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Crop-Weed Competition

and management under changing climate

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LONG-term changes in the average weather conditions of a region are considered as 'climate change'. Rapid global industrialization and other anthropogenic activities have resulted in production of greenhouse gases which still continue at an alarming pace. Direct effects of climate change influence not only the performance of individual organism but also impact interaction with other organisms at various stages through changes in physiology, morphology and chemistry. Carbon dioxide, being a major contributor of greenhouse gases, has significant impact on metabolism and performance of plant species.

Majority of plants posses either C_3 or C_4 photosynthetic pathway and plants of these two categories exhibit different adaptation strategies to the environment. For readers' convenience, name of some important weeds and their photosynthetic pathways are listed in Table 1.

Table 1. List of important weeds and their photosynthetic pathways

Botanical name	Photosynthetic pathway	Botanical name	Photosynthetic pathway
Phalaris minor	C3	*Cyperus rotundus*	C4
Chenopodium album	C3	*Cyperus esculentus*	C4
Convolvulus arvensis	C3	*Cyperus iria*	C4
Avena fatua	C3	*Cynodon dactylon*	C4
Tridax procumbens	C3	*Echinochloa colona*	C4
Bidens pilosa	C3	*Echinochloa crus-galli*	C4
Rumex dentatus	C3	*Eleusine indica*	C4
Asphodelus tenuifolius	C3	*Sorghum halepense*	C4
Ageratum conyzoides	C3	*Portulaca oleracea*	C4
Eichornia crassipes	C3	*Digitaria sanguinalis*	C4
Physalis minima	C3	*Amaranthus spinosus*	C4
Striga asiatica	C3	*Amaranthus viridis*	C4
Alternanthera sessilis	C3	*Amaranthus retroflexus*	C4
Commelina benghalensis	C3	*Rottboellia cochinchinensis*	C4
Phylanthus niruri	C3	*Leptochloa chinensis*	C4
Eclipta prostrata	C3	*Saccharum spontaneum*	C4
Ammannia baccifera	C3	*Paspalum distichum*	C4
Anagallis arvensis	C3	*Boerhavia diffusa*	C4
Chromolaena odorata	C3	*Dactyloctenium aegyptium*	C4
Cyperus difformis	C3	*Imperata cylindrica*	C4
Abutilon theophrasti	C3	*Ischaemum rugosum*	C4
Ipomea spp.	C3	*Fimbristylis dichotoma*	C4
Xanthium strumarium	C3	*Fimbristylis miliacea*	C4
Euphorbia geniculata	C3	*Trianthema portulacastrum*	C4
Parthenium hysterophorus	C3-C4	*Euphorbia hirta*	C4

Impact of Climate Variability on Crop-Weed Interaction

At present, India's emissions of greenhouse gases are low in comparison to other major world's economies but the country is already facing high degree of climate variability and may face additional challenges because of climate change. Composition of the atmospheric gases, minimum and maximum temperature during lifecycle (especially at critical growth stages), and pattern of precipitation are the key factors that have changed significantly during the last century and are subject to further changes in years to come. Agricultural weeds co-

Rise in temperature is the phenomenon associated with the 'greenhouse effect' commonly termed as 'global warming'. In comparison to crops, associated weeds in a given cropping system may have better plasticity and adaptability to the changing environment by virtue of greater genetic diversity and climate resilience. Photosynthetic pathway, phenological and developmental aspects need attention in the context of understanding and predicting impact of climate change on crop-weed interactions. Equally important is to find out factors responsible for behaviour of weed species under climate change conditions which definitely will complicate the weed management due to increase in invasiveness and weed shifts under futuristic climate change scenario.

evolved in response to domestication of crops and make a sizable loss to agricultural productivity. Interactions between crops and weeds are bound to change in the future due to alteration in climate change drivers, however, direction and magnitude of such changes are yet to be worked out.

Effect of High Atmospheric CO_2

Concentration of atmospheric CO_2 is continuously increasing globally and perhaps will be double by the end of this century as suggested by Inter-governmental Panel for Climate Change. Rise in atmospheric CO_2 are likely to influence plants mainly through direct effects on physiological processes like photosynthesis and stomatal physiology resulting in increased growth rates. Magnitude of response to CO_2 concentration varies significantly depending upon the species, growth stage, photosynthetic pathway and interaction with other climatic factors i.e. temperature. Inherent adaptive mechanisms like higher water use efficiency of weed species might help weeds to gain a competitive advantage over crops, and, if so, then weed species may become more invasive in high-CO_2 atmosphere. Response of crop and weed species to the increasing atmospheric CO_2 concentration may vary resulting in change in weed–crop competition and affecting crop yield. In an analysis of the impact of high atmospheric CO_2 on crop production and losses due to weeds, Ziska and co-workers suggested that (i) rising CO_2 would increase yield losses due to competition with weeds; (ii) weed control will be crucial in realizing any potential increase in economic yield of agronomic crops; and (iii) instead of C_4 weeds, C_3 weeds would pose more serious threat to crop production in future. However, such statements may not hold when factors like temperature and other environmental stresses are also taken into account.

Effect of Elevated Temperature

Gradual rise in temperature is the phenomenon associated with the 'greenhouse effect' commonly termed as 'global warming'. Different models predicted a rise in temperature (1.5 6 4.5°C) by the end of the current century depending on the geographical locations and success of mitigation strategies if adopted. Temperature is an important factor that plays an important role in biological and metabolic activities, and may impact the length of available duration suitable for growth, phenological development and incidence of heat or freezing stresses, hence, considered as a prominent determinant for final outcome of a crop. It is established that C_3 and C_4 species have differential temperature optima for physiological and metabolic processes because enzymes involved in different metabolic pathways exhibit differential kinetics at varying temperature. It simply implies that C_4 species would be able to tolerate higher temperature changes than C_3 species. High temperatures can be very harmful during flowering and initial stages of grain formation in crops. Such effect is not expected in case of associated weeds due to their well documented ability to survive in extreme harsh conditions. High temperature during late stages of wheat lead to advancement of the panicle emergence, while in rice, it delays the panicle emergence resulting in considerable loss in final outcome in both the cases. Rise in temperature may also facilitate weed shifts and expansion of growing region. Such weed shifts have been reported in case of *Striga* (a root parasite of corn) in USA. As C_3 and C_4 plants show differential response to temperature, it is quite logical to make a statement that competitive interaction will be shifted in field conditions depending on crop and composition of weed flora.

Combined Effect of Elevated CO_2 and Temperature

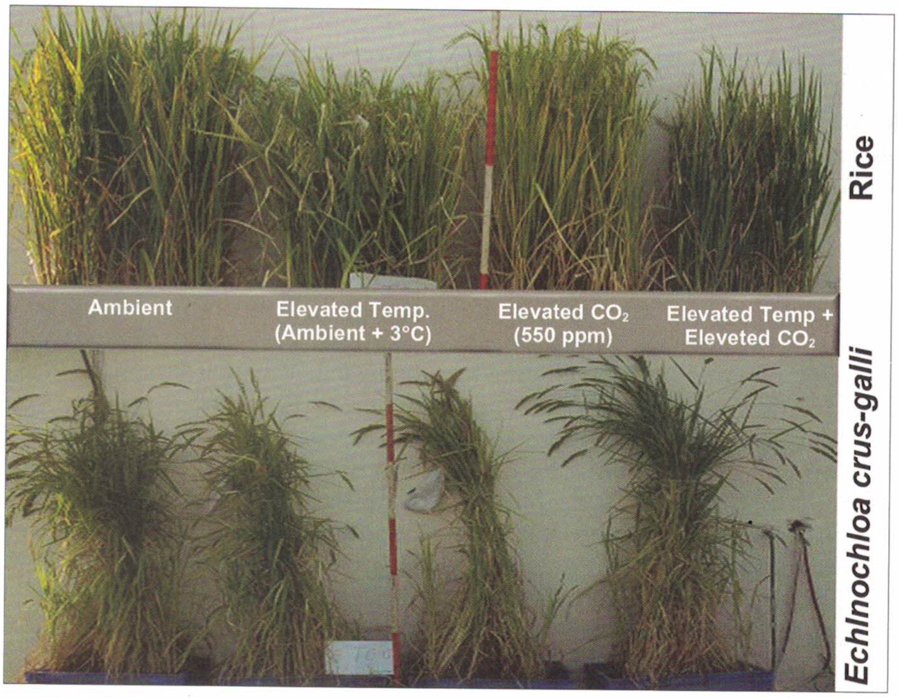
Although meagre studies based on the combined effect of elevated CO_2 and temperature seems to be more realistic and logical in prediction of impact of climate change in a given cropping system. Exposure to rising temperatures may reverse the beneficial effects on growth and yield in response to elevated CO_2, if any. However, such statement may not hold true universally and need to be validated keeping in mind the particular crop and associated weed flora. Review of literature available on the subject pointed that increase in CO_2 alone would favour C_3 species, but any simultaneous increase in temperature would be a beneficial C_4 species. In a study conducted at the Directorate of Weed Research, Jabalpur, it was noticed that elevated CO_2 and temperature, individually and more so in combination, delayed phenology (commencement of reproductive stage) and severely affected the grain setting as well as yield of rice, while no such adverse effects were noticed in case of *Echinochloa crus-galli* (a C_4 weed of rice crop).

Effect of Changes in Precipitation Pattern

With the rise in concentration of atmospheric greenhouse-gases and average temperature, global average precipitation is also expected to be changed in terms of quantity and distribution. During last decade, unprecedented changes in rainfall pattern have been evident in India. Changes in the pattern of the rainfall may cause the alteration in the water availability which eventually may lead to changes in flora composition. In a study conducted at DWR, it was observed that elevated CO_2 had partially ameliorated the negative effects of drought under competitive infestation by weeds (*Phalaris minor, Chenopodium album, Avena fatua*) in wheat. However, predicted rise in temperature is expected to aggravate impact of water deficit simply due to increase in evapotranspiration. Together, available evidences indicate that response to water availability in changing climate would be species-specific (C_3 vs C_4) which simply implies that performance of a crop/cropping system will depend on composition of weed flora and further on effectiveness of weed management practices.

Impact on Weed Management under Changing Climate

Climate extremes could also limit



Effect of elevated temperature and CO_2 on reproductive stage of rice and *E. crus-galli*

the opportunity for field operations. Changes in rice cultivation from transplanting to direct seeding under limited water availability necessitates emphasis on post emergence weed management in order to keep the yields high. Cultural practices like manual weeding and intercropping may also be affected by altered growing seasons induced by climate change. Increased temperature and drought can reduce herbicide uptake, increase volatility, structural degradation and reduce its effectiveness. Greater increases in biomass under high CO_2 may result in dilution of applied herbicide and thereby reducing its efficacy. The efficacy of the post-emergence herbicides would be reduced under elevated CO_2 because the time spent by the weeds in seedling stage, i.e. the stage of greatest herbicide sensitivity would be shortened under high CO_2 conditions (Table 2).

Strategies for Weed Management under Climate Change

If climate and land resources change, it is almost likely that weeds will win the race and over compete crop plants for the utilization of resources by virtue of greater adaptation potential. Following measures together may formulate a potential strategy for weed management under the regime of climate change.

Preventive Measures

Seeds of most crops are contaminated with weeds, especially where weed seeds resemble the shape, size and colour of crop seeds. An appropriate strategy is needed to avoid high weed infestations, and to prevent unacceptable competition with the emerging crop.

Cultural practices: Time of sowing must be manipulated in such a way that ecological conditions for the germination of weed seeds are not met. For example, in the north-western part of the Indo-Gangetic plains, farmers adopted advance wheat sowing by 2 weeks to minimize the infestation of *Phalaris minor* as this weed required a critical low temperature for germination.

Competitive and Climate-resilient cultivars of Crops: Use of crop cultivars resilient to climate changes viz. drought, flood, and high temperature may play a vital role in managing weeds. Crop species and cultivars are known to differ in their competitiveness with weeds. Therefore, identification and development of weed competitive cultivars having climate -resilience must be the foremost requirement for developing the integrated weed management tools in changing climate.

Crop Diversification: Crop diversification and cultivation of weed smothering crops is equally important for weed management. Instead of traditionally adopted cropping systems, inclusion of climate-smart weed smothering crops (i.e. millets) in a cropping system may help in minimizing the weed infestation to a great extent.

Resource Conservation Agriculture: Resource conservation agriculture which advocates the retention of previous crop residue cover on the soil surface, and sowing of crops with no-till method, is considered as a technology of future to achieve the goal of sustainable agriculture. An array of benefits can be achieved through resource conservation agriculture including reduced soil erosion and water runoff, increased productivity through improved soil quality, increased moisture availability due to retention of crop residue on soil surface, increased biotic diversity, and reduced labour demands. The most important benefit by adopting conservation agriculture may be in terms of advance sowing of the crop as no land preparation is required. For example, sowing of wheat crop under conservation agriculture system can be done just after harvesting of rice (within a day), which in turn, can facilitate early establishment of wheat crop. *Phalaris minor*, a dominant weed in wheat

Table 2. Effect of elevated CO_2 on the efficacy of different herbicides

Herbicides	Weed species	Dose	Days taken for complete death		
			Ambient (380 ppm)	Elevated (550 ppm)	Delayed by (Days)
Glyphosate	*Chenopodium album*	2.0 kg/ha	7	10	3
Isoproturon	*Phalaris minor*	1.5 kg/ha	6	15	9
Clodinafop	*Avena fatua*	60 g/ha	8	15	7
2,4-D	*Amaranthus viridis*	0.5 kg/ha	8	13	5
Sulfosulfuron	*Lathyrus sativus*	30 g/ha	No visible symptoms of death		

crop, can easily be managed by adopting early sowing of wheat crop. Adoption of such practice not only manage the *P. minor*, but at the same time also saves the cost, energy and time for land preparation.

Future Challenges

Alarming bells are already ringing over the strategies to manage the spread of weeds especially the invasive weed species. As depicted from evidences described above or elsewhere, changing climate will further threaten weed management strategies currently available with us. Weed shifts and invasions are gaining attention as a major threat to biodiversity and may have a significant impact on outcome of any farming system. Many weed species share traits that will allow them to capitalize on the various elements of climate change, hence, may increase the dominance of some species over the others and more so of weeds over the crops. In addition to the work already been done, following are the researchable avenues for crop and weed scientists.

- How combination of possible climate change drivers in combination (i.e. greenhouse gases, temperature, radiation, precipitation) will affect crops, weeds, and associated micro-organism?
- How weed management (i.e. efficacy of herbicide) will change under climate change conditions?
- What will be the extent of biological invasions and shifts (i.e. weed shift) in predicted climate change scenario?
- What is/are physiological, biochemical and molecular basis and mechanism(s) of dominance of some species over others?
- At what extent climate change would contribute to the success of agriculture weeds?
- How quality of crop harvest will be affected?
- Is it possible to sustain/increase the productivity of crops in change climate?
- Can we address the concerns associated with new technologies like 'herbicide tolerant crops' under climate change scenario?
- What can we borrow from the weeds for realization of climate-smart agriculture?

SUMMARY

Direct effects of climate change influence not only the performance of individual organism but also impact interaction with other organisms. Photosynthetic pathway, phenological and development aspects need attention in the context of understanding and predicting impact of climate change on crop-weed interactions. Concerns are being raised on the strategies to manage the speed of weed species especially the invasive weed species. In addition to the work already done on control of weed species, more research is required to be done on this front by the crop and weed scientists.

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