20	1.99	1.83	0.81	0.77	1.62	1.97
20-30	2.09	0.99	0.85	0.49	1.79	1.21
Total (0-30)	**1.80**	**1.90**	**0.73**	**0.79**	**1.71**	**1.91**
	(1.51-1.75)	**(1.63-1.81)**	**(0.66-0.73)**	**(0.77-0.79)**	**(1.96-2.26)**	**(1.26-1.93)**
	Post winter season soil seed bank					
0-10	1.47	1.82	0.65	0.79	1.74	1.49
10-20	1.58	1.49	0.72	0.71	1.41	1.36
20-30	1.64	1.16	0.74	0.58	1.12	1.20
Total (0-30)	**1.53**	**1.66**	**0.68**	**0.74**	**1.68**	**1.50**
	(1.71-1.86)	**(1.33-2.07)**	**(0.72-0.85)**	**(0.70-0.81)**	**(2.05-2.15)**	**(1.48-1.93)**

DISCUSSION

Diversity indices measured in this study were within the range of those reported for various cropping systems in diverse geographical areas (Clements *et al.*, 1994 Derksen et al. 1995). Values reported in the literature for Shannon's H' for weed communities generally are <2.0. Low plant diversity appears to be typical of arable land and intensively managed grassland (Wilson *et al.*, 2003). In the presently studied dryland and irrigated agroecosystems diversity fall within these values. Changes in aboveground weed diversity between presently studied agroecosystems also reflected in soil seed bank. After both cropping seasons, upto 30 cm soil depth, soil seed bank diversity was greater in irrigated agroecosystem compared to dryland, this is due to distinctly more diverse seed bank in upper soil layer (0-10 cm) in irrigated agroecosystem. Srivastava and Singh (2006) reported that in high input irrigated agroecosystem (in term of nitrogen and water addition), relatively fewer terrestrial and higher aquatic weeds in irrigated agroecosystem, as well adjusted to grow in flooded condition in rainy season and moist condition during winter to make efficient use of resources. Diverse aboveground weed community shed their seeds and diverse germinating soil seed bank obtained from upper soil layer in this system. Whereas in low input dryland agroecosystem (less nitrogen and no additional water) encountered by more adverse condition and reserve more seeds in lower (10-20 and 20-30 cm) soil layers. This may be adaptive mechanism of storage of weed diversity in dryland agroecosystem.

Aboveground weed species abundance and their depth wise distribution of soil seed bank vary between two agroecosystems. This is evident from low similarity index in both cropping seasons. It has been reported that variations in species abundance and density of weed flora between agroecosystem is due to varying cropping practices like increase use of fertilizers, irrigation and hydrology (Kent *et al.*, 2001 Johnson and Kent, 2002). Soil seed bank density declined in irrigated agroecosystem in both post rainy and post winter seasons soil seed bank (compared to dryland). This can be related to lowered weed seed production, particularly of the annual weeds. Annual weeds, most of them broad leaved type, generally show greater density and higher seed output per individual in the dryland agroecosystem. Greater seed production in the dryland agroecosystem seems to be a survival strategy of weeds under unfavorable, prolonged moisture deficit condition. The suppression or elimination of several broad leaved weed species due to change from dryland to irrigated condition leads to near total depletion of seeds of these species from the soil seed bank. In the total soil seed bank density major contribution by *Ammannia* *baccifera* in dryland agroecosystem and *Ammannia baccifera* and *Melilotus indica* in irrigated agroecosystem of broad leaves weeds, shows its wide tolerance range. *Echinochloa colona* and *Cyperus* spp., both abundant in presently studied soil seed bank of agroecosystems, have been recorded among the most important weeds across the world (Holm *et al.*, 1977). *Echinochloa colona* is a major weed of rice under both flooded and upland conditions (Shad and Siddiqui, 1996); its close resemblance with the rice seeds and seedlings results in getting it transplanted with rice. Few species resist control measures in agroecosystems and become dominant due to adaptation to the cropping system (Buhler *et al.*, 1997). The conversion of dryland to irrigated condition also affects the relative abundance of several seed bank species. Build up of very large seed bank of *Echinochloa colona* and *Cyperus rotundus* in the irrigated agroecosystem indicates that in future these species may become predominant weeds with the spread of irrigation. *Echinochloa colona* has been reported to succeed over the previously dominant weeds in Asia where direct seeding has been replaced by the rice transplanting (as in the present irrigated agroecosystem) (Ho & Itoh, 1991). On the other hand, considerable reduction in the seed bank of *Ammannia baccifera* in the irrigated agroecosystem shows the possibility for disappearance of this species in future.

In aboveground weed flora, there was distinctly higher density of forbs than grasses/sedges during winter season and reverse dominance in rainy season in both agroecosystems. It has been reported that monocotyledonous grasses/sedges (C_4 type) respond more rapidly than broad leaved forbs (C_3 type) to warm and moist condition whereas during winter season grasses/sedges likely to decrease (Shad and Siddiqui, 1996 Srivastava and Singh, 2006). During both seasons, some weeds are abundant in both agroecosystem due to their wider tolerance to varying moisture condition, but some are dominant to either drier soil dryland condition (e.g. *Anagallis arvensis*) or in wet irrigated condition (*Melilotus indica, Phalaris minor*). In both agroecosystem, the decline of soil seed bank density with increasing soil depths in both seasons soil seed bank is obviously related to less downward movement of seeds and creation of anaerobic condition in soil, simultaneously related to decrease seed density.

To sum up, this investigation documents the patterns of diversity and abundance of weed species seed production and their soil seed bank associated with two rice-based agroecosystems. Conversion of dryland to irrigated agroecosystem involves elimination and recruitment of weed species, resulting in distinctly changed weed community showing increased weeds and soil seed bank diversity in irrigated condition. Although water management suppresses the density of several weeds, it leads to dominance of some potentially noxious weeds (e.g., *Phalaris minor, Melilotus indica*). Approximately double soil seed bank size and greater seed production and higher diversity at lower depth may show an adaptive mechanism of storage of weed diversity in dryland agroecosystem.

ACKNOWLEDGEMENTS

We thank the Head and the Programme Co-ordinator, Centre of Advanced Study in the Department of Botany for providing laboratory and library facilities. Thanks are due to various authorities of Institute of Agricultural Sciences, BHU, for providing long term irrigated and dryland sites and other field facilities.

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