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Chapter
[3]

Weeds biodiversity: Challenges and opportunity in current context

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Abstract

In agro-ecosystems, different crops have a strong connection to biodiversity in the landscape. Weed density and behaviour pattern in our eco-system directly influence crop cultivation aspect. Weed biodiversity play a significant function in maintaining the processes and functions of ecosystems, including farming. Changes in climatic factors would alter the nature of vegetation and agriculture and it is true especially with the increasing atmospheric CO_2 concentration. While the variability in plant responses is large, C3 weeds generally increased their biological yield and LAI, under higher CO_2 concentrations compared with C4 weeds. However, the feasibility of crop pattern should be assessed not only in terms of crop yield but also adequate levels of biodiversity within cropland. Agricultural practices, which vary according to local climate, cause a disturbance to the agro-ecosystem, and change the dynamics of the weed community, creating ecological niches. Weed biodiversity plays a key role in supporting food webs and ecosystem services in agro-ecosystems. Weed miscellany provide ecosystem services for the upper trophic levels in crop land ecosystems. Pattern of distribution of the weed community (abundance and richness) are often difficult to predict so monitoring changes is recognized as crucial both in stable and unstable environments.

Keywords Biodiversity, Climate change, Ecology, Weed, Yield

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Introduction

Agriculture in India is facing several challenges which together are manifested into the sustainability issues. Changing in climate due to human intervention and other modern tool, aggravated the situation. The broad contours of the agricultural production system in the country have been defined by the need to achieve food security which calls for close attention. Day by day many unused plants, which earlier called as weed become get paramount important in modern medicine and day to day as food ingredient (Mukherjee, 2021). During the past few years, alteration of weather parameter has induced transformation in the weed distribution pattern in cultivated and non cultivated crop ecosystems throughout the world. Variation in climate distribution pattern from forest to terrestrial land gave different kind of environment to weed growth and development (Mukherjee, 2020a). Climate transform leads to three different patterns of transform occurred at diverse scale: (1) array shifts at the landscape scale, (2) niche shifts at the community scale, and (3) trait shifts of individual species at the population scale. Weeds are the part of dynamic ecosystems, start off in ordinary environment and become obstacle to the crops and change its pattern of appearance under slight weather change or modification (Mukheree, 2005). Weeds are a major biotic constraint limiting agricultural production. The problem is not only location-specific but also highly dynamic. With the globalization, invasive weeds menace may increase and some time reduced crop quality and economic value. Invasion of different weed species become threat and challenge to ecosystem, environment and social structure of our planet. It is measured as one of the most significant drivers of biodiversity loss and inhabitant genus endangerment and extinction. Rigorous monitoring through extensive surveys to detect invasive weeds, taking strict quarantine measures, evolving effective management strategies for containing the entrance and spread and preventing the losses caused by the invasive exotic weeds (e.g.: *Ambrosia trifida*, *Cenchrus tribuloides*, *Cynoglossum officinale*, *Chromolaena odorata*, *Eichhornia crassipes*, *Lantana camara*, *Parthenium hysterophorus*, *Mikania micrantha*, *Phalaris minor*, *Savlinia molesta*, *Solanum carolinense*, *Viola arvensis* and others) are essential. The efforts for managing weeds are going on since time immemorial, due to this we lose many of the important weed species and ultimately loose various diversity pattern of weeds. Further, the so-called modern cultivation practices, which involve extensive tillage and utilization of various inputs like seeds, irrigation water, organic manures, synthetic fertilizers and other agro-chemicals, are also leading to increased weed infestation and some places we found weed shifting. The threats posed by herbicide-resistance development in weeds, globalization and introduction of alien invasive weeds, and climate change favouring intense crop-weed competition are also a major concern. Despite the development of effective weed management technologies and their adoption on large areas throughout the country, there is a need for continuous monitoring and refinement of strategies in order to lessen the adverse effect on agricultural productivity, environment and biodiversity.

Association of weeds with different cropping system is sometime beneficial and harmful to the crop (Mukherjee, 2021). Various evidence revealed that, weed flora have changed over the past century, with some species declining in abundance, whereas others have increased mainly due to alteration of environment. Various evidence revealed that decline in the size of arable weed seed banks due to erratic or less rainfall pattern. Some of these changes reflect improved agricultural efficiency, changes to more intensive crop rotations and the use of more broad-spectrum herbicide combinations, which also affect our environment and socioeconomic status of farmer's. Interrogation of a database of records of phytophagous insects associated with plant species reveals that various weed group support a high diversity of insect species and under sling change of environment their insect micro-habitat will be changed. Reductions in abundances of host plants may affect associated insects and other taxa. A number of insect groups and farmland birds have shown marked population declines over the past four decades (Leon *et al*., 2017).

Soil texture and its pattern depend on intensity of rainfall and other factors which are directly related to our environment and influence distribution of weed distribution pattern and its ecosystem (Singh *et al*., 2003). Diverse ecosystems had to make room for monocultures of single crops, intensively managed with chemical pesticides. This leads to herbicide resistant weeds problem. During the era of high tech modern industrialized agriculture, with the use of intensive agro-input in nano form, we face challenge of different pest and disease. Some microbes, insects and weeds developed a resistance to the chemicals. So-called "super-weeds" and other pests remained untouched by the rain of pesticides (which happens naturally when one "weapon", in this case weed killers, is used too intensively). Intensive chemical input leads to pest become resistance and use of various pesticides becomes useless and we are in real trouble. Because now we have populations of super-adapted pests and a "weapon" that's rendered completely useless! And this phenomenon is happening more and more often in agriculture. which leads to lose of biodiversity.

Weeds associated with crops

Major weeds associated with different crops vary with crops and locations. Various works revealed that (a) infestations of little mallow (*Malva parviflora*), jangli palak (*Rumex retroflexus*), annual bluegrass *(Poa annua*), lessers wine cress (*Coronopus didymus)* and rabbit foot polypogon (*Polypogon monspliensis*) are increasing in the rice-wheat cropping zone; (b) tiger foot morning glory (*Ipomoea pestigridis*) has become a serious weed of sugarcane in Haryana and Uttaranchal; (c) the intensity of submerged weeds is gradually increasing in the rice-rice sequence in Assam; (d) ragweed (*Ambrosia artemisiifolia*) and parthenium (*Parthenium hysterophorus*) are gradually spreading beyond the non-cropped area and entering cropped and plantation areas; and (e) loranthus (*Loranthus longiflorus*) is likely to be a major problem for mango orchards in the southern part of the country. In addition, weedy rice (*Oryza sativa*.) is emerging as a major problem in direct-seeded rice.

Aquatic weed

Aquatic weeds are more scientifically termed as aquatic macrophytes. These have beneficial effect as well as harmful effect based on its utility pattern in our day-to-day practice. Few aquatic plant acts as a pillar of mineral recycling with their various enzymatic metabolic action. Aquatic plants are an essential component of aquatic ecosystems, and as some of them may reach excessive proportions they pose a serious threat to fishery industry. Aquatic weeds compete with fish for water, nutrients, light, niche and oxygen, and thus reduce fish yields. The major aquatic weed species such as water hyacinth, bullrush (*Typha angustata*), homwort (*Ceratophyllum demersum*), salvinia (*Salvinia molesta*), lotus (*Nelumbo nuciferct*), alligator weed (*Altemanthera philoxeroides*), *Hydrilla verticillata*, *Vallisneria spiralis, Chara* sp., *Nitella* sp. and *Potamogeton* sp. are a primary concern in India (Kumar, 2011). The aquatic weed problems vary from one state to the other. For example, the major aquatic weeds in Kerala include water hyacinth, *Salvinia* sp., *E. crassipes*, *Pistia stratiotes*, *Altemanthera* sp., *Azolla* and *Lemna minor* (Jayan and Sathyanathan, 2012). In Madhya Pradesh, predominant aquatic weeds include *Vallisneria* sp., *Potamogeton* sp., *Ipomoea* sp., *Lemna* sp., *Azolla* sp., *Pistia* sp., *Hydrilla* sp., *Chara* sp. and *Myriophyllum* sp. (Singh and Nigam, 2014). Management of aquatic weeds become very challenging due to complicated soil-water ecosystem. Scientist mainly focused on minimized weed seed bank and support only to the level of biological diversity within the crop. Aquatic weeds can be used as source of mulching and fertilizer in number of crop field. Utilization of various end product of unwanted plant tissue in compost form help in soil mineralization and act as an effective source of natural fertilizer under different crop sequence. Best use of aquatic weeds for horticulture would be to apply them as a thick layer (as mulch) in different plantation and orchard field, on the soil to suppress weeds, conserve moisture and restore soil fertility.

Crop-weed association

Different kind of weeds associate in different way to different crop based on their behavioural pattern and mimicry. Some weed association with crop depend on few aspect, these area mainly as:

Morphological similarity: Under different field condition few of the weeds species (*Echinochloa crusgalli* , *Phalaris minor* etc.) are quite similar to main crop (rice, wheat etc.). Morphological alike weed be complicated to manage both by chemical (herbicide etc.) and mechanical measures. As we saw rice crop looks alike with *Echinochloa crusgalli, as* rice uprooted for transplanting in main field, this weeds also enter with rice seedling into main field and grow simultaneously with the crop, and compete with plant for light, nutrient and water. This can be very difficult to control with normal herbicide as our rice crop will also suffer.

Seed shedding behaviour: Number of unwanted plants complete their life cycle prior to the harvest of main crop in the field in which they are associated. The seeds which are drop in the field during one season, become the basis of invasion during the next crop season. Nearly 65-72 % seeds of problematic weeds such as *Avena ludoviciana, Ischaemum rugosum Phalaris minor, Trianthema portulacastrum* and *Echinochloa crusgalli* are drop in the same field. Behavioural pattern of seed shedding is one of the main reasons of alliance of a specific weed with a particular crop when sown on same field regularly.

Seed separation problem: Few plant seeds are quite similar to the seed of few obnoxious weeds, and they cannot be separate from crop seed, even they easily pass-out from the sieving during post harvest management. Such weed seeds easily escape from seed separation and are sown with crop seed during seed sowing in field. For example, *Rumex spinosus, Avena ludoviciana, Convolvulus arvensis* etc. seed size and shape are quite similar to wheat seed and these cannot be separate out even through sieve. The harvested produce swamped with such unwanted plant seeds must be kept away from seed production programme.

Friendly milieu: Weeds association with different crop not only depends on cropping pattern but it also influenced by crop behaviour in particular environment. This can be easily understood as in field condition *Avena ludoviciana* (wild oats) infestation in wheat crop can be checked through wheat-rice rotation for 3 to 4 years. Seeds of *Avena ludoviciana* are porous in nature, and soak up water and loose feasibility under constant standing condition (water). The nonstop wet situation gets rid of wild oats but could provide support to *Phalaris minor* establishment due to pleasant ecological situation formed with the promotion of paddy cultivation.

Germination in flush: Seed germination pattern of various weed species vary, and some seed germinate with number of flushes and become very tough to control them because of irregular behaviour of seeds. During field condition we found that few weeds germinate just after application of herbicide (resistant nature) and become very difficult to control in rest part of crop life cycle, even though under good crop management practice. For instance, *Phalaris minor* seeds sprout in numerous flushes in wheat crop and owing to this feature it is very hard to manage this weed.

Dominance of single set of weedicides: Age old herbicide or continuation application of same nature of herbicide or weedicide led to resistance feature in plant (weed). For example, due to single application of isoproturon for long time leads to *Phalaris minor* resistant in wheat field (Punjab, Haryana and Uttar Pradesh). Even though application of high dose of isoproturon could not curb the problem of *Phalaris minor*. So, this plant continued to grow with wheat by physiological change. Mixed application of different herbicide or rotational utilize of chemical control measures, helps a lot to evade alliance of a specific weed with a particular crop.

Weed utilization

For considerable time, the utilization of weeds uprooted from farm crops has been largely confined to their consumption as (i) green (leafy vegetables), (ii) animal forage, (iii) medicinal plants, and (iv) compost material. Their utilization as greens is a specific species–based activity with weeds like *Chenopodium album, Amaranthus viridis, Commelina benghalensis, Rumex spp*. and *Portulaca spp*., which are consumed, sometimes, in urban areas as a delicacy. But there is no denying fact that it is an extra micro –dimension utilization of weeds vis-a-vis tons of weeds that invade each hectare of crop land (when neglected). The utilization of weeds as forage for mulch animals involves consumption of mixed growth of varied weed species collected from neglected crop fields. Strange enough, this recommendation has been made by some scientists without reporting any critical analysis of individual weed species, particularly in respect of their alkaloid contents. It is a common observation that animals fed on either weeds or weedy forages, often yield tainted and foul-smelling milk and meat. That is why utilization of weeds for animal feed has not been accepted extensively. Regarding the medicinal uses of certain weed species, it may be useful to note that no doubt several weed species occurring on crop lands (and other places) possess certain very useful medicinal constituents, but manufacturers of plant medicines do not use these weeds for the purpose. They, in fact, cultivate the very same plant species separately, under best cultivation care on their medicinal farms as medicinal crops. Sometimes, the mixed growth of weeds uprooted from neglected farm crop fields is attempted to be utilized for composting on farms. However, the idea is beset with survival of many live weed seeds, thus compost disseminates many weed seeds throughout the crop fields. That is why the crop fields treated with FYM/ arid compost are found to be weedier than the urea and like synthetic fertilizer treated plots. Over and above the analysis of various modes of utilization of weeds presented so far, the fundamental issue is whether we want to grow crops or weeds on our farmlands (Figure 1a-1h). Weed utilized in number of ways according to their suitability for a particular community such as:

Utilization of weeds from non-crop lands and water bodies

Tons of weeds infest our grazing lands, plantations, National Parks and large waterbodies. And these grow by leaps and bounds each day, covering more and more area. On an average, it is observed that such weeds add 1–2 t/ha of biomass everyday. Water hyacinth (*Eichhorrnia crassipes*) is the oldest example of such a weed in water bodies throughout India. Among the terrestrial weeds, *Lantana camara* in northern India and *Mimosa*, *Mikania*, *Chromolaena*and *Solanum spps*. in southern India are of immediate concern. Unfortunately, no control measure (chemical, biological or physical) of the above weeds has been found feasible so far and these weeds continue to grow and expand fast. Their control by utilization is a good proposition, provided we are talking of their bulk or mass utilization which could be capable to outsmart their average per day growth rates started earlier. Insignificant utilization methods of such gigantic weeds often reported in literature, like thatching and furniture material, cannot be helpful in recovering our wasted lands and water bodies. A rapid, extensive and economical method of composting of terrestrial and aquatic weeds is an attractive proposition for their management in near future. Intensive research is, however, required in this respect, jointly by the agronomists, microbiologists and biotechnologists. Weed composting become very easy under control condition with proper technical guidance.

Weeds as medicinal plant

Various medicinal plant, which were earlier treated as weeds, become now valuable herbs and used as impotent medicinal plant (Mukherjee, 2008). Studies revealed that, few plant become very important for many community as medicinal plant (Table 1 and 2) such as: *Aconitum ferox, Acorus calamus, Artemisia vulgaris, Astilbe rivularis, Bergenia ciliate, Cephaelis ipecacuanha*, *Ceritella asiatica, Clematis buchanaria, Dioscorea composite, Dichroa febrifuga*, *Drymaria diandra, Digitalis purpurea* , *Eupatorium cannabinum, Ficus semicordatus, Fraxinus floribunda, Gentiana kurro, Heracleum wallichii, Litsaea cubeba, Nardostachys grandiflora, Oroxylum indicum, Panax pseudo-ginseng, Paederia foetida, Phytolacca acinosa, Picrorhiza kurrooa, Podophylum hexandrum, Przewalski atangutica, Pteris biaurita, Rheum modi, Rhus semialata, Rumex nepalensis, Swertia chirata, Thysamolaena maxima, Urtica dioica, Viscum articulatum, Valeriana officinalis* (Mukherjee, 2014a).Our field observation revealed that, Darjeeling range ($87^0 59'$ - $88^0 53'$E and $28^0 31'$-

Table 1. List of plant which has high medicinal value.

S. No.	Scientific name
1	*Alsophila costularis* Bak
2	*Angiopteris evacta* Forst
3	*Aralia sikkimensis* Parry
4	*Cinnamomum tamala* Nees & Ebern
5	*Cinnamomum obtusifolium* Nees
6.	*Dioscorea deltoidea Wall ex Kunth.*Thunb
7	*Gloriosa superba* Linn
8	*Pinus roxburghii* Sargent
9	*Rauvolfia serpentina* Benth ex Kurtz
10	*Swertia chirata* Buch Ham.
11	*Taxus baccata* Linn

Table 2. Potential impacts of climate change on weeds significant to agriculture (Source: Australian Module, 2008).

Common name	Scientific name	Expect impact
Blackberry	*Rubus fruticosus*	Expected to grow towards south wards in high altitudes range, because it is sensitive to more temperature and drought
Chilean needle grass	*Nassella neesiana* (Trin. & Rupr.) Barkworth	Expected to increase its ranges because it highly invasive (long lived, seed dispersal by wind andwater) and drought tolerant.
Gorse	*Ulex europaeus*	Expected to retreated southwards because it is drought sensitive.
Lantana	*Lantana camara*	Expected to continue its moves southwards into high rainfall zone of northern new south wales.
Mesquite	*Prosopis glandulosa*	Some risk that it may move into lower rainfall areas because it is very drought tolerant.
Parthenium	*Parthenium hysterophorus*	Not suited to winter dominant rainfall areas, may move into summer dominant high rainfall (>500mm) region.
Serrated tussock	*Nassella trichotoma* (Nees.) Hack.ex Arechav.	Expected to retreat southwards and to high altitude because it is sensitive to temperature. As drought tolerant plant, it should become more invasive in an areas where temperature allows.
Prickly acacia	*Acacia nilotica*	Expected to move southwards and into arid areas

Figure 1a. Wheat field infestation with *Parthenium*: An emerging problem due to seed admixture.

Figure 1b. *Azolla* (earlier as weeds) cultivation and utilization in field crops.

Figure 1c. Monitoring of weed diversity pattern in fallow land.

Figure 1d. *Polygonum aviculare* (knotweed) infection in wheat field due to weed shifting (Coochbehar, West Bengal).

Figure 1e. Collection of soil sample for weeds seed bank.

Figure 1f. Reduced weed problem under zero tillage practice.

Figure 1g. Study on change in weed pattern under changing climate.

Figure 1h. Monitoring and weed management programme, Kalyani (Nadia, West Bengal).

27^{0}13′N) was one of the native places of different kind of *Swertia* species. Out of various species, *Swertia chirayita h*as long been used in the various treatments. The bitter infusion of the plant is used for skin disease, blood purification and as a bitter tonic for fever and indigestion. The presence of xanthones in the species is reported to remedy tuberculosis. Various species of Swertia is still treat as weeds because of little knowledge about their use. We did few survey programmes in North Eastern Himalaya during 2005 to 2014 and found number of plants which become quite beneficial for one community, and have no value for other people because of weedy in nature (Mukherjee, 2009a).

Biological diversity of weeds

Biological diversity is a term that may refer to diversity in a gene, species, community of species, or ecosystem. According to the Convention on Biological Diversity, biodiversity means "the variability amid living organisms from all source including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part" (CBD, 1992). Weeds have numerous interactions with other organisms and some of these interactions can have direct effects on the functioning of the agro-ecosystem. Such association create lot of biological diversity in our ecosystem. Few plant (may be weeds) are major food source for animals such as pollinators that preserve uncommon plant species, earthworms, granivorous and omnivorous arthropods such as carabid beetles, ants, pollinators, e.g., farmland birds and mammals. These plans can be conserved, based on their utility in nature (field condition), keeping in mind ecosystem balance feature. Weeds are the part of dynamic ecosystems, start off in ordinary environment and become obstacle to the crops, however this is the important source of pollination and home of number of beneficial insects. Weed biodiversity plays a key role in supporting food webs and ecosystem services in agro-ecosystems. One important service, that reduces weed abundance, is the predation of weed seeds by invertebrates and vertebrates. Weed biodiversity may be helpful to maintain seed predator occurrence (Kulkarni *et al.*, 2017; Schumacher *et al.*, 2020).

Impact of farming practices on weed biodiversity

Mechanized and improve farming practices become threat to not only our ecosystem but also very challenging for conservation of biodiversity pattern also. From a human perspective plant can provide sources of fuel, medicines, raw materials for many processes, protection, as well as aesthetic pleasure. Crop, animal, horticultural and forestry production systems are essential for food and non-food products. These are critical component of modern land use, that have evolved as agriculture and associated industries have developed. Plants are a key part of biological diversity as well. Threats to plants from non-target impacts of weed management within production systems may impact on biological diversity. Those impacts, mediated directly or indirectly through the elimination of plants or effects for example on reproductive potential, could influence ecology function by affecting soil processes, nutrient cycling and trophic interactions via fauna, flora, microflora and fungi. A balance is needed between the methods of production applied, the demand for products and the environmental impacts that occur. Changes in farming practices that have been recognized as causing declines in biodiversity include 1) concentration on one season crop either winter or rainy season crops with a consequent loss of other season crops, 2) increased farm specialisation with a decline in livestock and grass enterprises in arable areas and 3) change in farming date. Plant species diversity is negatively influenced by high soil fertility, herbicide application and spray drift into the margin, high disturbance levels, decreasing landscape connectivity and reducing habitat quality. Species diversity generally declines with increasing soil fertility. This is likely to be the indirect effect of fertility through competition rather than a direct effect. Fast-growing species outcompete the slower-growing ones for light and nutrients. Soil fertility can be reduced by maximising the off-take, e.g., in crop yield, or manipulation of stores and fluxes, e.g., nutrient cycling. Research has found that fertilisation increased vegetation productivity significantly and tillage decreased community biomass at the start of the growing season. Disturbance increases below-ground competition and fertilisation encourages above-ground competition. Productivity is suggested to affect species diversity. Colonisation rate of perennial forbs and grasses decreased and extinction increased with increasing productivity of the vegetation. Accumulated litter and lower light penetration in highly productive vegetation possibly inhibit germination and survival of seedlings, thus decreasing the colonisation rate. Competitive displacement in vegetation on fertile soils increases the extinction rate, thus resulting in a loss of species diversity. Just as all plants, weeds are a home and a source of food to a number of animals. Weeds matter for the biodiversity of all kinds of creatures (insects visiting flowering weeds or of birds eating their seeds). Therefore, we can say weeds has lots of beneficial effect in our agro-ecosystem. They do tender an assortment of remarkable profit to all of us, as well as to our food growers. For example, scientist establish that the bright blue cornflowers – which are weeds, too – specifically attract hoverflies. Hoverflies are true *friends*, as they pollinate plants and eat aphids, a feared crop pest. When hoverflies and other so-called natural enemies of pests (such as ladybugs) are attracted to the field by weeds, they devour aphids.

Weed shift

Shifting of various weed in crop field mainly owing due to different weed management practice, which do not control the total weed community or population in particular field. The management practice could be herbicide use or any other practice such as tillage, manure application, or harvest schedule that brings about a change in weed species composition (Mukherjee, 2018). 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 others do not encounter the management practice (dormant at application). Shifting of weed flora pattern under changing climatic situation become very challenging for food growers, scientist and researcher. For example, due to growing rice under alternating flooding regimes and residual soil moisture conditions prevalent in the Cauvery Delta region of Tamil Nadu, red sprangle top *(Leptochloa chinensis)* and European water clover *(Marsile'a qu'adrifolia*) became predominant in rice fields by replacing barnyard grass *(Echinochloa* sp.) (Yaduraju, 2012). In the eastern Indo-Gangetic Plains, adoption of zero tillage has resulted in an increase in population of globally-significant perennial weeds such as purple nutsedge (*Cyperus rotundus* L.) and Bermuda grass (*Cynodon dactylon*) (Malik and Kumar, 2014). Observation revealed that, effective weed control with various tillage option enhances crop yield significantly, with little effect on weed biotypes (Mukherjee, 2017), Such shifts are likely to occur in other production system as well suggesting that weed flora need to be monitored continuously in all cropping systems and agro-ecological regions in order to assess emerging weed problems and plan weed management strategies accordingly (Mandal and Mukherjee, 2018).

The weedy rice problem become quite significant under lowland rice ecosystem (Mukherjee, 2014). Weedy rice is broadly defined as plants from the genus *Oryza* that much resemble, mimic, infest and compete with rice. Pattern of weed distribution varies in different season of rice from lowland to upland situation (Mukheree, 2009). Weedy rice is reported as a serious pest of direct seeded rice systems (DSR). Weedy rice can spread rapidly, is highly competitive and can dramatically reduce rice yield and quality. The particular problem is that seeds of weedy rice species mature and shatter before rice, injecting large seed numbers into the soil seedbank. The shift to DSR accompanied by widespread, often exclusive, use of herbicides for weed control in rice can rapidly result in major problems with weedy *Oryza* species. Due to many morphological and physiological similarities between weedy rice and rice plants the control is a difficult and complex long-term endeavour. Research undertaken at Research farm and at farmers' fields in Haryana showed that there was a quick shift in weed flora with change of establishment method from puddle transplanted rice (PTR) to DSR (Yadav *et al*., 2011). Aerobic grass weeds such as *Leptochloa chinensis, Eragrostis sp., Dactyloctenium aegyptium*and *Eleusine indica* which were minor weeds in PTR became major weeds in DSR. Infestation of various sedges such as *Fimbristylis miliacea, Cyperus sp*. also increased under DSR. On the other hand, *Echinochloa crus-galli* still remains the dominant weed under puddle transplanted rice with little or no infestation of aerobic grass weed species. Weed infestation in DSR research trials was so high that in unweeded situations rice grain yield was reduced by more than 50%. In addition to the diverse weed flora, the prolonged weed emergence further added to the complexity of weed management in DSR. Within DSR, there was less and delayed weed emergence under moist sowing of DSR than dry sowing (irrigating the field after sowing). Stale seedbed technique proved effective in reducing weed infestation in DSR, along with controlling previous season's volunteer rice plants. Inclusion of green cover crops like mungbean, cowpea and *Sesbania* also helped in decreasing the weed infestation in the main DSR crop, along with their added advantage as green/ brown manure manure (Yadav *et al*., 2011).

Bruckner *et al.* (1997) surveyed weeds in maize area between 1 July and 31 September 1996, and the findings compared with those of surveys conducted in 1990. An increase in the average cover and frequency of occurrence of *Panicum miliaceum*, *Mercurialis annua* and *Ambrosia artemisiifolia* was observed. Many species not recorded in 1990 were registered (*Eragrostis minor*, *Amaranthus graecizans*, *Digitaria sanguinalis* and *Geranium pusillum*). Such changes in weed flora composition over time are referred to as weed shifts. A weed shift may be defined as 'the change in the symphony or relative frequencies of weeds in a weed population or community in reply to human-made or natural ecological change in a farming system'. 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. The behavior of a weed population rely on the nature of the environment experienced by individual plants. Increase in the size of a population is achieved through reproduction of the individuals that survive to maturity and by gains from immigration. Survival may occur by persistence in a dormant state (as seeds in the soil) or by escape from control as seedlings or plants (through chance or due to genotype, as in herbicide resistance). It is therefore, the reproductive contribution of these survivors that is important in the expansion of the population. Examples of weed shifts that have occurred in recent history include the following:

Community shift in response to herbicide use: With the use of clodinafop in wheat weed flora was mainly composed of *Poa annua*. Similarly in maize continuous use of pre-emergence atrazine give subsequent flushes of *Commelina banghalensis*, *Brachariar amosa* and *Ageratum conyzoides*. In the Corn Belt and winter wheat areas of the western United States, changes in weed communities were noted within 10 years of the introduction of 2,4-D for the control of broadleaf weeds. In corn, summer annual grass species increased as broadleaf species were controlled. In wheat, winter annual grass species replaced broadleaf species as the predominant troublesome species.

Community shift in response to tillage change: Changes from conventional to reduced tillage systems often cause weed community shifts that include increases in summer annual grasses and small-seeded summer annual broadleaves, winter annual, biennial, and perennial species, and decreases in large-seeded summer annual species.

Community shift due to new localized or long-distance introductions: Common lambs quarters, a weed believed to be native to Europe and Asia, is now found throughout much of the United States. In much of Pennsylvania, common lambsquarters has become predominant in the weed community. The shift occurred because the species grows aggressively, is difficult to control, and is a prolific seed producer. Long-distance dispersal has also resulted in the introduction of many noxious weeds to the United States, some of which have caused weed community shifts (including field bindweed in the western plains, leafy spurge in rangeland, and multiflora rose in pasture). Under Indian conditions, *Phalaris minor* in wheat and invasion of grasslands and pastures and other non-cropped areas with *Lantana* and *Parthenium* are typical examples.

Population biotype shifts in response to herbicide use (herbicide-resistant populations): In the mid-west, in many populations of common water hemp (pigweed species), biotypes differed in susceptibility to ALS-inhibiting herbicides. With recurrent spraying of ALS-inhibiting herbicides, populations shifted from susceptible to highly resistant biotypes. Other ALS-resistant pigweed species have also developed in several areas of the United States, including the northeast. Most recently, glyphosate resistant weeds such as horseweed (mares tail) and pigweed species are a problem in different regions of the U.S. as a direct result of glyphosate use in herbicide resistant crops.

Practices influence weed biodiversity pattern

All food webs are built on the primary trophic level of producers, which are plants. In agro-ecosystems weeds provide shelter, food, mating sites and oviposition. Consequently, reduction in unwanted plant species affect top level of trophic. Mainly invertebrate species intimately linked with specific weed species have gone or lost along with their possessions. Preservation of weed flora diversity, thus a means to the restoration of higher or top order taxa (invertebrates and vertebrates) in the food web.

Under this situation, weeds or any unwanted plant species not only supporting overall food webs and species range, but they also offer numerous bionetwork services such as pest control and pollination etc. They rely on the species and the diversity of the species performing the respective service and their functional interactions to work properly. This connection between biodiversity and bionetwork services in farming systems has been describe for cover crops and grasslands (Baraibar *et al*., 2018), but rarely for weed community (Blaix *et al*., 2018). Pest control (insect, weed etc.) is one of the most important aspect of our agricultural system. Amidst various pest measures, weeds reduced crop yield by 33 to 79 % per annum (Mukherjee, 2019). Distribution of weed flora in farming area or field depends on tillage, crop type, use of herbicide pattern, that choose a explicit set of weed species from the soil seed bank (Ryan *et al*., 2010; Schumacher *et al*., 2018). Therefore, management decisions of the farmer were reflected by the weed community composition and diversity and are often linked to a certain farming intensity.

Few measures such as in no till system of gave 5 to 40 % higher weed seed predation (Navntoft *et al*., 2016) and with more recurrent harrowing harmfully impact on the arthropod population (Navntoft *et al*., 2009) can furthermore affect the populations of seed predators. Herbicide use has been documented to cause a decrease in seed removal of 10-20% and abridged weed population by 15-47 % (Mukherjee, 2020) most presumably through removal of aboveground vegetation. WSP rates are therefore influenced by particular farming practices and their intensity. A diverse weed flora provides a wide spectrum of different seeds for seed predators. The food preferences of the predators can differ significantly at the species level (Wall and Nielsen, 2012). Therefore, an increased food resource diversity has most likely a positive effect on food web interactions (Harvey *et al*., 2008).

Weeds pattern in conservation agriculture

Effective soil tillage in farming practice, influence unwanted plants by uprooting, dismember, and bury them deep enough in soil to prevent further sprouting or emergence. Ploughing also moves weed seeds both horizontally and vertically, and changes the soil environment; thereby inhibiting or promoting weed seed germination and emergence. Reduction in tillage intensity and frequency, as practiced under conservation agriculture (CA), generally increases weed infestation (Singh *et al*., 2015). Our observation revealed that, in comparison with conventional tillage (CT), presence of weed seeds was more in the soil surface under zero tillage (ZT), which favours relatively higher weed germination. Use of different tillage option with various fertilizer level become quite economical in term of yield and check the weed population up to certain extent depend on soil edaphic factor (Mukherjee, 2019). Increased weed infestation was recorded in aerobic direct-seeded rice than with conventionally puddled transplanted rice (Singh *et al*., 2008). Similarly, Mishra *et al*. (2012) observed that over the course of time, a ZT–ZT sequence favoured relatively higher weed growth over a CT–CT sequence in a rice– wheat system. While weed growth in the initial year was not higher under the ZT–ZT sequence, in the third year of experimentation total weed dry weight was significantly higher under the ZT–ZT than CT–CT tillage sequence. Further, changes from conventional to conservation farming practices often lead toa weed flora shift in the crop field, which in turn dictate the requirements of new weed management technologies involving various approaches, viz. preventive measures, cultural practices (tillage, crop residues as mulches, intercropping, competitive crop cultivars, herbicide tolerant cultivars, planting dates, crop rotations etc.), and herbicides, is of paramount importance in diversified cropping systems. It may be noted that weed control in CA depends upon herbicides and agronomic practices. However, the recent development of post-emergence broad-spectrum herbicides provides an opportunity to control weeds in CA, and enabling to have uniform crop stands and yield levels similar to conventional tillage systems. In CA systems, the presence of residue on the soil surface may influence soil temperature and moisture regimes that affect weed seed germination and emergence patterns over the growing season. The composition of weed species and their relative time of emergence differ between CA systems and soil-inverting CT systems. There is mounting evidence that retention of preceding crop residues suppresses the development and germination of weeds in minimum tillage systems, thus enhancing system productivity. The composition of weed species and their relative time of emergence differ between CA systems and soil inverting CT systems. Brar and Walia (2007) reported that CT favoured the germination of grassy weeds in wheat compared with ZT in a rice-wheat system across different geographical locations of Punjab, while the reverse was true in respect to broad-leaved weeds. Some weed seeds require scarification and disturbance for germination and emergence, which maybe enhanced by the types of equipment used in soil inverting tillage systems than by conservation tillage equipment. The timing of weed emergence also seems to be species dependent. Bullied *et al.* (2003) found that species such as common lambs quarters (*Chenopodium album*), field penny cress (*Thlaspi arvense*), green foxtail (*Setari aviridis*), wild buckwheat (*Polygonum convolvulus*), and wild oat (*Avena fatua*) emerged earlier in a CA system than in a CT system. However, redroot pigweed (*Amaranthus retroflexus*) and wild mustard (*Sinapis arvensis*) emerged earlier in the CT system. Changes in weed flora make it necessary to study the composition of weed communities under different environmental and agricultural conditions. Certain weed species germinate and grow more profusely than others under a continuous ZT system. As a consequence, a weed shift occurs due to the change from a CT to a ZT system. For example, the infestation of awn less barnyard grass (Mishra and Singh, 2012), rice flat sedge (Ladha and Kumar, 2009), Indian Sorrel (Chhokar *et al*., 2007), nutsedge (Ladha and Kumar, 2009), field bindweed (Shrestha *et al*. 2003), crabgrass (Chauhanand Johnson 2009), Burclover (Mishra and Singh, 2012), goat weed (Chauhan and Johnson, 2009), crow foot grass (Chauhan and Johnson, 2009) has been found to increase; while others like little canary grass (Chhokar *et al*., 2009), wild oat and lambs quarters (Mishra and Singh, 2012), Bermuda grass, Italian ryegrass and yellow star thistle (Scursoni *et al*., 2014) showed decline under ZT compared with CT. Some weed species are not affected by tillage systems followed. For example, although emergence of awn less barnyard grass (*Echinochloa colona*) and rice flat sedge (*Cyperus iria*) was higher under continuous ZT than continuous CT or rotational tillage systems (ZT– CT and CT– ZT); no such tillage effect was noticed on pink node flower (*Caesulia axillaris*). Higher seedling emergence of awn less barnyard grass (*Echinochloa colona*) and rice flat sedge (*Cyperus iria*) under continuous ZT was attributed to their small seed size, which failed to germinate when buried deeply in CT (Mishra and Singh, 2012). A shift in weed populations towards small-seeded annuals is generally observed under conservation tillage systems. Contrary to this, in spite of small seed size, little canary grass has shown a remarkable reduction in their population under ZT compared to CTsystem in the Indo-Gangetic Plains. Weeds shifting towards perennials have also been observed in conservation tillage systems. Perennial weeds thrive in reduced or no-tillage due to non-uniform distribution pattern of root and herbicide were not effective to control them. Perennial monocots are considered a greater threat thanperennial dicots in the adoption of reduced tillage systems. Unlike annuals, many perennial weeds can reproduce from several structural organs other than seeds. For example, purple nutsedge (*Cyperus rotundus*), tiger grass (*Saccharum spontaneum*) and Johnson grass (*Sorghum halepense*) generally reproduce from underground plant storage structures, i.e., tubers or nuts and rhizomes. Conservation tillage may encourage these perennial reproductive structures by not burying them to depths that are unfavourable for emergence or by failing to uproot and kill them. Change in weed distribution pattern due to weed shifting and loss in crop yield because of more weed biomass production resulted in less adoption of conservation agriculture.

Climate change effect on weed flora

The multiple adverse impacts of global warming and climate change on food production involves many factors The global climate is changing along with measuring temperature and CO_2 level changes that are considered major drivers of climate change, there is also increasing attention being given to its impact on agricultural production systems (including weeds). Climate change scenarios include higher temperatures, changes in precipitation, and higher atmospheric CO_2 concentrations. Climate conditions exert a significant influence on the spread, inhabitants' dynamics, existence cycle duration, infestation pressure and the overall occurrence of the majority of agricultural pests (Mukheree, 2018a). Weeds are among the agricultural pest that can be influenced by climate change. It is expected that climate change will bring about a shift in the floral composition of several ecosystems at higher latitudes and altitudes, as changes in temperature and humidity will be reflected on flowering, fruiting and seed dormancy. Changes in atmospheric CO_2 levels, rainfall, temperature and other growing conditions will affect weed species 'distribution and their competitiveness within a weed population and within crop. Changing and increment of temperature is one main characteristics of climate change which may affect existing plants (weeds distribution) and allow some other plants (weeds) to replace native and will be expand in to new areas which is not existed before (Mukheree, 2014b). The direct impacts of climate change will be either on the biology of the biological control agent and/or on the ability of the host plant to resist, tolerate or compensate for the presence of the herbivore or plant pathogen. Rising temperature would be likely to amplify the rate of life cycles of both the biological control agents and the unwanted plants. Weeds have a greater genetic diversity than crops. As a result, if a resource such as water, light, nutrients or CO_2 changes within the milieu, it is more likely that weeds will show a better growth and reproductive reaction. Many weed species have the C4 photosynthetic pathway and so will show a lesser retort to atmospheric CO_2 relative to C3 crops. Till date, for all weed/crop competition studies where the photosynthetic pathway is the same, weed growth is favoured as CO_2 is improved (Ziska, 2010). Scientist observed significant increase in photosynthesis and decrease in stomata conductance in C3 weed (*Chenopodium album*) but no change in *Amaranthus retroflexus* (C4 weed) at elevated CO_2 level (Ziska *et al*., 1999; Ziska and Georg, 2004). Response of different plant under drought situation varies and few crop cultivar become more tolerant to other species. Under drought situation, few weeds produce alleleo-chemical that made weeds to flourish well and fight with crop (Patterson, 1995).

Upland and rainfed lowland rice with limited precipitation face severe competition with C4 weeds. Under imposed drought, (Patterson, 1986) found that the effects of water stress and significantly increased leaf area and total dry weight of the three C4 grasses: *Echinochloa crusgalli, Eleusine indica* and *Digitaria ciliaris*. Further, scientist also concluded that CO_2 enrichment can increase the growth of both C4 and C3 plants under water stress, but growth stimulation can be expected to be greater in C3 plants. Weeds of rangelands like cheat grass (*Bromus tectorum*) and yellow star thistle (*Centaurea solstitialis*) depend largely on available soil moisture for seed germination. Long-lasting or profound winters that deeply improve the soil moisture favour more production of seed in above mentioned two species (Patterson, 1995). Further these two species are also drought tolerant. However, their drought adaptive feature varies as per field situation by shorter lifespan in cheat grass and deeper root system for star thistle, compare to other native species.

Weeds monitoring and weed management strategies

Weeds are opportunistic '*colonising species*' or '*pioneers of secondary succession*' that are well adapted to grow in locations where disturbances, caused either by humans or by natural causes, have opened up space. Species can turn out to be weeds, as they are adjustable, aggressive, highly prolific, and are able to abide a broad array of ecological situation, including those in farms, or disturbed habitat. Recognition of new weeds phenotype in field condition and their main cause of dispersion (weed escapes) is vital for preventing shifts in weed populations or weed establishment. Significant advancement in improved weed management methods have allowed farmers to attain increases in crops productivity under well managed situation, without losing crop biodiversity. In spite of this, the weeds menace is increasing in cultivated and non-cultivated lands, as the weeds are dynamic. This may be attributed partly to weeds response to high-input and intensive cropping systems adoption with lesser adoption of traditional practices like intercropping, mulching and crop rotations; herbicide resistance development in weeds like *Phalaris minor*; changing climate and occurrence and predominance of more aggressive and adopted weed species; growing menace of: i) weedy rice or wild rice in many states, particularly where direct-seeding of rice is adopted; ii) *Orobanche* in mustard growing areas; iii) alien weeds (*Parthenium hysterophorus*, *Lantana camara*, *Ageratum conyzoides*, *Chromolaena odorata* and *Mikania micrantha*) invasion in many states of India. Hence, continuous weeds monitoring and weed management strategies and technologies development is needed to reduce the adverse effects weeds on farm productivity and maintain positive ecological balance (Mukherjee, 2019a).

Properly and timely weed control measure on regular basis through improve monitoring technique, is an important component of integrated weed management (IWM). Proper identification of different weed species during the seedling stage, based on its socioeconomic value is important. Seedling stage become more important because it is easier to control either via herbicide or via mechanical measures without affecting main crop. Perennial weeds are susceptible to control at early phase (i.e., bud stage) or during fall when the plants begin to go dormant. Chemical control measures at these stages can be translocated to the rhizomes or roots to enhanced kill the unwanted plant or weed. Weeds frequently grow up in patch so it can be managed through spot application of herbicide instead of whole field. A spot treatment can save money and time while getting better weed control and keep biological diversity as well. A handheld GPS unit is helpful to mark various patch of difficult weeds for spot treatment and succeeding monitoring. Keeping in mind weed biodiversity importance weed management strategy should focus on:

- Better understanding of weeds
- Monitoring of weed dynamics and its behaviour patterns
- Herbicide resistant weeds monitoring and prevention
- Climate resilient IWM strategy and technologies development.
- Herbicide residue management
- Invasive weeds management
- Adopting cautious approach on herbicide tolerant crops

Conclusion and recommendations

Sustainable strategies for managing weeds are crucial to meeting agriculture's latent to feed the world's population while conserve the ecosystems and biodiversity on which we depend. Under the threat of climate change, the core concern is the balance between adequate weed control, including the prevention of weed seed build-up, and the requirement for some plants to support biological diversity within crops. For some, clean crops and zero tolerance of weeds is the approach, with non-crop areas supporting biodiversity. A balance is essential amid the methods of production applied, the demand for products and the environmental impacts that occur. In relation to weed control, there are initiatives to apply herbicides only to the areas of fields where competitive weeds occur. This will require weed detection systems and/or accurate weed mapping and possibly real-time control of the application of different herbicide products.

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