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Diversity in Weed Phenological Pattern and Seed Rain in Dryland and Irrigated Agroecosystems of Indian Dry Tropics

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Abstract

This study was carried out to compare the diversity in weed phenological events, seed production and seed rain in a dryland and an irrigated agroecosystems of Indian dry tropics. Diverse weed phenological patterns were noted in dryland and irrigated agroecosystems. During winter season, in dryland agroecosystem, dominant weeds like *Anagallis arvensis, Chenopodium album* and *Phalaris minor* showed approximately one month early germination and vegetative stage compared to irrigated agroecosystem for same species. The annual flower, fruit and seed production were higher in the dryland agroecosystem (344-351, 219-238 and 365-397 x 10^3 m^{-2}, respectively) compared to irrigated agroecosystem (211-237, 132-142 and 252-261 x 10^3 m^{-2}, respectively). The estimated annual seed rain by all species in the dryland agroecosystem (102-112 × 10^3 m^{-2}) significantly exceeded ($P < 0.05$) the seed rain in the irrigated agroecosystem (73–80 × 10^3 m^{-2}) during both annual cycles. The difference was more marked during the winter season, when more than 3 fold the number of seeds were collected in seed rain during the dryland agroecosystem. There was strong positive correlation between seed production and seed rain, showing the dependency of seed rain (mostly dominated by annual species) on seed production in agroecosystems. Two different agricultural practices that continued for more 50 years on same type of land have cause changes in weed phenological pattern. Greater seed production, seed rain, and longer seed formation period indicate an adaptive mechanism of weed seeds in the dryland agroecosystem.

1. Introduction

Many studies on weed population dynamics attribute the success of weeds in agroecosystems mainly to their high diversity and enormous capacity to produce seeds for propagation (Dekker, 1997; Srivastava and Singh, 2005). Weed management approaches in agroecosystems should be based on sound knowledge of weed ecology, especially an understanding of the strategies enabling the establishment of plant populations (Ghersa *et al.,* 2000). Weed management practices sometimes also decide the quality of soil that can positively or negatively affect the crop production (Smith *et al.,* 2011). Useful information related to weed management can be derived from studies on weed population dynamics, particularly by understanding seed germination, flowering and seed production, and dispersal (Ghersa and Holt, 1995). Seed dispersal and seed rain are an important factors that determine the weed seed bank in soil and in this way affect the weed flora of that ecosystem. The importance of phenological surveys in weed science has been emphasized by several researchers (Brainard *et al.,* 2005; Peters, 2006; Otto *et al.,* 2007; Searcy, 2008). Phenological stages of weeds such as germination, vegetative growth, flowering, fruiting, seed maturation and senescence reflect its growth in response to changing environmental conditions. The phenological stages of weed species could be used in making weed management decisions focusing on cultural practices. It can also be used to predict timing of chemical control practices (Bhowmik, 1997; Salehian *et al.,* 2013).

Composition of weeds, their diversity and seed production capacity is influenced by different crop production practices used in agroecosystems (Buhler *et al.,* 1997; Srivastava and Singh, 2014). The floristic composition of weed community can be assumed to follow the temporal pattern of environmental changes, which results from the seasonal climatic variables, habitat types, soil texture and farming practices (Martinez-Ghersa *et al.,* 2000; Gomma, 2012; El-Sheikh, 2013). An understanding of the seed production capacity of weeds, and methods to preventing them from producing seeds for a few years can help reducing weed seed density in soil and thereby enhance agricultural crop production.

There is need to evaluate changes in weed phenological diversity, seed production and seed rain that result from the conversion of dryland to irrigated agroecosystem in tropics. The present study, carried out in the Indian dry tropics, was focused on a comparative analysis of two contrasting rice-based agroecosystems (dryland and irrigated), both located in close vicinity, with the objective of quantifying the differences in the: (i) diversity in weed phenological pattern, flower, fruit and seed production; and (ii) composition and size of the weed seed rain and its relationship with seed production. These two agroecosystems represent differing agroecological conditions and varying soil properties (Srivastava and Singh, 2002) which affect weed composition, seed production and dynamics of the seed bank. It was hypothesized that in tropical agroecosystems the shift from a dryland to an irrigated cropping condition would lead to variations in weed phenology, and flower, fruit and seed production, which in turn would bring about changes in the weed seed rain. The quantification of resulting changes in the seed production and seed rain generates critical baseline information for weed management strategies.

2. Materials and Methods

2.1. Study sites

This study was carried out in the Farm of 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) in 2012 (Fig. 1). A part of the Farm area has been set-aside since 1958 for research on dryland (rainfed) agriculture. In the adjoining area irrigated agriculture is practiced, creating two contrasting adjacent agroecosystems on the initially same soil type. First, Dryland agroecosystem: supporting seed broadcast rice in the rainy season, and lentil, wheat or barley in winter season; it depends entirely on rainfall, no irrigation is provided. Second, Irrigated agroecosystem: supporting transplanted rice in water logged soil during the rainy season; wheat, mustard, barley or chickpea grown with repeated irrigation during the winter season (Fig. 1).

This region has a tropical sub-humid climate, characterized by strong seasonality with respect to temperature and rainfall. During summer (April-June) the temperature ranges between 30 and 42C during the day. In the winter season, day temperature falls between 15 and 31C with occasional light rain received from the retreating western monsoon. Warm conditions (29-37C) and high relative humidity (62-95%) prevail during the rainy season (June-September) that receives about 90% of the annual rainfall. Excepting the 4-month long rainy season, the remaining 8 months constitute the dry period. During the study period annual rainfall was 1140 mm and 1087 mm during the two years of study.

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 and Singh, 2002).

2.2. Permanent plots

Three permanent plots (10 m x 9 m each) in different fields were randomly established in dryland and irrigated agroecosystems. Six subplots (2 sub-plots per plot, each 50 cm x 50 cm) were permanently demarcated at each site for weed analysis. Test crops 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.

2.3. Phenological observations

Composition and density of weeds in dryland and irrigated agroecosystems were recorded at monthly interval in subplots, beginning 30 days after crop sowing/transplanting during winter and rainy crop periods. Six phenological stages (i.e. seedling, vegetative, flowering, fruiting, seed maturation and senescence) were recognized. Phenological observations were made at 30 days intervals during the study period (1998-2000). Seedling stage was recognized on the basis of plant height (<2 cm in grasses/sedges), or number of leaves (2-4 leaves in forbs), and size of leaves depending upon species. Individuals growing beyond seedling stage but without flowers were considered as vegetative stage. In case of

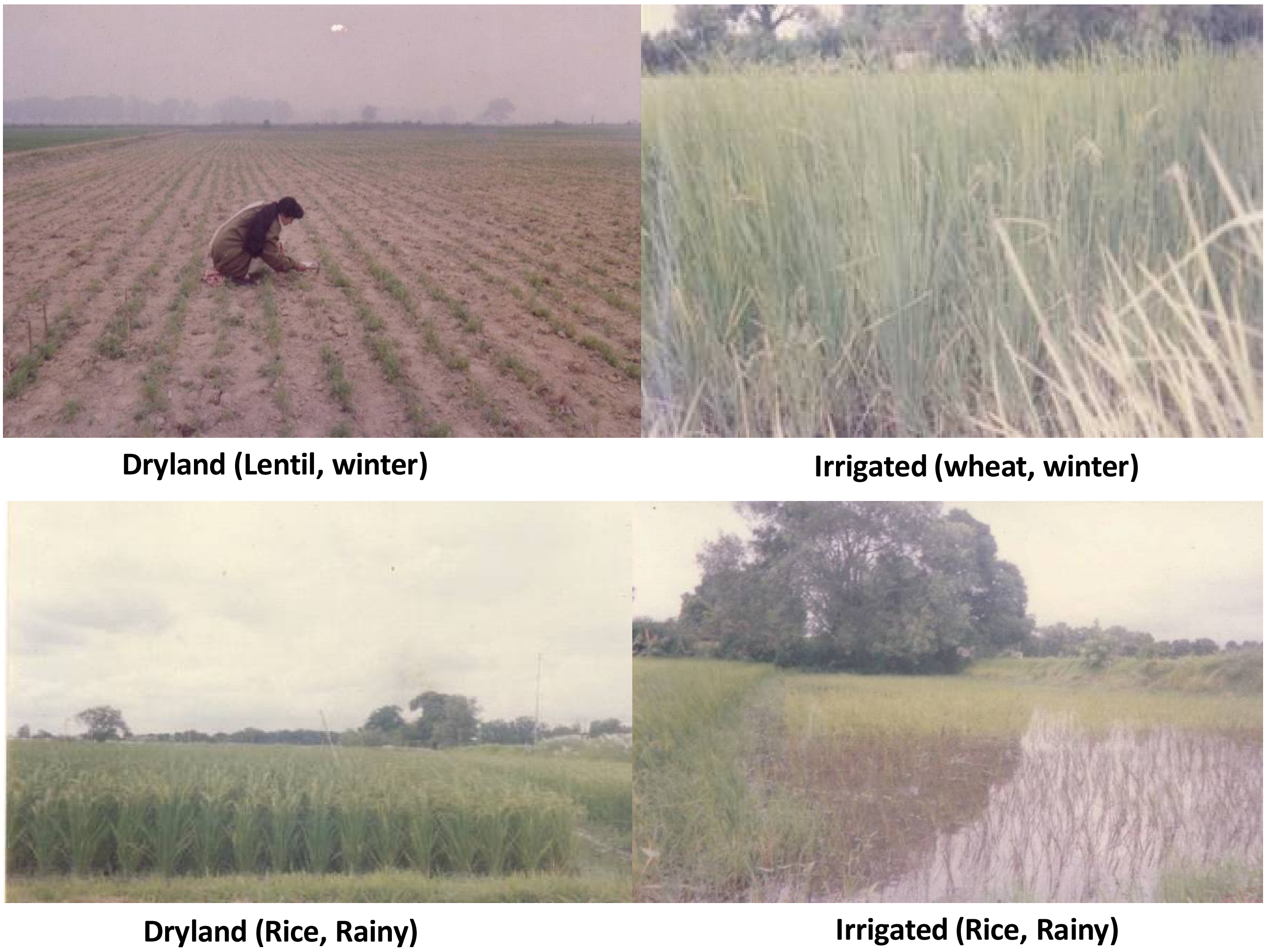

Fig. 1: General view of study sites, dryland and irrigated agroecosystems during winter and rainy cropping periods in the Farm of Agricultural Sciences, Banaras Hindu University.

broad-leaved weeds an 'individual' represented a plant that originated from a single root-stock whereas in grasses/sedges every tiller that was at least partially self-dependent was counted as individual. Flowering, fruiting and seed maturation stages for a species were recognized when more than 50% individuals of that species showed that stage. Florets in Asteraceae and spikelets in Poaceae were counted as flowers. Seeds in this study included units such as achenes (as used by Grime *et al*., 1998).

2.4. Flower, fruit and seed production

Counts of flowers and fruits were made on 30 plants at each site (10 plants per plots). Similarly, number of seeds was counted in 30 fruits per species. Thus, the calculation of total number of flower, fruit and seed production was based on average of 30 individuals per species in each agroecosystem. Mean number of flowers, fruits and seeds of a species were multiplied with the total number of individuals of that species at each sampling time. Sum of these values for all sampling dates were considered as total number of flowers, fruits and seeds produced per species during the cropping season. It was assumed that flowers at a preceding sampling either aborted or developed into fruits by the succeeding sampling, and the flowers present at the later sampling were newly produced. It is, however, possible that some flowers may have appeared and fallen-off during the intervening period between the two sampling dates and were not documented. The same may also be true in the case of fruit production in some instances. In case of dehisced fruits the scars left on shoot were also counted. While counting the seeds, abortive (those that do not develop at all) as well as immature (those that do not attain the same colour, size and shape as the mature ones) seeds, whenever present, were ignored. Seeds of different species obtained in the field were stored to help identification of seed rain.

2.5. Seed rain estimation

For the seed rain estimation, six petriplates (9 cm diameter) coated with white 5 mm thick vaseline were placed at each sub-plots in both agroecosystems. In both agroecosystems, petriplates were placed 30 days after crop sowing, and every following month they were recovered and replaced by new petriplates throughout the crop period. Last sets of petriplates were removed from the field just after the harvest of crop. Seed rain was estimated by determining number and species of seeds present in the petriplates. Seeds obtained from seed-rain were counted and identified with the help of previously stored specimen seeds of different weed species. Some seeds could not be identified and were grouped as unidentified seeds.

2.6. Statistical analysis

The flower, fruit and seed production estimates in the dryland and irrigated agroecosystems were compared on the basis of Least Significant Difference (*L*SD) at 5% level of significance, using SPSS (v. 18.0; IBM SPSS Statistics, Armonk, New York) PC+software. Number of flowers, fruits, seeds and seed rain were expressed in term of per unit land area (m^{-2}). Using *L*SD test, the seed rain in these agroecosystems was compared in both seasons (the dryland winter season to the irrigated winter season and the dryland rainy season to the irrigated rainy season in the first year and second year) and also on an annual basis. Bivariate correlation and regression computations were made relating seed production and seed rain.

3. Results

3.1. Diversity in weed phenology

A comparable number of weed species (12-14), mostly annuals were recorded in the two agroecosystems during both cropping seasons (Table 1). However, the weed species composition differed with the agroecosystem and with the season. In both seasons, more than half of the total species were common and few were exclusive in both agroecosystems.

Diverse weed phenological patterns were noted in dryland and irrigated agroecosystems during different seasons (Fig. 2). During the winter season, dominant weeds like *Anagallis arvensis, Chenopodium album* and *Phalaris minor* showed approximately one month earlier onset of germination and vegetative stage in the dryland agroecosystem, compared to the irrigated one.

In a very short duration of time flowers were converted into fruits and fruits matured seeds. Seed formation stage was comparatively longer in the dryland agroecosystem. In irrigated agroecosystem, vegetative stage was longer especially in *Lathyrus aphaca* and *L. sativa*. In dryland agroecosystem, the number of capsules/fruits per weed plant and number of seeds per capsules/fruits were greater compared to irrigated agroecosystem. In case of grasses/sedges (*Cynodon dactylon, Cyperus iria, Dichanthium annulatum* and *Sporobolus diander*) longer period of vegetative event was seen in both agroecosystems. In both agroecosystems senescence stage was not noted during winter season in case of grasses/sedges (Fig. 2).

Table 1: Total number of weed species present in winter and rainy seasons in dryland and irrigated agroecosystems. The values in parentheses show the number of annual species.

Number of species	Seasons	
	Winter	Rainy
Dryland agroecosystem	14 (11)	12 (8)
Irrigated agroecosystem	12 (10)	13 (10)
Common in both	10[a]	7[b]
Exclusive in dryland agroecosystem	4[c]	5[d]
Exclusive in irrigated agroecosystem	2[e]	6[f]

[a]*Anagallis arvensis*, *Chenopodium album*, *Cynodon dactylon*, *Cyperus iria*, *Dichanthium annulatum*, *Lathyrus aphaca*, *Lathyrus sativa*, *Phalaris minor*, *Polygonum plebejum*, *Rumex crispus*

[b]*Ammannia baccifera*, *Corchorus acutangulus*, *Cyanotis axillaris*, *Cyperus iria*, *Cyperus rotundus*, *Dichanthium. annulatum*, *Echinochloa colona*

[c]*Alternanthera sessilis*, *Gnaphalium indicum*, *Solanum igrum*, *Sporobolus diander*

[d]*Alternanthera sessilis*, *Cynodon dactylon*, *Lindernia ciliata*, *Lindernia crustacea*, *Sphaeranthus indicus*

[e]*Melilotus alba*, *Melilotus indica*

[f]*Commelina benghalensis*, *Eclipta alba*, *Ipomoea aquatica*, *Ludwigia parviflora*, *Marsilea minuta*, *Polygonum hydropiper.*

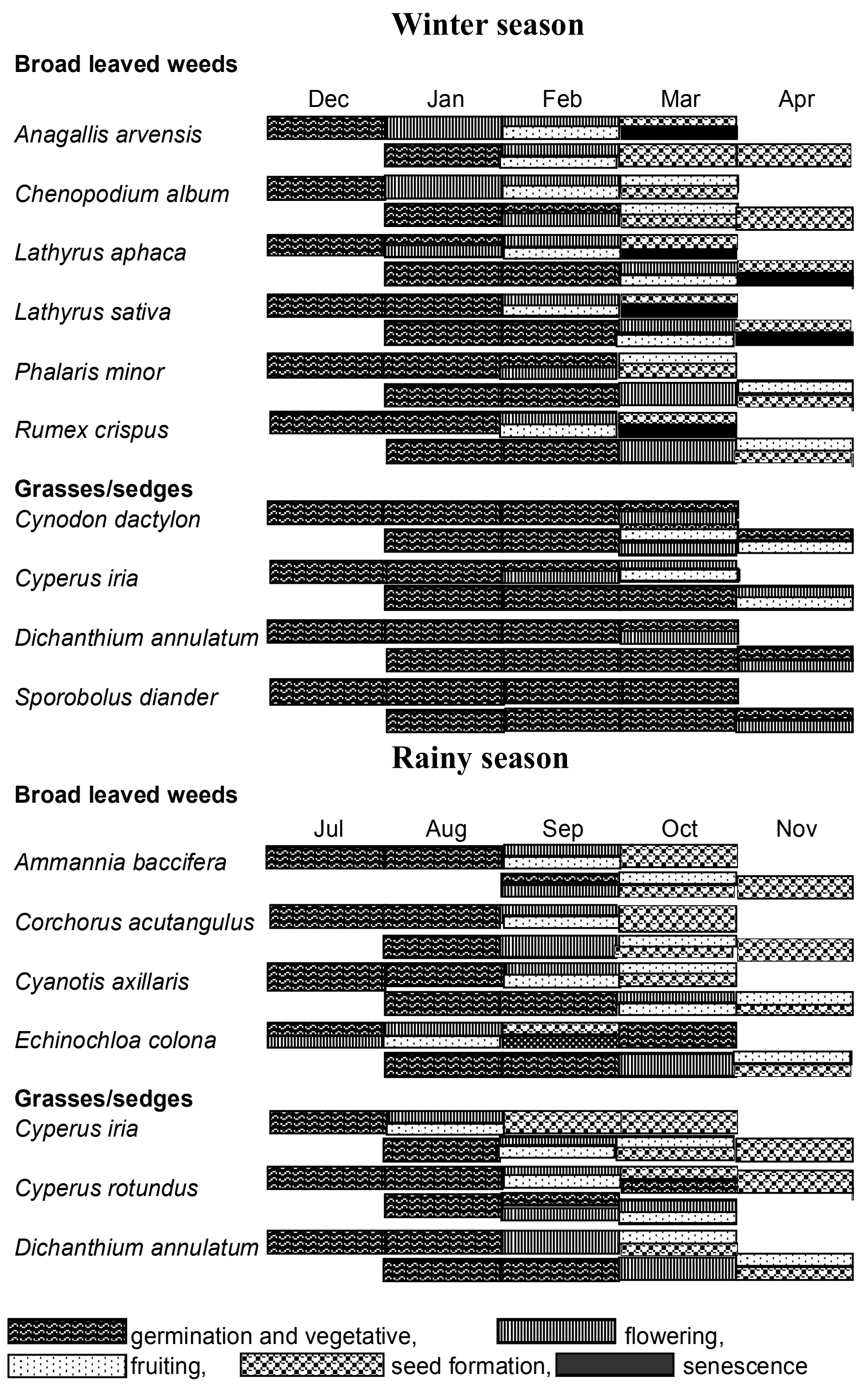

Fig. 2: Diversity in weed phenological events during winter and rainy cropping seasons in two agroecosystems. In each column, upper row represent phenological events for dryland agroecosystem weeds and corresponding lower row is for irrigated agroecosystem for same species.

In the rainy season, the dominant weed *Ammannia baccifera* showed approximately, 45-50 days later germination in irrigated agroecosystem in rainy the season. In other weed species also (e.g. *Corchorus acutangulus, Cyanotis axillaris* and *Echinochloa colona*) all phenological stages showed about one month shift. Most grasses/sedges showed seeds towards end of season, during March end in irrigated agroecosystem and April end in dryland agroecosystem. Overall, in dryland agroecosystem greater numbers of seeds were produced for longer period of time in both seasons whereas longer vegetative stage was noticed in the irrigated agroecosystem.

3.2. Flower, fruit and seed production

The annual flower, fruit and seed production were higher in the dryland agroecosystem (344-351, 219-238 and 365-397 x 10^3 m^{-2}, respectively) compared to the irrigated agroecosystem (211-237, 132-142 and 252-261 x $10^3 m^{-2}$, respectively) (Table 2). No significant variations were observed in the number of flowers produced in the two seasons (rainy and winter) in dryland agroecosystem. However, in the irrigated agroecosystem the number of flowers produced were significantly greater in the winter season (145-160 x $10^3 m^{-2}$) than in rainy season (66-77 x $10^3 m^{-2}$). There was no difference with respect to flowers produced in both agroecosystems in winter season, whereas, in the rainy season significantly higher number of flowers were produced in the dryland agroecosystem. In the dryland agroecosystem 64-68% flowers were converted into fruits (c.f. 60-63% flower conversion into fruit in irrigated agroecosystem). During the two annual cycles, the maturation of fruits to seeds were considerably greater in the rainy season (353-412%) than in winter season (87-93%).

In dryland agroecosystem, majority of species (9 species) were broad-leaved during winter season whereas in the rainy season broad-leaved weeds (6 species) and grasses/sedges (7 species) contributed equally in flower, fruit and seed production (Fig. 3A). Of the total flowers, fruits and seeds produced during winter season the contributions of broad-leaved weeds were greater (88%, 86% and 92%, respectively) than the share of grasses/sedges in dryland agroecosystem. Major broad-leaved weed species *Anagallis arvensis*, *Chenopodium album* and *Rumex crispus* together contributed 86% in total of flower production, 85% of fruit production, and 91% of total seed production during two year study period. In the case of grasses/sedges, 82% flowers were recorded as fruits and seed formation was 90% of these fruits. Among grasses/sedges the major contributing species were: *Phalaris minor* and *Sporobolus diander*.

During the rainy season contribution of broad-leaved weeds was lesser compared to grasses/sedges. Total number of flowers, fruits and seeds produced by broad-leaved species were 9%, 7% and 63%, respectively (Fig. 3A). Corresponding values for grasses/sedges were 92%, 93% and 38%,

Table 2: Total number of flower, fruit and seed production during winter and rainy seasons in dryland and irrigated agroecosystems.

Variable	Flowers	Fruits	Seeds
1998-1999 annual cycle			
Dryland			
Winter (lentil)	169.3±14.0 NS	119.4±12.5*	194.2±8.3**
Rainy (rice)	175.4±34.9**	99.6±20.6*	171.2±31.4NS
Annual	344.8**	219.1**	365.5**
Irrigated			
Winter (wheat)	160.2 ±10.0 NS	94.4±10.1*	52.7±5.5**
Rainy (rice)	77.5±11.0**	48.4±5.8*	171.2±42.8 NS
Annual	237.7**	142.9**	252.9**
1999-2000 annual cycle			
Dryland			
Winter (lentil)	193.4±22.6 NS	132.4±16.3*	212.3±30.9**
Rainy (rice)	157.5±26.5**	105.6±21.5**	185.2±28.9 NS
Annual	351.0**	238.0**	397.5**
Irrigated			
Winter (wheat)	145.0±13.0 NS	88.9±12.5*	82.7±9.3**
Rainy (rice)	66.4±14.0**	43.4±10.1**	179.0±47.5 NS
Annual	211.4**	132.4**	261.8**

Significant at * $P < 0.05$ and ** $P < 0.001$, Comparison is between dryland winter season and irrigated winter season; between dryland rainy season and irrigated rainy season and on annual basis in both annual cycles.

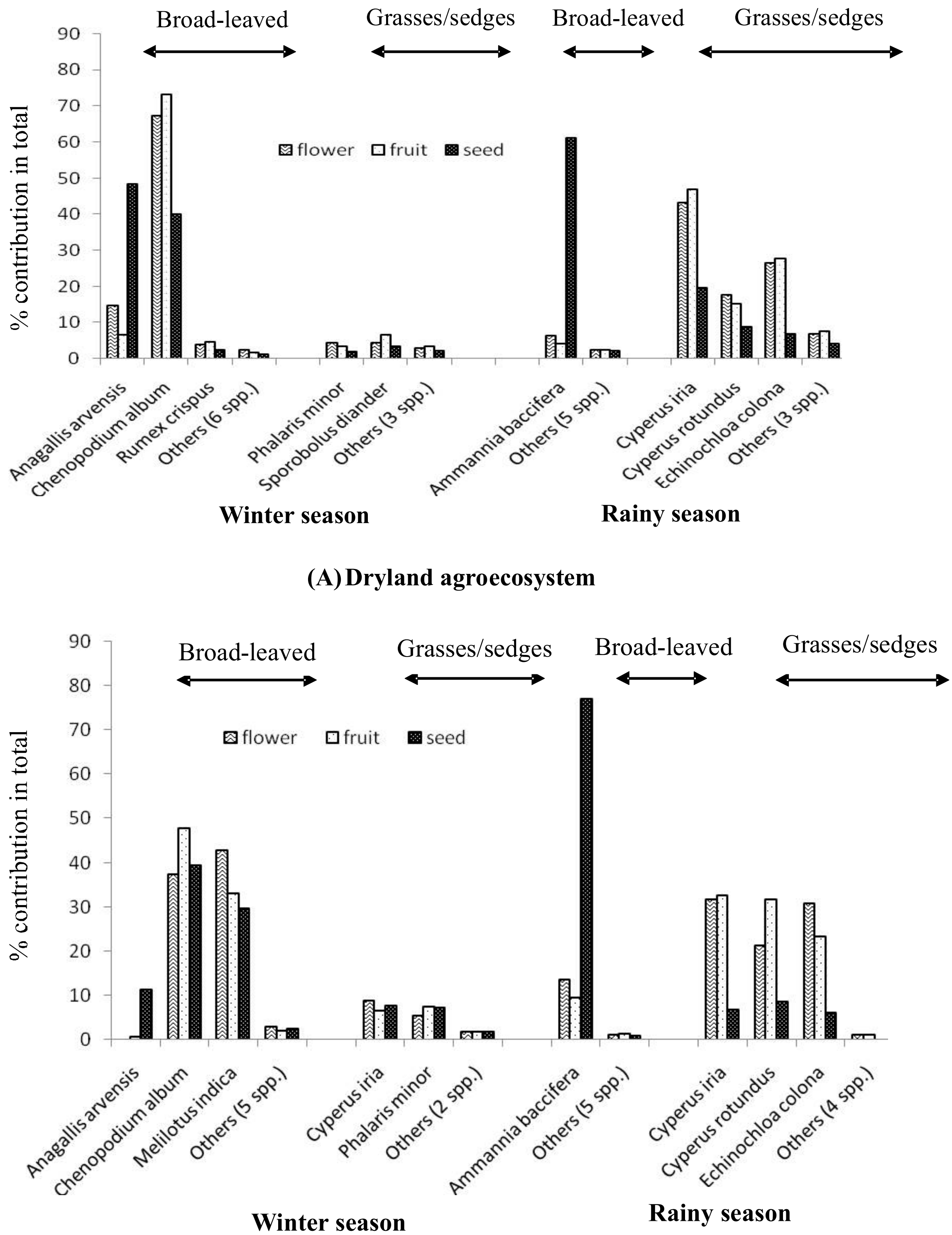

Fig. 3: Percent ccontribution of different weed species in total flowers, fruits and seeds production in dryland (A) and irrigated (B) agroecosystems during winter and rainy cropping seasons. Values are mean of two annual cycles.

respectively. Of the total number of flowers produced by broad-leaved weeds in this season about 41% were converted into fruits and the number of seeds produced by these species was about four times greater (167%). In broad-leaved weeds substantially greater number (22-23 times) of seeds were produced per fruit whereas in grasses/sedges the seed production per fruit was only 0.6-0.7%. *Ammannia baccifera*, the dominant broad-leaved species contributed 72% of flower production, 63% of fruit production and 97% of seed production. Dominant grasses/sedges were: *Cyperus iria, Cyperus rotundus* and *Echinochloa colona*.

In the irrigated agroecosystem, out of the total 12 weed species present during winter season, two-third were broad-leaved weeds and the remaining one-third were grasses/sedges (Fig. 3B). In winter season, ccontributions to flower, fruit and seed production by broad-leaved weeds were greater (84%, 84% and 83%, respectively) than the grasses/sedges (16%, 16%, and 17%, respectively). Major broad-leaved weed species in irrigated agroecosystem during the winter season (*Anagallis arvensis, Chenopodium album* and *Melilotus indica*). These species contributed 81%, 82% and 81%, respectively, of total number of flowers, fruits and seeds produced in winter season. Among grasses/sedges the dominant species were: *Cyperus iria* and *Phalaris minor,* and these species contributed 14%, 14% and 15%, respectively, of flower, fruit and seed production in this season. In case of broad-leaved weeds, 59% flowers were converted into fruit and these fruits produce 86% seeds. Corresponding conversions in fruits and seeds in grasses/sedges were: 58% and 87%, respectively, during the winter crop.

During rainy season, 46% of total weed flowers were converted into fruits, which form greater number of seeds from these fruits (25-28 times) in forbs (Fig.

Table 3: Estimated total seed rain ($10^3 \pm$ SE m^{-2}) during the winter and rainy seasons in the dryland and irrigated agroecosystems. The two agroecosystems were compared for: (i) annual seed rain; and (ii) total seed rain in the winter and rainy seasons (* $P < 0.05$, ** $P < 0.001$ and NS, not significant). The contribution of different weed species (the mean of two annual cycles) is shown as the % total seed rain.

	Dryland		Irrigated	
	Winter	Rainy	Winter	Rainy
Total seed rain (1998-1999)	59.14±3.3**	43.47±5.6NS	18.47±4.6**	54.74±16.3NS
Annual total seed rain	102.6±2.8*		73.22±1.7*	
Total seed rain (1999-2000)	62.20±18.1**	50.38±7.5NS	20.0±7.2**	59.96±10.8NS
Annual total seed rain	112.6±15.9*		79.9±13.3*	
Broad leaved weeds (% total seed rain)				
Anagallis arvensis	52		12	
Chenopodium album	33		24	
Rumex crispus	6		2	
Melilotus indica			33	
Melilotus alba			2	
Ammannia baccifera		74		82
Corchorous acutangulus				
Grasses/Sedges (% total seed rain)				
Phalaris minor	2		14	
Sporobolus diander	2		5	
Cyperus spp.	1	9		8
Echinochloa colona		11		7
Cynodon dactylon	1	2	2	
Polygonum hydropiper				1
Unidentified	1	2	5	1
Others (% total seed rain)	2	2	1	1

Others: *Alternanthera sessilis*, *Commelina benghalensis, Corchorus acutangulus, Cyanotis axillaris, Dichanthium annulatum, Ipomoea aquatic, Ludwigia parviflora, Polygonum plebejum, Lathyrus aphaca, L. sativa, Solanum nigrum.*

3B). In grasses/sedges 65% flowers were converted into fruits and 87% of these fruits formed seeds. Total number of flowers and fruits produced by all grasses/sedges were considerably greater than broad-leaved weeds. However, the conversions of seeds from fruits were much higher (80%) in broad-leaved weeds compared to grasses/sedges (23%). Dominant broad-leaved weed species *Ammannia baccifera* contributed 92% in flower, 88% in fruit and 98% in seed production. Amongst grasses/sedges, *Cyprus iria, Cyperus rotundus* and *Echinochloa colona,* dominant weed species, contributed about 84%, 88% and 98%, respectively to flower, fruit and seed production (Fig. 3B).

3.3. Seed rain

The estimated annual seed rain by all species in the dryland agroecosystem (102-112 × 10^3 m^{-2}) significantly exceeded (P < 0.05) the seed rain in the irrigated agroecosystem (73–80 × 10^3 m^{-2}) during both annual cycles (Table 3). The difference was more marked during the winter season (P < 0.001), when more than 3 fold seeds were collected in seed rain in the dryland agroecosystem. The seed rain in the two agroecosystems did not differ significantly in the rainy season. The major contributors to seed rain during the winter season were *Anagallis arvensis* and *Chenopodium album* in the dryland agroecosystem and *C. album*, *Melilotus indica* and *Anagallis arvensis* in the irrigated agroecosystem. During the rainy season, *Ammannia baccifera*, *Cyperus* spp and. *Echinochloa colona* were the major contributors in both agroecosystems.

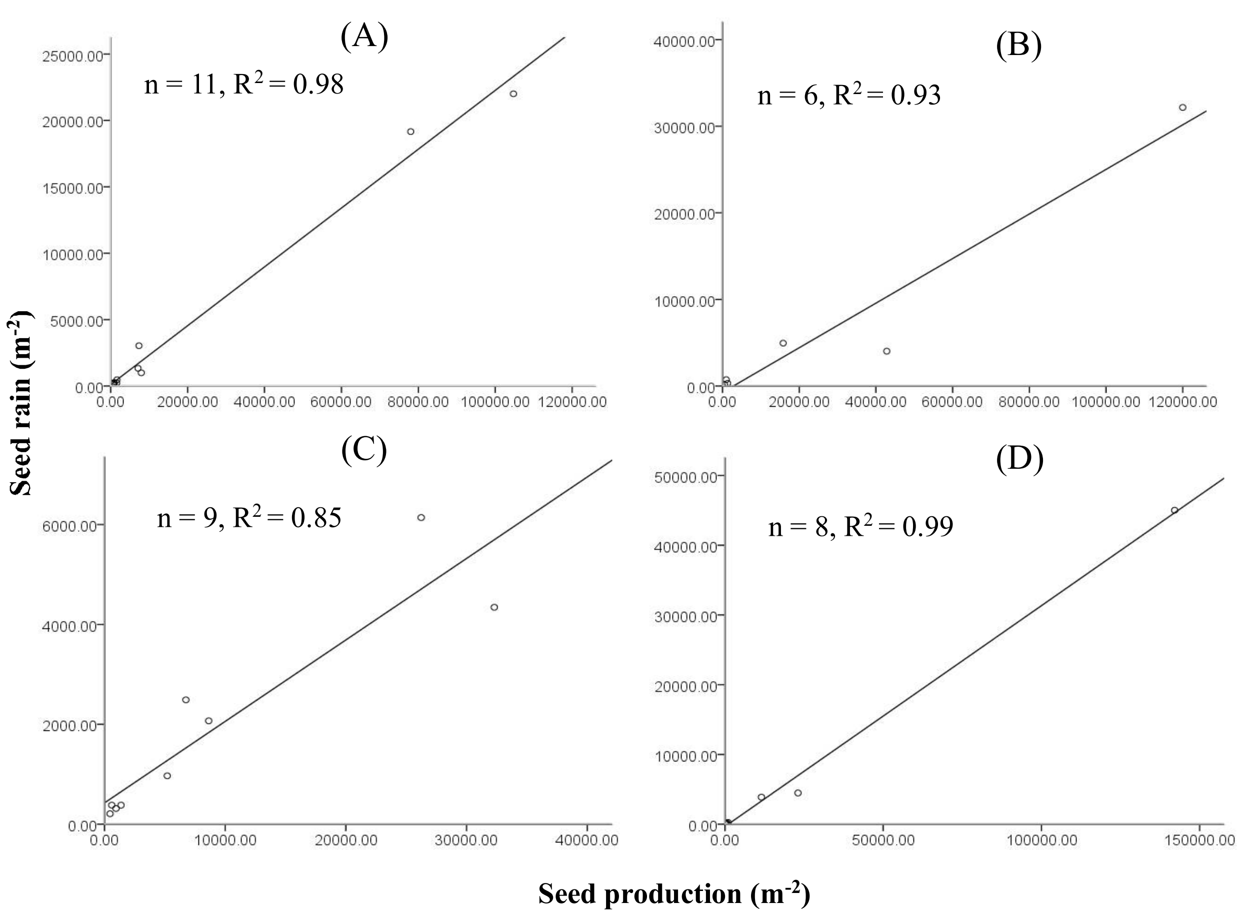

Fig. 4: Relationship between seed production and seed rain by all weed species during: (A) winter season in dryland agroecosystem, (B) rainy season in dryland agroecosystem, (C) winter season in Irrigated agroecosystem, and (D) rainy season in Irrigated agroecosystem. n represents number of species whose seed production and seed rain were determined. All values are significantly correlated at p>0.001.

3.4. Relationship between seed production and seed rain

In different seasons the relationship between total seed production and total seed rain in the two agroecosystems were examined by correlation analysis, compositing the data of 11 species (R^2=0.98) in winter and 6 species in rainy (R^2=0.93) in dryland agroecosystem and 9 species in winter (R^2=0.85) and 8 species in rainy (R^2=0.99) in irrigated agroecosystem (Fig. 4A-D). In all four instances the correlation coefficients were significant (p<0.001). Although the constituent species showed considerable differences in seed production and seed rain, the composited data for the ecosystem exhibited rather close fit.

4. Discussion

The knowledge of weed phenotypic plasticity due to different agricultural practices and variation in their reproductive potential can be useful in developing new weed management tactics for cropping systems (Martinez-Gharsa *et al.,* 2000; Otto *et al.,* 2007). In both kinds of agroecosystems, weed emergence were restricted to the crop growth periods. Complete elimination of weed flora at the time of tillage operations used for the seedbed preparation resulted in temporal separation of rainy and winter season weeds along with their respective crops. Compared to the dryland agroecosystem, late weed emergence in the irrigated agroecosystem may have been mainly due to late sowing/soil disturbance. Shrestha and Swanton (2007) analyzed phenological development of selected annual weeds under non-cropped field condition and showed that phenology of weeds affected by different planting dates, whereas, it is comparable in natural and experimental field condition. Rice transplanting has been considered as one of the oldest weed control practice (Bastiaans *et al.,* 2000), but due to the limitation imposed by soil moisture this practice is not acceptable in tropical dryland agroecosystem. Rice transplant in irrigated and direct sowing in dryland may be the cause of temporal difference in weed species composition and their phenological events in the two agroecosystems. In both agroecosystems, some species (e.g. *Anagallis arvensis, Chenopodium album, Lathyrus aphaca* and *Lathyrus sativa*) appeared earlier during the winter season and showed their high ability to acquire resources. Whereas, late emerging individuals of weed flora face high mortality and/or reduced seed set. In this study also early emerged species produce high seeds. It has been reported that many species of slightly disturbed habitats possess short vegetative period, a long flowering period and correspondingly long period when the seed is ripened and released (Harper, 1987). In the presently studied dryland agroecosystem, seed formation stage is longer than the vegetative period. In contrast, the weeds of irrigated agroecosystems usually show longer vegetative period and short seed production period and delayed seed maturity/ripping, and in some cases require the act of harvesting and full threshing for full release of the seeds. The weeds of agroecosystems have evolved a dispersal habit parallel to that of the crop to maximize the chance of dispersal with the crop seed. In the dryland agroecosystem early seed ripening and release compared to the irrigated agroecosystem is possibly related to early sowing of crop and early emergence of associated weed species. The early sowing in dryland agroecosystem is also responsible for the maximum utilization of soil moisture from previous cropping season.

Species shifts and adaptation may occur when an environment changes over time (Martinez-Ghersa *et al.,* 2000). Changed soil conditions due to different agricultural practices resulted in shifts in species and their adaptation to the habitat. It has been reported that weed density and species composition vary greatly and are closely linked to cropping history in agricultural systems (Buhler, 1999). Thus, variations in the phenological responses are of considerable importance in agroecosystems where an annual agricultural cycle is repeated along with natural weed colonization processes. Floristic compositions of the weed community and species adaptation have been assumed to follow the temporal pattern of environmental change. This results in the interaction of climatic variables with agronomic variables with respect to particular region and farming practices (Ghersa *et al.,* 1994). Most weed species completed their life cycle within the growing period of crops in both agroecosystems. However, few late emerging weeds, mostly annuals (e.g. *Cynodon dactylon, Dicanthium annulatum* and *Sporobulus diander*) remained present even after the harvest of the crops, as a result of which they shed their seeds during the fallow period (May-June). Probably this reflected their requirement of a longer time period for their growth and maturity. It has been reported that apart from seed germination these weed species also sprout out from root buds, which remain viable through the winter months, and they sprout with the advent of spring (Bhowmik, 1997). High temperatures and high humidity favour the growth and establishment of

Cynodon dactylon so it flourishes in the summer monsoon season and competes strongly with every field crop (Shad, 1989).

The weeds that escape the controls in agroecosystems produced greater seeds for future infestation, yet very little information is available for weed seed production in different tropical agroecosystems. A successful weed is able to produce seeds even under unfavorable conditions i.e. low soil fertility, water deficiency or stress, extreme temperature and shortened growing season (Ross and Lembi, 1985). The seed production of a weed reflects its capacity contributing to survival and evolution. Abundant small seeds production is a common adaptation, which ensures a higher probability of dispersal and reinfestation (Moles *et al.,* 2000). As in the case of presently studied dryland agroecosystem where higher seed production and seed rain will greatly ensure their future re-infestation. Number of seeds produced by each species have been reported to depend on the seed size. Jakobson and Eriksson (2000) found a significant negative correlation between seed number and seed size. Reddy (1990) has reported that *Anagallis arvensis* and *Chenopodium album* were associated with high seed number and low seed weight. Rao and Agarwal (1984) also reported that *Chenopodiun album, Melilotus indica, Phalaris minor, Ammannia baccifera, Cyperus rotundus* and *Echinochloa colona* produced large number of seeds per plant. The seed production recorded in the present study is also comparable to their observations. Most grasses/sedges produced large number of small seeds. In the presently studied agroecosystems seed production by broad-leaved weeds were greater than that of grasses/sedges.

During the winter period broad-leaved weeds dominated over grasses/sedges in both agroecosystems. Number of annual weed species was greater than the perennials in both agroecosystems during both cropping seasons. It has been reported that vast majority of seed produced in agroecosystems comes from the annual plant species (Hume and Archibald, 1986). The high seed output of these species can explain regular weed dispersion in the agroecosystems, because seed output has been reported as an important factor governing the species composition of the community. Broad-leaved weeds have been reported to be more competitive than grasses/sedges (Shad, 1988). Shad and Siddiqui (1996) reported that during the winter crop period in the irrigated agroecosystems, high temperature and high humidity favour the growth and establishment of *Cynodon dactylon*. In the present study, *Phalaris minor,* which was present in both agroecosystems with winter season crop, produced greater number of seeds in the irrigated agroecosystem than in the dryland agroecosystem. This was mainly due to greater density of this species in the irrigated agroecosystem. Although, higher seed production per fruit per plant in the dryland agroecosystem. In contrast, Naeem *et al.* (1993) reported higher seed production by *Phalaris minor* in rainfed areas compared to areas with high rainfall. Quite higher numbers of seed were produced annually in presently studied two agroecosystems. This was mainly due to the occurrence of many broad-leaved weed species like *Anagallis arvensis, Ammannia baccifera, Lathyrus aphaca, Lathyrus sativa* and *Corchorus acutangulus*. These species produced 5-30 seeds per fruit, as a result of which the seed number enormously exceeded the number of flowers and fruits. Seed production in dryland agroecosystem was higher in the winter season compared to the rainy season; whereas, in the irrigated agroecosystem number of seeds produced in the rainy season were higher than in winter season. Soil moisture deficiency in dryland and water logging condition in irrigated agroecosystems created unfavorable conditions during the rainy and winter seasons. Probably in agroecosystems weed species have the tendency to produce more seeds under unfavorable conditions.

Seed input through seed rain in the two agroecosystems varied greatly due to seasons and agro-ecological condition. Significantly greater seed rain was recorded in the dryland agroecosystem compared to irrigated agroecosystem. Seed rain is mainly dependent upon the seed production of the system by different species. Strong positive correlation between weed seed production and seed rain in this study showed dependency of seed rain on seed production in agroecosystems. In the agroecosystems mostly the weeds were annual that complete their life cycle with the crops and produce seeds at the end of the season. The major portion of seed rain occurred in last one or two months of the cropping season (data not shown). Reduction in seed inputs can be achieved by curtailing seed production and/or harvesting seeds before and/or after they are shed to the ground (Ghersa and Holt, 1995). In most weed species seed rain has been found to be responsible for the existence of soil seed bank and in highly disturbed agroecosystems it is dependent on yearly input of seeds (Cavers and Benoit, 1989). But due to lack of information about the timing and quantity of seed production by the various weeds in different agroecosystems, management practices are not much effective in weed control.

Thus, the changes in weed phenological pattern, seed production and seed rain are mainly attributed to differences in water management, which tends to reduce seed production period and seed rain in irrigated agroecosystem. Greater seed production and seed rain, and longer seed formation period indicate an adaptive mechanism of weed seeds in the dryland agroecosystem.

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Author contributions

In present papers there are two authors, first and corresponding author is Dr. Rajani Srivastava, she collected the data, developed new methods and wrote the manuscript. Professor K. P. Singh, is second author and supervisor of this work. He help in designed the research and improving the manuscript.

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