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Crop-weed interactions and their management under climate change: A review

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Abstract
Weeds pose as biggest threat to crop production accounting about 43% yield loss globally. Unchecked human activities such as over-expanded use of fossil fuels and deforestation have resulted in climate change which further worsens the present situation by impacting both crop and weed. Predicted alteration in atmospheric CO_2, temperature and frequent extreme events (e.g., droughts and floods) owing to climate change will reduce crop yields by affecting plant growth as well as pest pressure (weed, insect pest and pathogens) and their invasiveness, thus threatening global food security.
CO_2 fertilization due to rising CO_2 level will benefit C_3 crops, thus reducing the competitive ability of most of troublesome weeds which are C_4 plants. However, weeds are predicted to become more competitive over crops owing its wide genetic diversity, colonising ability and enhanced aggressively of C_3 weeds consequently making weed management in field situations costlier and more difficult.
Change in environmental factors like temperature, atmospheric humidity, elevated CO_2 and soil moisture can manipulate efficacy of various weed control measures like mechanical weed control, herbicides and bio-control agents. Extensive research and evaluation of new herbicides, higher chemical concentrations and new bio-control agents will be required for managing weeds under this scenario. Adoption of ecological approaches (crop rotation, intercropping, live mulching, early planting of crops, nutrient management, selection of suitable crop varieties), improved tillage practices, genetic improvement of crops (breeding allelopathic crops cultivars and drought- and stress resistant varieties) may enable to reduce weed problem. Holistic weed management will be the need of the hour for tackling weed menace in this context.

Keywords: Climate change, crop, ecological approaches, genetic improvement, tillage, weeds

Introduction

Weeds can be simply defined as plants that are growing at unwanted place causing certain economic and social damage to mankind. They can be crops, native plants as well as non-native species that create nuisance where they are growing. Generally, they cause huge reductions in crop yields, impair quality of produce, interfere with agricultural operations, increase cost of cultivation, reduce input efficiency and also act as alternate hosts for several insect pests, diseases and nematodes. They are complex in nature and exert marked negative impacts on agriculture, forestry, human health and many other activities. Globally, weeds are recognised as biggest threat to crop production amounting about 43% yield loss (Lemessa and Wakjira, 2014) [33]. The extent of crop yield losses is estimated to be higher in developing or emerging countries than developed countries (FAO, 2006) [18].

Climate change is a global phenomenon which results from unchecked human activities like excessive use of fossil fuels, deforestation, urbanization and industrialization thus altering atmospheric CO_2 level and global surface temperature with increased frequency of extreme events like droughts and floods. As per reports of NOAA Earth System Research Laboratory, there has been linear increase in global CO_2 concentration (Fig. 1), and presently, the global CO_2 concentration is 408.75 ppm (https://www.esrl.noaa.gov/gmd/ccgg/trends/global.html). There has been prediction of rise in global CO_2 concentration up to 600-700 ppm along increase in global surface temperature by 1.4 to 5.8 °C in 2100 (IPCC, 2014).This situation will further intensify crop-weed competition and consequently increasing more yield loss as weeds have better survival mechanisms and adaptability than crops. Severe yield reduction in crop production may lead to food crisis in near future, if suitable measures are not taken up in time to nullify these adverse impacts of climate change.

For this, it is necessary to understand the crop-weed interaction under changing climate scenario and its impact of weed management practices.

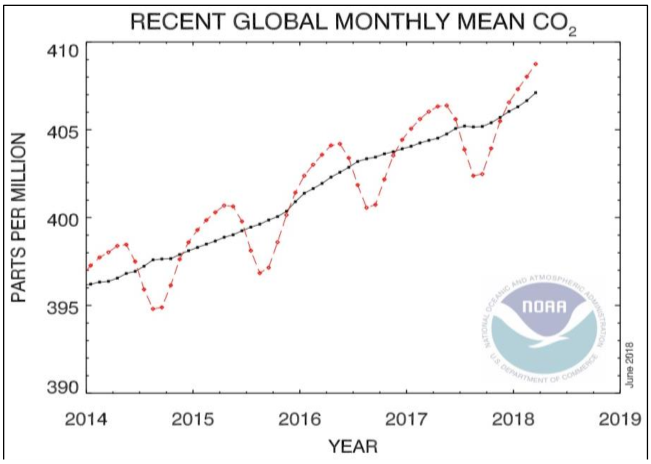

Fig 1: Recent global monthly mean CO_2 concentration from past 5 years to March 2018. (Source: https://www.esrl.noaa.gov/gmd/ccgg/trends/global.html)

Crop-weed interaction under climate change

Alteration in environmental conditions will not only influence the performance of an organism, including both crops and weeds, but also impact its interaction with other organisms at various stages of life cycle. Some of the pronounced changes in atmosphere due to climate change are increased CO_2 level, temperature and associated moisture stress, which will directly influence photosynthesis, physiology and morphology of different plant species. There may arise different situations of crop-weed competition may under climate change like (a) C_3 crop competing with C_3 and C_4weeds, and (b) C_4 crop competing with C_3 and C_4weeds. Several research findings indicated that CO_2 enrichment will benefit C_3 crops (rice, wheat, pulses and oilseeds) thus giving a competitive edge over most of the notorious weeds which are C_4 plants. But it will not be right to assume that there will be reduced weed competition owing to increased CO_2 level as majority of crops fall under C_3 category while most of the weeds are C_4.At present, there are more than 450 "troublesome" weed species (both C_3 and C_4) that associate with about 50 major crops all over the world. This implies that if a C_4 weed species does not respond to elevated CO_2, there are certain chances that a C_3 weed species will respond to it. Several number of important C_3 weeds (*Avena ludoviciana*, *Ammania baccifera*, *Chenopodium album*, *Phalaris minor* etc.) will be benefitted by increased CO_2 level due to reduced stomatal aperture and enhanced water use efficiency (Patterson, 1995) [51], thus making them more aggressive and difficult-to-control. The effects of elevated CO_2 and temperature on some of the major C_3 and C_4 weeds are summarized in Table 1. Moreover, most competitive weed for a given crop is similar in growth habit or photosynthetic pathway to that particular crop and becomes more competitive even in altered environment. For instance, C_3 weeds like *Phalaris minor* and *Avena ludoviciana* in wheat (C_3) would aggravate with the increase in CO_2 due to climate change (Naidu, 2015) [43]. Many C_3 weeds have indicated significant increase in growth with substantial reduction in the yields of competing crops, due to escalated CO_2. Ziska (2000) [79] reported a 65% rise in the biomass accumulation of *Chenopodium album*, a C_3 weed, with an analogous 39% seed yield loss of soybean at increased CO_2 concentrations. On the contrary, there was no change in biomass of *Amaranthus retroflexus*, a C_4 weed, at elevated CO_2 and yield loss in soybean decreased from 45% to 30% in competition with this weed. Similarly, increase in biomass and seed yield of weedy rice was observed compared with cultivated rice under elevated CO_2which indicates larger yield reduction in cultivated rice in the presence of C_3 weeds in future CO_2 concentrations (Ziska *et al*., 2010) [81].

Rising temperature will favour plant with C_4 pathways than C_3 pathways under CO_2 enriched condition. Simultaneous increase in both CO_2 and temperature above the crop's optimum level may reduce or reverse the increment in yield as reported in various C_3 crops (Groundnut; Prasad *et al*., 2003 [54]; French bean; Prasad *et al*., 2002 [53]; Tomato; Valerio *et al*. (2013) [70] and C_4 crops (Sorghum; Prasad *et al*., 2006) [52]. Findings of Alberto *et al*. (1996) [1] indicated that under elevated CO_2 level alone, rice, a C_3 crop competed better with a C_4 weed (*Echinochloa glabrescens*) but when both CO_2 and temperature were simultaneously increased, C_4 species emerged out as better competitor. Thus, the differential response of C_3 and C_4 plants to higher CO_2 and temperature may have significant impacts on crop-weed competition. Plants are likely to experience high-temperature stress, which can affect growth rates because of changes in temperature thresholds during specific developmental phases. Plants like C_4 species are better adapted to heat stress and may show stimulation of meristematic regions, rapid canopy growth, and root proliferation at high temperatures that often inhibit growth in C_3 species (Morgan *et al*., 2001) [41].

Table 1: Effect of elevated CO_2 and temperature on major C_3 and C_4 weeds

Photosynthetic pathway	Physiological difference	Major weeds		Climate change parameter		References
		Species	Common name	Elevated CO_2	Rise in temperature	
C_3 type	Chloroplasts present only in mesophyll cells	*Avenafatua* *Chenopodium album* *Cirsium arvensis* *Abutilon theophrasti*	Wild oat Lambsquarters Canada thistle Velvetleaf	High stimulation of photosynthesis and growth	Increase in photorespiration and decrease in net photosynthesis	O'Donnell and Adkins (2001) [47] Miri *et al*.(2012) [39] Davis and Ainsworth (2012) [15] Ziska *et al*. (2004) [77] Valerio *et al*. (2013) [70] Ziska (2013) [76] Jia *et al*. (2011) [26] Zelikova *et al*. (2013) [74]
	CO_2 fixed by RUBP carboxylase	*Lolium multiflorum* *Polygonum convolvulus*	Italian ryegrass			
	High photorespiration	*Convolvulus arvensis*	Field bindweed			
	Optimum temperature 15-25 °C	*Xanthium strumarium* *Elymu srepens* *Bromus tectorum*	Cocklebur Quack grass Cheat grass			
C_4 type	Chloroplasts present in mesophyll and bundle sheath cells	*Kochia scoparia* *Sorghum helepense* *Sorghum bicolor*	Kochia Johnson grass Shattercane	Lower stimulation of photosynthesis	Stimulation of photosynthesis and growth at high CO_2	McDonald *et al*. (2009) [37] Mahajan *et al*. (2012) [35]

		Eleusine indica	Goosegrass	and growth		Valerio *et al*. (2011) [71] Satrapova *et al*. (2013) [61] Zheng *et al*. (2011) [75] Rodenburg *et al*. (2011) [58]
	CO_2 fixed by PEP carboxylase	*Echinochloa crusgali* *Digitaria sanguinalis*	Barnyard grass Large crabgrass			
	Low photorespiration	*Amaranthus retroflexus*	Redwood pigweed			
	Optimum temperature 30-40 °C	*Cynodon dactylon* *Cyperus rotundus* *Amaranthus palmeri*	Bermuda grass Purple nutsedge Palmer amaranth			

Climate change will influence precipitation pattern making it more capricious with more frequent events of droughts and floods under elevated CO_2 level. This might favour weeds more than crops in this situation. Under increased CO_2 level, wheat gained biomass against *Phalaris minor*. However, *Phalaris minor* was more competitive over wheat with CO_2 enrichment under drought condition (Naidu and Varshney, 2011) [45]. Bjorkman (1976) [9] reported that moisture stress under increased CO_2 will favour C_4 weeds over C_3 crops. As a result, weeds that are well adapted to such conditions might have a comparative advantage under rainfed condition in which moisture scarcity is common. In addition to drought-tolerant C_4 weeds, there are many parasitic weeds that thrive in moisture scarce conditions (e.g., *Striga hermonthica)* or temporarily submerged environments *(e.g., Rhamphicarpa fistulosa)* and they might be benefitted under altered climatic condition (Bir *et al*., 2014) [8]. However, according to Sionit and Patterson (1985) [62] CO_2 enrichment could reduce the harmful effects of drought. An increase in temperature with accompanying soil moisture stress will offset the growth benefits from CO_2 fertilization; the net effect depends on the level of moisture stress (Naidu and Murthy, 2014) [44].

Weeds as colonizers/invaders

Attributing to their wide genetic diversity and adaptability, weeds are excellent "colonising plants" which can survive and flourish vigorously under changed environmental conditions. These colonising plants/ invaders are range-expanding present at the peripheries of their distribution and can tolerate fluctuations better than the native species (Barrett, 2000) [5]. Thus, invasive species will rise as big threat in changing climate due to their strong response to higher CO_2 and temperature and associated frequent extreme events like prolonged drought periods and occasional very wet years as established vegetation and crops will be more vulnerable. Bradley *et al*. (2010) [10] highlighted certain risks of weed invasion associated with climate change (Table 1). Increased disturbance as a result of extreme weather events can differentiate plant communities according to specific traits (Jauni and Hyvönen, 2012) [25] and this situation has already favoured some alien species such as *Centaurea solstitialis* and *Hypericum maculatum* (Hierro *et al*., 2013) [23]. Expansion of invasive weed *Parthenium hysterophorus* due to climate shift especially under elevated CO_2have been reported by Naidu (2013) [42]. Elevated temperatures will make condition more congenial for expansion of habitat range for invasive species and their destructive outbreaks (Trumble, 2013) [68]. Also, amount of rainfall and their distribution may influence weeds to search for new habitats under altered climatic conditions. McFadyen (2008) [38] opined that *Lantana camara* could expand in some areas if rainfall increased. Weeds possess special characters like high fecundity, shorter life cycles, vegetative reproduction and easy seed dispersal mechanisms which provide better opportunities to establish them under predicted calamities like cyclones and floods.

Table 2: Probable effect of climate change on invasion risks by weeds (Source: Bradley *et al*., 2010) [10]

Climate change factor	Risks of invasiveness
Elevated CO_2	Increase
Rising temperature	Might increase or decrease
Changing precipitation regime	Might increase or decrease

Patterson (1995) [51] rightly pointed out that any factor which increases environmental stresses on crops may make them more vulnerable to attack by insects and plant pathogens and less competitive with weeds. Agricultural adaptations to climate change, including new products and shifts into new areas, will also create more opportunities for weeds.Shift in crop establishment methods; for instance, from transplanting to direct seeding of rice under moisture scarcity will certainly induce change in weed dynamics. Indeed, weeds flora will also be influenced by these environmental stresses, but by virtue of its genetic diversity and wider adaptability weeds are expected to emerge out as winner over crops under such adverse situations. So, weeds will become more competitive over crops making weed management in field situations costlier and more difficult in this context.

Impacts of climate change on weed management

Any change in environmental factors like temperature, soil moisture availability, CO_2 level, humidity will have a significant bearing on weed management. Herbicide efficacy is influenced either directly or indirectly by environmental factors. It is well perceived by agricultural scientists that pesticides work best in rapidly growing and metabolizing plants under environmental stress free condition. Elevated CO_2 and temperature coupled with moisture stress may influence anatomical, morphological and physiological changes in weeds thus affecting entry of herbicide into plant and their uptake, translocation and metabolism. Increasing CO_2 level enhances leaf thickness and reduces stomata number and conductance possibly limiting the uptake of foliar applied herbicides (Naidu, 2015) [43]. Decline in glyphosate efficacy with rising CO_2 level in Canada thistle was demonstrated by Ziska and George (2004) [80]. Probable reason for such response could be increased biomass accumulation under high CO_2 level thus diluting the effect of glyphosate in Canada thistle. Similar observations were reported by Manea *et al*. (2011) [36] in C_4 grasses. Effectiveness of both pre- and post-emergence herbicides will be lowered against weeds, especially those exposed to drought as active plant growth is essential for action of systemic herbicides (Naidu, 2015) [43]. Varanasi *et al*. (2016) [72] opined that climate change will influence not only modes of action within herbicide but also among herbicides having same mode of action. Extensive research on the impact of climate change factors and their interactions on all commonly used herbicides is necessary to understand the implications for weed management in future climate scenarios.

Like chemical herbicides, bio-control efficiency for weed control will be influenced by alteration in climate due to change in the development, morphology and reproduction of target pest. Bio-control agents being living micro-organisms and insects are sensitive to the climatic extremes like heat, cold, wind and rains. Precipitation changes can also affect predators, parasites and pathogens of weeds resulting in a complex dynamics. Under changing climate, pathogenic fungi might be either benefitted by prolonged humidity conditions or significantly reduced by drier conditions (Newton *et al*., 2011) [46]. Direct impacts of CO_2enrichment could alter C: N ratio which might affect the feeding habits of herbivores. This could enhance control of some weeds by bio-control agents, yet, it could also elevate the incidence of particular crop pests, consequently affecting on crop-weed competition.

Tillage is often regarded as global weed control method that is important especially in developing countries. Extremes of moisture availability, *viz*. flood as well as drought under climate change will affect physical methods like hoeing, inter-cultivation, etc. Due to vigorous growth of roots and rhizomes, especially in perennial weeds under elevated CO_2mechanical methods of weed control will be more difficult (Rogers *et al*., 2008) [59]. As a result, adoption of tillage may enable rapid asexual multiplication of perennial weeds in CO_2 enriched environment, thus affecting weed control (Ziska and Goins, 2006) [78].

Adaptive strategies in weed management

From above discussion, it is obvious that weed menace will drastically affect crop production in futuristic situation of climate change. Also, agronomic practices for specific crops keep evolving according to region and time. With the advent of new classes of herbicides, tillage innovations, cultivars and irrigation methods there will be change in spatial distribution and extent of crop damage due to agricultural weeds. For example, cultivation of recently introduced herbicide resistant crops can markedly alter weed flora composition. Moreover, weeds will likely evolve new traits in response to changing climate and non-climate selection pressures (Clements *et al*., 2004) [14]. Minimising the ill-effects of weeds and preventing invasion of new weeds are obligatory to improve the resilience of ecosystems and providing native species the best opportunity to cope up with adverse impacts of climate change. So, in order to tackle these problems, it becomes essential for all countries to conduct risk assessments at the appropriate level to lower the new threats posed by weeds. Co-operation at both regional and global level is mandatory to set up new networks and the capacity for early detection and rapid response systems. Information gathered through local and regional surveys on distribution and abundance of potential invaders should be shared among nations and used to strengthen their border protection through quarantine in the future.

Climate change may affect all dimensions of chemical weed control including application, spray drift, persistence, metabolism and herbicide efficacy. This warrants for diversifying present weed management tactics as well as the urgency of a sound knowledge regarding the ecology and biology of weeds under the scenario of changing climate. On farm level, integration of various weed management strategies in well planned fashion may come to rescue under these grave situations of climate change. No single method will prove effective to reduce weed pressure and improve yield in this scenario. Holistic weed management will be the need of the hour for tackling weed menace in this context. Careful selection and integration of the following approaches along with herbicides may enable to reduce weed problem under shift in climate:

a) Ecological approaches (alteration or adjustment to the general crop management or cropping systems design for better regulation of weed populations and minimize the ill-effects of weeds on crop production).
b) Improved tillage practices.
c) c)Bio-control methods.
d) Genetic improvement of crops (breeding allelopathic crops/cultivars and drought- and stress-resistant varieties)

Ecological approaches: These approaches in weed management chiefly rely on three principles- reduction in weeds recruitment from the soil seed bank, modification of crop-weed competition in favour of crop and a steady diminishing of the size of the weed seed bank (Bastiaans *et al*., 2008) [6]. Several agro-ecological management practices which enhance agro-ecosystem diversity and complexity over time and space for better adaptation under extreme climatic events are as follows:

I. **Suitable crop or cultivars:** Identification of crop or cultivars with certain traits like faster seedling emergence, quick canopy establishment and higher growth rates in the early stages, profuse branching or tillering, broader leaves (Rasmussen and Rasmussen, 2000; Lemerle *et al*., 2001; Sunyob *et al*., 2015) [56, 32, 65] and production and release of allelochemicals (Olofsdotter, 2001) [48] besides being resilient to climate changes with competitive edge over weeds is essential.

II. **Manipulation in sowing/planting time:** Change in crop sowing/planting time can minimize emergence of weeds and/or strengthen crop competitive ability (Mohler, 1996; Spandl *et al*. (1998) [40, 63], however this effect may vary with crop species and environment. Early planting of wheat in North India gives the crop a competitive advantage over *Phalaris minor*, a noxious grassy weed species (Chauhan and Mahajan, 2012) [35].

III. **Crop rotation:** Rotation of crops is an efficient method to regulate seed and root weeds by creating an unstable and inhospitable environment for weed establishment and survival. For different crops different cultural practices are followed, which interferes with growing cycle of weeds and, as such, prevents selection of the flora towards increased abundance of problem species (Karlen, 1994) [28].

IV. **Optimum plant population and spacing:** High planting density of a crop develops canopy rapidly and suppresses weeds more effectively (Sunyob *et al*., 2012) [64], and in contrast, widely spaced plants encourage weed growth (Guillermo *et al*. 2009) [22]. In order to apply this approach, the limiting weeds must be known and the seasons in which they occur. Narrower rows and/or higher population densities of crops ensure rapid canopy development, enhanced canopy radiation interception, thereby increasing crop growth rates and yields and suppressing weed growth and competitiveness.

V. **Cover crop:** Growing of cover crops like cowpea, *sesbania* and sunhemp prevent growth and development of weeds through niche pre-emption in which they capture the space and resources that would otherwise available to weeds. Cover crops as living mulches act as buffer zones or break crops which help in promoting in-field biodiversity and contributing to weed management. Also, incorporated or mulched cover crop residues can inhibit or retard germination, emergence and establishment of weeds due to both allelopathic and physical effects (Chauhan and Johnson, 2010; Kruidhof *et al*., 2009; Saha *et al*., 2018; Turk and Tawaha, 2003) [12, 30, 60, 69].

VI. **Inter-cropping:** Intercropping of Indian mustard with sugarcane (Kaur *et al*., 2016) [29] exhibited higher weed suppression through enhanced the utilization of resources like light, space and water besides increasing diversity in the cropping system. This practice can also help to reduce weeds thus limiting herbicide application in the cropping system. Intercropping using competitive cultivars in maize has been reported to reduce the use of herbicides to control weeds (Gomes *et al*., 2007) [19]. Similar findings were reported by Kaur *et al*. (2016) [29] in which intercropping of Indian mustard with sugarcane exhibited higher weed suppression than sole sugarcane.

VII. **Nutrient management:** Nutrient management practices as per crop need like Pre-sowing N fertilization in sunflower (Paolini *et al*., 1998) [49], delay of top-dressing N application in sugar beet (Paolini *et al*., 1999) [50] can realize an ideal growth of the crop, which enhances growth of the crop over weeds. Application of fertilizers along with or near the crop row can improve weed management because it increases the relative chances of the crop to capture nutrients (especially N) to the detriment of weeds (Rasmussen, 2000) [57].

Tillage: The method, depth, timing and frequency of tillage may influence the composition, density and long-term persistence of the weed population. Soil cultivation methods can influence the total weed pressure as well as the composition of weeds. Rahman (2017) [55] reported shifts in weed population dynamics in minimum/no tillage in conservation agricultural systems due to altered distribution of weed seed within the soil, with increasing problems of perennial weed species. Because weed seeds can germinate between soil cultivation and sowing of the crop, weed cures before sowing can be effective at reducing weed pressure. Application of superficial stubble treatment works well against persisting weeds. It should be done under dry weather conditions to allow the weed roots which have been brought to the surface to dry out. The response of the weed flora to reduced cultivations may depend on the balance between the buried seed reserves and freshly shed seed. Changes in the soil structure associated with tillage may also influence the species composition by affecting seed germination and seedling establishment.

Biological methods: Application of bio-control agent for weed management is one of the cost-effective technologies and permanent strategy, because an efficient and successful bio-control agent is self-sustaining. Some biological control agents invade roots and thereby stunting plant growth. Various bacteria harbour on root surfaces and excrete toxins thus reducing stunt root growth. Different fungi infect roots and obstruct the water transport system, which reduces leaf growth. Beneficial insects and nematodes feed directly on the weed roots causing injury which allows bacteria and fungi to penetrate. Soil-borne fungus *Fusarium oxysporum* was found to be very effective in minimizing *Striga hermonthica* in various crops thus increasing yield (Teka, 2014) [66]. Performance of bio-control agents, however, may be affected by changing environmental conditions due to climate. So, extensive research on new and existing bio-control agents is necessary to understand the implications for weed management in future climate scenarios.

Genetic improvement: An important objective for genetic improvement of crops is to adapt our present food crops to elevated temperature, moisture stress, rising salinity, and changing pest threats (World Bank 2007; Gregory *et al*. 2009) [73, 20]. This approach encompasses breeding more allelopathic crops and modification of crops by introducing genes to transfer competitive traits along with improved yield components, and increased resistance to pests. Exploitation several traits of weeds for better adaptability and performance through transgenic approaches are mandatory for genetic improvement of crops, thus enabling to cope up with futuristic climate change conditions. Advance scientific tools like molecular biology and biotechnology are being used to illuminate physiological and genetic attributes that make weeds difficult to manage. Attempts were made to improve the allelopathic property of crop plants through traditional breeding, however, were unsuccessful. This provides ample opportunities for biotechnology for genetic enhancement of crops (Duke, 2003) [16]. Many researchers have used molecular biology and transgenic approaches to improve production of the allelochemical “sorgoleone” in Sorghum species (Duke *et al*., 2001; Duke, 2003) [17, 16]. Genomics may help to access weed genetics and physiology in ways earlier unavailable to weed scientists. However, genomic approaches for study of weed biology and ecology are in their infancy (Tranel and Horvath, 2009) [67].

Conclusion

It can generalised that both crops and weeds may variably be influenced by climate change, however weeds are anticipated to flourish more and emerge as winner over crop due to huge genetic diversity and better adaptation mechanisms. Efficacy of both herbicide and bio-control agent has been predicted to be reduced significantly due to change in environmental conditions. Managing weeds is probably going to be more cumbersome and expensive under the scenario of climate change. So, in order to sustain high production level in predicted future climatic conditions and extreme weather events, integration of various weed management practices is inevitable. Synchrony in the timing of control strategies with the weed life cycle will be warranted as this will be influenced by climate change. Long term field studies of weed management based on simulated conditions of future climate are to be conducted for better prediction with higher accuracy. Extensive research and evaluation of existing and new herbicides, higher chemical concentrations and new bio-control agents will be required for managing weeds under this scenario. However, climate is not the only factor that will be changing in future. Other factors like population growth, socio-economic and technological changes will have effect no less than climate change. Hence, all factors should be taken into account while planning and integrating various weed management approaches for its feasibility and adoptability by farmers under climate change.

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