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Weed flora shift as affected by cropping systems

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Abstract
Weed composition is dynamic and changes with place, time and management practices. There are numerous factors such as climate, soil, nature of cropping system and management practices that influence the infestation of particular weed flora. The change in the composition or relative frequencies of weeds in a weed population (all individuals of a single species in a defined area) or community (all plant populations in a defined area) in response to natural or human-made environmental changes in an agricultural system is known as weed shift. The reduction in the abundance of a particular weed species due to management practice will lead to increased infestation of other type of weed flora. Agronomic practices recognized as integral part of agro-ecosystem and acts as "filter" that either allow or constrain the growth and infestation of specific weed flora present in weed species pool in a niche. It has been found that weed densities are lower in crop rotational systems than in monocultures. Rotation of crops acts as a key to improve crop yields, soil quality and weed management. Monoculture leads to less diverse and difficult to control weed flora. *Phalaris minor* and *Avena sativa* were found to be major weeds I rice-wheat system but their occurrence could be reduced by 30-50 per cent where both or either of the crop were replaced. *Echinochloa* sp. and *Cyperus* sp. in rice-rice and *Cyanotis axillaris*, *Euphorbia hirta* and *Ipomea aquatica* in rice-mung+sesame system. Weedy species can easily adapt to changes in production practices in order to take advantage of the available niches. Weed community shifts either increase, decrease, or extinction of weed species occur as there are many change in ecological and agronomic factors along with crops that influence weeds. Variation in weed species in crop rotation could be either due to the direct result of crop rotation or agronomic and weed management practices associated with cultivation of crop.

Keywords: Weed shift, cropping systems, crop rotation, herbicide resistance, ecology

Introduction

Agricultural weeds are a unique group of plant species because of their ability to infest and thrive in intensively disturbed habitats. Composition of weeds in a particular situation depends largely on specific crop and its management practices (Chhokar, *et al*., 2021) [17]. Therefore; shifts in weeds are not new. Weed shifts have happened as long as humans have cultivated crops. Weedy and invasive species can easily adapt to changes in production practices in order to take advantage of the available niches (Rana and Rana 2015) [44]. Weeds are well equipped to flourish in disturbed agricultural systems. Weeds are genetically diverse and can readily take advantage of the variety of conditions created by any crop production system. Therefore, one key to reduce the predominance of any given weed species is to increase the diversity of crops within the cropping system as cropping sequence acts as the most dominating factor in defining weed composition in a region (Chhokar, *et al*., 2021) [17]. Weed shifts can also occur both within a population of a certain species (e.g., surviving mutants), or within a plant community (e.g. certain species). A weed species shift can result in the emergence of weeds tolerant of existing weed management practices (Liebman *et al*., 2001) [33] and crop rotation is an important measure for diversifying weed communities and reducing selection pressure (Radosevich *et al*., 1997) [43]. The diverse mechanisms, such as, diversifying spatial and temporal resource availability, niche disruption, dissimilar planting and harvesting dates, growth habit, competitive ability of the crops and soil disturbance, etc by which crop rotation reduces weed numbers. (Liebman and Dyck, 1993; Buhler, 2002) [32, 14]. Therefore, need to recognize and understand shifts in weed populations in various cropping systems are important. The objective of the present study was to study the weed shift scenario along with different cropping systems.

Weed shift: Weed shift is the change in the composition or relative frequencies of weeds in a weed population (all individuals of a single species in a defined area) or community (all plant populations in a defined area) in response to natural or human-made environmental changes in an agricultural system (Rana *et al*., 2020) [45]. Shifts in weeds are not new. Weed shifts happened as long as human had started cultivation of crops. Weeds are well equipped to flourish in disturbed agricultural systems as they are genetically diverse and can readily take advantage of the variety of conditions created by any crop production system. Weed shifts occur when weed management practices do not control the entire weed community or population. Invasive species of weeds can easily adapt to changes in production practices in order to take advantage of the available niches. Therefore, one key to reducing the predominance of any given weed species is to increase the diversity of crops within the cropping system. The management practice could be crop rotation, herbicide use or any other practices such as tillage, manure application or harvest schedule that brings about a change in weed species composition. Some species or biotypes are killed by (or susceptible to) the weed management practice, others are not affected by the management practice (tolerant or resistant), and still some others do not encounter the management practice (dormant at application). Those species that are not controlled can grow, reproduce, and increase in the community; resulting in a weed shift. Any cultural, physiological, biological, or chemical practice that modifies the growing environment without controlling all species equally can result in a weed shift. A weed shift does not necessarily have to be a shift to a different species; for example, with a foliar herbicide without residual activity like glyphosate, there could also be a shift within a weed species to a late emerging biotype that emerges after application. In contrast to weed shift, weed resistance is a change in the population of weeds that were previously susceptible to an herbicide, turning them into a population of the same species that is no longer controlled by that herbicide. While weed shifts occur with any agronomic practice such as crop rotation, tillage, frequent harvest or use of particular herbicide, the evolution of weed resistance is only the result of continued herbicide application. The use of a single class herbicide application continuously over time creates selection pressure so that resistant individuals of a species survive and reproduce, while susceptible ones are killed.

Crop rotation/crop diversification/cropping systems

There are numerous factors such as climate, soil, nature of cropping system and management practices that influence the infestation of particular weed flora (Fried *et al*., 2008; Fried *et al*., 2012; Gaba *et al*., 2014; Susha *et al*., 2018) [24, 25, 26, 53]. Crop rotation is considered as an essential management component of integrated weed management systems (Clements *et al*., 1994) [19]. Diversified crop rotations, led to wide variations in germination, emergence, growth and type of weeds (Chhokar *et al*., 2021, Nichols *et al*., 2015; Ball, 1992) [17, 40, 7]. It has also been suggested that weed densities are lower in crop rotational systems than in monocultures (Doucet *et al*., 1999) [23]. Diverse cropping system leads to diverse weed community with less dominant weed species as generally observed in simple rotation or monoculture (Cardina *et al*., 2002) [15]. Limited diversity in weed flora under monotonous cropping is associated with similar selection pressure of management practices and favouring the species with phenotypes and phenology similar to the crop (Koocheki *et al*., 2009) [29]. Each crop smears certain restrictions on weed flora, which promote the growth of some weeds and suppress others (Shahzad *et al*, (2016) [47]. Liebman and Gallandt, (1997) [31] also explained that through use of diverse sets of crops that differ in planting and harvest dates and attendant different management practices, can affect the weed composition. Weisberger *et al*., (2019) [59] found that diversifying crop rotation sequences with additional species reduced weed densities by an average of 49%, regardless of auxiliary herbicide use. Rotation of crops acts as a key to improve crop yields, soil quality and pest management system. Monoculture leads to less diverse and difficult to control weed flora. Variation in weed species could be either due to the direct result of crop rotation or agronomic and weed management practices associated with cultivation of crop. Cropping system diversity is recognized as the proactive weed resistance management strategy (Beckie, 2009) [10]. Diverse cropping system leads to diverse weed community with less dominant weed species as generally observed in simple rotation or monoculture (Cardina *et al*., 2002) [15]. Limited diversity in weed flora under monotonous cropping is associated with similar selection pressure of management practices and favoring the species with phenotypes and phenology similar to the crop (Koocheki *et al*., 2009) [29]. Furthermore, the diversification effect on weed density was greatest for rotation sequences with the largest variance around crop planting dates. However, Tiwari, *et al*, (2020) [54], reported that cropping system has no effect on weed shift and crop performance. Likewise, Stevenson *et al*., (1997) [51] opioned that weed diversity has been shown to increase under crop rotation compared to monoculture.

Table 1: Different cropping systems under rainfed and irrigated conditions in India

Rainfed	**Cropping systems**
Intercropping	Upland rice + Pulses/Sesame/ Maize/ Millets, Deep water rice + greengram/ sesame/ jute/ maize
Relay cropping	Rice + lentil/ linseed/ gram/ peas/ urd/ mung/ lathyrus
Sequential cropping	
Assam	Jute-rice-rapeseed/ lentil, Rice-blackgram
Bihar	Rice-linseed/ chickpea/ khesari
Orissa	Rice-mung/ urd/ sesame/ groundnut
Eastern U.P.	Rice-chickpea/ peas/ linseed/ lentil
West Bengal	Rice-lentil/ mustard/ safflower/ sunflower
Irrigated	
	Rice-rice
	Rice-wheat
	Rice-rice-rice
	Rice-cotton/ pulses
	Rice-potato-mung/ urd
	Rice-pea-mung/ sunflower

Reddy, *et al*. (2004) [46]

Crops differ in their ability to compete with weeds; some weeds are a problem in some crops, while they are less problematic in others. Rotation, therefore, would not favour any particular weed spectrum to grow and proliferate. Adopting cultivation of a crop/cropping system continuously for years together, leads to emergence of super weeds, shift in weed flora. As a result, no single weed spices or biotype would become dominant. Ramanjaneyulu *et al*. (2006) [42], reported that *Phalaris minor* and *Avena sativa* were found to be major weeds in rice-wheat system while *Echinochloa sp*. and *Cyperus sp*. in rice-rice and *Cyanotis axillaris*, *Euphorbia hirta* and *Ipomea aquatica* in rice-mung + sesame system. The most notable example in this respect is little seed canary grass (*Phalaris minor*) in wheat. Its menace was started in late 1970s with the introduction of new varieties and high input use. Banga, R S. (1997) [9] reported that population of *Phalaris minor* was very high between 2000 and 2350 plants/m^2 in rice-wheat/ rice – cotton, cotton - wheat system. However, its menace could be reduced to the minimum (18-35 plants/m^2) with the adoption of rice-maize/ maize-wheat/ maize-sunflower system. Malik *et al.* (1998) [33] from Hussar, noticed maximum percentage occurrence of *Phalaris minor*, *Avena* sp., *Melilotus indica* and *Anagallis arvensis* in rice-wheat zone of Haryana, while their occurrence was less by 30-50 per cent in other zones where both or either of the crop were replaced. They also reported that the menace of *P. minor* could be reduced by introducing sunflower in Punjab. In wheat after rice, continuous ZT reduced the population of wild oats [*Avena ludoviciana* (L.) Dur.] and *C. album* L. Long-term (10 years) studies in rice -wheat and rice-mustard system at IARI, New Delhi showed that there was gradual reduction in weed population in DSR - wheat and DSR - mustard crops (Baghel *et al.*, 2018, Baghel *et al*, 2020, Das *et al.*, 2020a) [4, 5, 20] and weed species dynamics/shift was observed over the years. This also led to dominance of perennial sedges due to lack of natural competition from the annual weeds. This differential response and shift in weed flora could be associated with distribution of wheat associated weed seeds during tillage and puddling operation in the preceding rice crop (Chhokar *et al.*, 2007) [16]. The potential of brown manuring with *Sesbania* crop to reduce *C. rotundus* infestation was also reported in maize (Susha *et al.*, 2018; Das *et al.*, 2020b). [53, 21] Bhan, V.M. (1987) [11] reported 100% control by replacing wheat with sugarcane in rice based cropping system. Monocropping of rice leads to dominance of some grassy weeds. Smith and Frans (1969) [52] reported that by growing rice continuously for 10 years, increased infestation of *Echinochloa crusgalli* and C*yperus iria*, while, rotation of rice and soybean even in a two-year cycle also reduced these weeds and changed the weed species, i.e. the appearance of new species and the elimination of certain weed species due to change in the cropping system Water stagnant condition of transplanted rice is responsible for elimination of the infestation of *T. portulacastrum*, *C. rotundus*, *D. aegypetium* and *D. sanguinalis.* (Chhokar *et al.* 2014) [18]. The density of *Dinebra retroflexa* was high during the first year maize cropping, but *Panicum repens* became dominant when sunflower was grown after maize. Likewse, *Cyperus rotundus*, originally the dominant sedge, was smothered by *Cynodon dactylon*. The dominant weed species in maize field *Dactyloctenium aegyptium*, while *Parthenium hysterophorus* was the dominant weed species in sunflower. The proportions of *Datura fastuosa*, *Parthenium hysterophorus*, *Trianthema portulacastrum*, *Amaranthus viridis*, *Amaranthus polygamus*, *Flaveria austerlagica*, *Gynandropsis pentaphylla* and *Portulaca quadrifida* were higher during the 1st year maize cropping, while later their density were gradually reduced due to the inclusion of sunflower in the system. Ahmed and Moody (1980) [1] and Moody and Drost (1983) [37] have reported less intensity of *Paspalum dialatum*, *Amaranthus spinosus*, *Echinochloa colonum* and *Ludviga chinensis* but increased infestation of *Digitaria ciliaris*, *Ipomea triloba* and *Monochoria vaginalis* in rice-maize-mung, rice-maize, upland rice-transplanted rice, respectively.

Different crops/cropping systems, soil, water and weed control practices bring a lot of changes in weed community. Transplanted rice environment is different from upland rice (Smith and Frans, 1969) [52]. Moody and De Datta (1977) [36] reported that *Scirpus maritimus* became persistent in continuous cultivation of transplanted rice. Weeds like *E. colonum*, *E. crusgalliand* and *Eleusine indica* were found to be more in upland transplanted rice, whereas *C. iria* and *Digitaria sanguinalis* were more in transplanted rice reported by Patel and Panda (1982) [41]. When crops like aerobic rice, maize and mungbean were rotated with wetland rice, there was less of *S. maritimus*. In rice-rice-black gram/cotton rotation, the predominant grassy weed, *Echinochloa colonum* was less in the second rice crop compared to first one but its population had increased in rice-cotton. In case of rice – black gram sequence there was no infestation of *E. colonum. Cyperus difform is* progressively increased in rice-rice-cotton but decreased in rice-rice-black gram sequence as reported by Balasubramanian, N. (1991) [6]. Ahmed and Moody (1980) [1] and Moody and Drost (1983) [36] had also reported the less intensity of *Paspalum dialatum*, *Amaranthus spinosus*, *Echinochloa colonum* and *Ludviga chinensis* but increased infestation of *Digitaria ciliaris*, *Ipomea triloba* and *Monochoria vaginalis* in rice-maize-mung, rice-maize, upland rice-transplanted rice, respectively. Rice crop management system supports the survival of *P. minor* seed in rice-wheat system. New emerging weeds like *Sphenoclea zeylanica* in rice and *Rumex retroflexus* and *Malva parviflora* in wheat may be the likely menace of future in rice-wheat system.

Table 2: Density of grasses, sedges and broad-leaved weeds and weed dry matter accumulation in rice at 25 DAT under different crop sequence

Crop sequence	Grasses		Sedges		Broad-leaved weeds (No./m^2)		Weed dry matter production (g/m^2)	
	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04
Rice---wheat	7.44 * (56.5)**	6.80 (6.80)	5.06 (25.5)	4.43 (20.8)	5.25 (28)	4.10 (16.8)	6.12 (37.3)	4..37 (18.7)
Rice- chickpeaa	5.77 (35.5)	5.13 (29.0)	4.72 (22.0)	4.17 (18.5)	4.07 (16.5)	3.03 (10.5)	5.78 (33.9)	4.08 (16.6)
Rice-wheat-green gram	3.29 (13.8)	2.18 (6.0)	2.44 (9.5)	1.97 (5.0)	1.93 (5.5)	1.14 (1.0)	3.15 (10.8)	3.09 (9.1)
Rice-wheat-*Sesbania* (GM)	4.19 (20.5)	2.93 (14.3)	3.78 (14.8)	3.36 (11.3)	3.62 (13.5)	2.01 (5.3)	4.75 (25.0)	3.77 (13.8)
Rice-mustard-greegram	4.32 (20.5)	3.04 (11.8)	3.36 (12.8)	2.44 (7.0)	3.00 (10.8)	2.00 (3.5)	4.27 (18.4)	3.72 (13.5)
Rice-Lentil-Cowpea(F)	3.75 (16.8)	3.29 (14.5)	3.06 (10.8)	2.33 (6.0)	2.58 (7.8)	1.28 (1.5)	3.80 (14.6)	3.52 (12.1)
Rice-pea	5.85 (34.8)	5.42 (29.5)	4.41(22.0)	4.29 (19.3)	4.14 (19.8)	3.36 (13.5)	5.83 (35.0)	4.26 (17.9)
Rice-lentil-mustard (3:1)-cowpea	4.34 (19.8)	3.12 (14.5)	3.30 (15.5)	2.79 (7.5)	2.90 (9.8)	1.76 (3.0)	4.17 (17.5)	3.60 (12.8)
Rice-Maize + pea (1:1) - cowpea	4.68 (22.0)	3.71 (16.8)	3.54 (16.3)	2.78 (8.8)	3.75 (14.8)	2.56 (7.3)	5.08 (25.7)	3.84 (14.3)
Rice-potato-green gram	3.97 (18.0)	2.38 (7.0)	3.70 (14)	2.48 (6.8)	2.84 (8.3)	1.40 (1.5)	4.08 (16.9)	3.52 (12.2)
S.Em-+	0.80	0.99	-	0.58	-	0.53	0.58	0.24
LSD(p=0.05)	2.32	2.87	NS	1.69	NS	1.53	1.69	0.71

Rotation of crops or cropping systems can change the overall composition of weed flora. Knowledge of theses shifts can help in changing the composition of the weed seed bank from undesirable to easy-to-manage species. Singh *et al*. (2014) [49] reported that rotation can cause a shift in weed species composition. They reported that when rice-wheat cropping system is changed, there is reduction in weed density and weed dry matter production and Rice-wheat-green gram sequence recorded lowest population of all the three groups of weeds. Brar, L.S. (2002) [13] also explained that wheat crop rotation has been extensively used as an effective method of *Phalaris minor* management because, selection pressure is diversified by changing patterns of disturbances. Zero tillage direct seeded rice with sesbania as cover crop (*V. unguiculata, S. aculeatas*) could reduced weed dry matter accumulation by 60.0%, respectively compared to transplanted rice in rice-wheat cropping system (Jat *et al.*, 2019) [28]. Population of *P. minor can be reduced* by about 67, 80, 86, 89, 89, 89, 89, 92 and 97%, respectively by following different cropping systems, *viz*., cotton-wheat, maize-wheat, maize-wheat-summer green gram, maize-potato-summer green gram, maize-potato- onion, as compared to rice-wheat, cotton-African sarson (*Brassica carinata* A. Braun), cotton-gobhi sarson transplanted (*Brassica napus*sub sp. *Oleifera*var. *annua*), summer groundnut-toria (*Brassica rapa* var.*toria*) + gobhi sarson and summer groundnut-potato-pearl millet (*Pennisetum glaucum* L.) as compared to rice-wheat system (Walia *et al.*, 2011) [58]. Diversification of the area under rice-wheat cropping system will not only bring changes in weed spectrum but will also create soil conditions unfavorable for *Phalaris minor*. Replacing wheat with alternate crops like berseem, potato, sunflower, gobhi sarson for 2-3 years in rice-wheat cropping system, population of *P. minor* was reduced significantly (Table 3). Crop rotation having perennial forage species, may reduce the seed bank of annual species because of the decline in seed production due to crop competition as well as by predation, and decay of weed seeds (Chhokar, *et al*., 2021) [17].

Table 3: Status of seed bank of *Phalaris minor* in different crop rotations in Kapurthala and Patiala districts.

Cropping system	No. of seeds 100g of soil/plot			
	0 – 0.75 cm		0.75 –15 cm	
	Kapurthala	Patiala	Kapurthala	Patiala
Rice-wheat	4.0	3.0	1.8	1.0
Rice-potato-sunflower/wheat	0.7	0	0.3	0
Rice-toria-sunflower	0	-	0	-
Rice-berseem	0	0	0	0
Rice-gobhi sarson	0.5	-	0	-
Rice-onion-wheat	-	0	-	0

Source: Brar, L.S. (2002) [13]

Intercropping

Intercropping is also a mean to manage weeds in different cropping systems where close growing crops like rice, wheat, etc are main crops. Intercropping has been found to be beneficial in densely sown crops such as rice under upland situation. Several leguminous crops like arhar, mung, urd, groundnut and soybean are ideally suited as intercrops with upland rice. Vongsarojet, P. (1991) [56] from Thailand, estimated weed flora shift in rice based intercropping with sesame and mung. Intercropping of rice with sesame and mung was found to be effective in terms of reducing weed population of *Cyanotis axillaris*, *Euphorbia hirta* and *Ipomea aquatica*.

Tillage or land preparation is one of the important operations for growing of crops in different situations. Adoption of cultural practices exerts selection pressure on individual weed species, which may change the weed species composition in the soil seed bank (Mashavakure *et al.*, 2020, Mukherjee, 2020) [38, 39]. Shift in weed population depends on method and depth of tillage required for different crop in the cropping system. Adoption of cultural practices also exerts selection pressure on individual weed species, which may change the weed species composition in the soil seed bank (Mashavakure *et al.*, 2020) [38].

Shift in weed population from annual to perennials have been observed in the Conservation Tillage (CT) (Singh, *et al*., 2014) [49]. Different Scientist also reported that tillage practices (minimum or zero tillage) cause changes in the abundance and diversity of weed species in cropping systems (Ball and Miller, 1990, Alarcon *et al*., 2018) [8, 2]. This may be due to lack of disturbance of the root system and may encourage theses perennials reproductive structures by not burying them to depths that are unfavorable to emergence or by failing to uproot and kill them (Kumar, *et al*, 2022) [30]. Weed species and bio mass are lowest under conventional tillage (Menalled, F., 2008) [35]. Reduced tillage seems to favor occurrence of perennial weeds (Gill and Arshad, 1995) [27]. The perennial species, sow thistle (*Sonchus* L.) and quack grass (*Elymus repens* L.) have been associated with conventional and reduced tillage systems and have increased in zero-tillage (Derksen *et al.*, 2002) [22]. The infestation of couch grass (*Elymus repens* L.) in reduced tillage is often so severe that chemical control with glyphosate is needed (Vanhala and Pietola, 2003) [55]. Tillage systems also influence the periodicity of weed emergence. Dormancy and hard seed generally require physical or chemical scarification or weathering in the soil to enhance germination. Dormancy in some weed species, such as wild radish, is largely due to pod surrounding the seeds. Seeds of some species, such as *Malva parviflora* L. have a hard seed coat that needs to be scarified to stimulate germination. Therefore any mechanism that can increase pod breakdown will result in an increase in germination and emergence in these types of seeds. In CT systems the presence of residue on the soil surface may influence soil temperature and moisture regimes that affect weed seed germination and emergence patterns by altering the environment surrounding the seeds over the growing season. Also decaying residues can immobilize large amounts of nitrogen, resulting in low nitrate content in the soil, which could prevent alleviation of dormancy of species. Generally through, weed emergence decreases if the system buries surface seed deeper in the soil. Different types of tillage equipments leave weed seeds at different depths and this differential distribution of the seed in the soil profile has the potential to change seedling recruitment and weed population dynamics. Walia and Brar (2006) [57] reported that the zero till wheat crop sown after direct seeded rice recorded significantly higher dry matter accumulation by *Phalaris minor* as compared to conventionally sown wheat.

Annual weeds did not show dependable response to tillage system except *E. colonum* which decreased with increase in tillage intensity (Arif *et al.*, 2007) [3]. These results agree with Bostrom and Fogelfors (1999) [12] who reported that soil disturbance has limited influence on the summer annual weeds. Among the perennial weeds, the density of *C. dactylon* decreased with increase in tillage intensity while *C. rotundus* showed inconsistent response to tillage intensity. Many researchers stated that reduced tillage system increases perennial weed densities and diversity (Gill and Arshad, 1995) [27].

Conclusion

The reduction in the abundance of a particular weed species due to management practice will lead to increased infestation of other type of weed flora. Thus the changes in the environment may be as a result of differences in crop species, tillage, fertilizers, herbicides and other weed control practices that directly affect weed physiology and growth, weed/crop competition, weed distribution and accelerate weed shift. This differentials weed ecology and management practices in cropping systems results in a shift in weed dynamics. For these reasons, crop diversity through crop rotation and/or intercropping resulting in significant influences on weeds, both spatially and temporally, that may have an edge against weeds because of which rotation is considered as an important weed management tool in low input agricultural systems.

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