Review Article

EMERGING WEED PROBLEMS UNDER CHANGING CLIMATIC CONDITION – A REVIEW

Abstract

Climate is a major force in Earth's environmental system, and even minor changes in climate can have complex and serious effects on the environment and nature. Atmospheric CO_2, temperature and precipitation are major important abiotic variables that directly affect weed physiology and growth. Weeds are more genetically diverse than crops, hence show enhanced growth and reproductive stability than crops. As with crops, weeds with C3 or C4 photosynthetic pathways exhibit differences in their response to changing climate. The C3 weeds (*Argemone mexicana*, *Chenopodium album* and *Phalaris minor etc.,*) shows more response in photosynthesis to increased CO_2 level in atmosphere. Elevated CO_2 under sufficient water condition will lead to higher C3 weed competitiveness in C4 crops. So weed growth is favoured as CO_2 is increased.

Temperature changes resulted in an expansion of weeds, with some species shifting to higher latitude and altitude. Based on the differences in temperature optima for physiological processes, C4 *spp.* able to tolerate high temperature than C3 *spp*. Therefore, C4 weeds (*Digitaria ciliaris, Cyperus spp., Echinochloa colona etc.,*) benefit more than the C3 crops from any temperature increases that accompany elevated CO_2 levels. Normally, the mean temperatures increases over a long period, weeds expand their range into new areas. Precipitation is also important climate variable that influences the growth and distribution of weed vegetation. Although CO_2 concentrations and temperature rise in future are predictable, distribution and variation in the intensity of precipitation patterns remains much more uncertain. Moisture is a key factor required for weed seed germination and establishment. Climate change can affect the frequency and intensity of rainfall and result in occurrences of extreme events such as floods and droughts; consequently, weeds adapted to these conditions will have a higher competitive advantage.

Key words: *Climate Change, elevated CO_2, Temperature, Precipitation, C3 and C4 weeds*

Introduction:

The difficult of climate change is increasingly more receiving attention from scientists, public peoples, and policy makers. Climate change is now a broadly accepted term (Petit et al. 1999; Loss et al. 2011). Climate Change defines ‘‘a change of climate which is credited directly or indirectly to human activity by alters the compositions in the atmosphere negatively” (Robinson and Gross 2010). The atmospheric CO_2 concentration have risen from about 280 ppm (pre-industrial period) to today’s about 390 ppm and it is expected that by the end of 21^{st} century, it will reach to the levels of 600-700 ppm, if current emission trends continue (IPCC, 2001; Leegood, 2002). Climate models projected that the earth surface temperature is likely to rise in a range of 1.1 to 6.4°C during the 21^{st} century due to the rising of carbon dioxide concentration in the atmosphere (IPCC, 2004; Houghton, 2001). There are concerns that global CO_2 enrichment will affect the drymatter of weeds and crop yields directly or indirectly through global warming and its associated changes in climate such as alteration in precipitation, wind pattern, rise in sea level and more flood and drought. It has been reported that elevated CO_2 concentration cause an increases in photosynthesis (Kendall *et al.* 1985; Ghannoum et al. 2000; Dass *et al.*, 2017), decrease in photorespiration and respiration (Ziska, 2000), different crop and weed species differ in their response to elevated CO_2 concentration levels (Poorter, 1993).

The various responses of C3 and C4 plants (weeds & crops) to elevated CO_2 and air temperature have important implications on crop/weed competition as most of the weeds are C4. But this basic idea that the most crops are C3 photosynthesis and most weeds are C4 photosynthesis, and hence weeds are mature and decay as earlier (Ziska, 2003; Pautasso *et al.* 2010; Singh *et al*. 2011). Evidently, there are four major C4 crops of economic importance (Maize, Pearlmillet, Sorghum, and Sugarcane), and many important C3 weeds (e.g. *Chenopodium album, Avena ludoviciana, Phalaris minor, Eclipta prostrate, Ammania baccifera* etc.). Generally, it is reported that plants with C3 photosynthetic pathways are expected to benefit more than C4 from CO_2 enrichment but inverse is true with rising temperature (Jinger *et al.*, 2016).

Climate change may bring changes in weed population and in their phenology (Patterson, 1995). Many weed species may expand their range and spread to new areas. In addition to its impact on agricultural weed, literature suggest that invasive species may become more of a threat in changing climate because of their strong response to elevated CO_2 and changing climate compared to other native species.

Moreover, some weed species which directly impact human health through allergic reactions, skin irritations, or internal poisoning have shown positive response to changing climate particularly to elevated CO_2 concentration by producing higher plant biomass, pollens or poisonous compounds (Dukes *et al*., 2009; Singer *et al*., 2013). Weeds may show a greater range of responses to increasing temperatures because of their wider gene pool compared with crops, which enables them to adapt to diverse environment conditions (Treharne, 1989). The degree of photosynthetic stimulation and growth response varies between C3 and C4 plants as the temperature increases (Morgan *et al*., 2001).

Precipitation is another important climate variable that influences the growth and distribution of vegetation (Lobell and Burke, 2008; Robinson and Gross, 2010). Although CO_2 concentrations and temperature rise in future are predictable, distribution and variation in the intensity of precipitation patterns remains much more uncertain. Moisture is a key factor required for weed seed germination and establishment (Skov and Svenning 2004; Bergmann et al. 2010). Climate change can affect the frequency and intensity of rainfall and result in occurrences of extreme events such as floods and droughts; consequently, weeds adapted to these conditions will have a higher competitive advantage (Rodenburg *et al*., 2011). Finally, the present reviews covered a weed emergence problem under changing climatic condition. Further investigations and research areas are needed in this concern.

Weeds – Characteristics

In this world totally 46 major crops are there but, over 410 “serious” weed species.

1. Produces larger number of seeds compare to crops
2. Most of the weed seeds are small in size and contribute enormously to the seed reserves.
3. Weed seeds germinate earlier and their seedlings grow faster than crop seeds.
4. The viability of seeds remains intact, even if they are buried deep in the soil.
5. Weed seeds do not lose their viability for years even under adverse conditions.
6. They flower earlier and mature ahead of the crop they infest.

7. They have the capacity to germinate under varied conditions, but very characteristically, season bound. The peak period of germination always takes place in certain seasons in regular succession year after year.
8. Weed seeds possess the phenomenon of dormancy
9. Most of the weeds possess C4 type of photosynthesis, which is an added advantage during moisture stress.
10. They possess extensive root system, which go deeper as well as of creeping type.
11. Quick response to available soil moisture and nutrients.
12. Tolerance to shading effects by the crops at the time of establishment
13. Mimicry: Resembles the crop plants, morphological characters are similar to the crop Plants.
14. Weed dispersal has no geographical boundaries. Common agents of weed dispersal are wind, water, animals, birds, organic manures, agriculture implements and human beings.

Climate Change on Weeds

The main parameters for climate change impacts on weeds include increased atmospheric CO_2 levels, temperatures, changed rainfall, more extreme weather, more frequent frosts, changed phenology and changed land use (Patterson, 1995; Ziska, 2016). The rate of response of invasive plants and weeds is expected to be faster than for other plants, including native species and crops. Secondly, climate change is likely to foster the appearance of a new set of weed species (Dukes *et al*. 2009; Singer *et al*. 2013).

Change in atmospheric CO_2, temperature, rainfall and wind will affect on Weed species distribution, growth and physiology, prevalence within weed and crop communities, affect crop-weed balance and lead to weed invasion (Patterson, 1995; Ramesh *et al*., 2017; Anwar *et al*., 2021).

Impact of climate change on weed biology (Ziska, 2000)

- Weed shifts and spread of invasive species
- Elevated CO_2 and its effects on weeds
- Effect of increased temperature on weeds
- Effect of change in precipitation on weeds

- Other environmental stresses and weed competitiveness.

Table 1 : Impact of climate change on risks of invasiveness (Bradley *et al.*, 2010)

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

Weeds response to increasing of CO_2 levels

Elevated atmospheric CO_2

Weeds have a greater genetic diversity than crops. Consequently, if a resource (light, water, nutrients or carbon dioxide) changes within the environment, it is more likely that weeds will show a greater growth and reproductive response Elevated atmospheric CO_2 is improve the growth of plants due to increased efficiency (Ziska, 2008). The interaction between eCO_2 and growth is strongly influenced by the mode of energy capture (photosynthesis), with some plants (C4 and CAM), including many grasses and succulents, being more efficient than others (C3 plants) (Patterson, 1995; Batts *et al.* 1997; Morison and Lawlor, 1999).

Many of the weed species have the C4 photosynthetic pathway. However, this argument does not consider the range of available C3 and C4 weeds present in any agronomic environment. Hence, if a C4 weed species does not respond, it is likely that a C3 weed species will (Morison and Lawlor, 1999). In addition, many growers recognize that the worst weeds for a given crop are similar in growth habit or photosynthetic pathway; indeed, they are often the same uncultivated or "wild" species, e.g. oat and wild oat, sorghum, rice and red rice. To date, for all weed/crop competition studies where the photosynthetic pathway is the same, weed growth is favoured as CO_2 is increased (Carter and Peterson 1983; Ziska, 2003).

Direct physiological effects of elevated CO_2 on photosynthesis and plant growth have been well documented. Plants with C3 photosynthetic pathways are expected to benefit more than C4 from CO_2 enrichment (Patterson and Flint, 1980). This differential response of C3 and C4 plants to elevated CO_2 can have important implications on crop/weed competition as most of the weeds are C4. Therefore, it can be argued that because of C4 photosynthetic pathway of many weed species, they will show smaller response to elevated CO_2 relative to crops which are mostly C3 (Zangerl and Bazzaz, 1984; Ziska, 2003; Rogers et al. 2008). Therefore, it is important to examine crop/weed competition cropping system based to develop effective weed management practice for the emerging species in the changing climate scenario.

Impacts (Reddy, *et al*., 2010)

1. Higher CO_2 : Stimulate Photosynthesis and Growth, Reduce ET and Increase WUE
2. Many C3 weeds have shown significant increases in growth, with substantial decreases in the yields of competing crops.
3. Rising CO_2 levels - Positive effect on the establishment and persistence of invasive species. (eg. *Bromus tectorum*).

INDIA: CO_2 VS Weeds

Common weeds species found in India such as *Ageratum conyzoides*, Digitaria ciliaris, *Cyperus spp.*, *Echinochloa colona*, *Paspalum orbiculare* and *Setaria glauca* and having C4 photosynthetic pathway will show smaller response in photosynthesis to increased CO_2 level in atmosphere (Singh, *et al*., 2011).

Whereas weed species with C3 photosynthetic pathways like *Agropyron repens, Argemone mexicana, Chenopodium album, Phalaris minor, Poa annua* and *Rumex acetosella,* may show enhanced photosynthesis to increased CO_2 level in atmosphere, in addition, many of the worst weed for given crop are similar in growth habit or photosynthetic pathways for example, oat and wild oat, wheat and little seed canary grass, rice and wild rice, and hence weed growth is more favoured due to increased CO_2 level in the atmosphere (Patterson, 1985; Patterson, 1995; Mishra, 2003).

Table 2 : Important C3 and C4 weed species of rice and wheat crops in India

Crop	C3 weeds	C4 weeds
Rice	Weedy rice, *Scirpus spp,* *Monochoria,* *Eclipta prostrata,* *Ammania baccifera*	*Echinochloa spp,* *Cyperus spp.,* *Leptochloa chinensis,* *Bracharia*
Wheat	*Chenopodium album,* *Phalaris minor,* *Avena fatua,* *Convolvulus arvensis,* *Canada thistle*	*Cynadon dactylon*

Table 3 : Response of C3 and C4 weeds to double atmospheric CO_2 levels (Chandrasena, 2009)

Sn.	C3	Range of response biomass	C4	Range of response biomass
1	*Abutilon theophratsii*	1.0-1.52	*Amaranthus retroflexus*	0.9-1.41
2	*Bromusmollis*	1.37	*Andropogon virginius*	0.8-1.17
3	*Bromustectorum*	1.54	*Cyperus rotundus*	1.02
4	*Cassia obtusifolia*	1.4-1.8	*Digitaria ciliaris*	1.06-1.6
5	*Chenopodium album*	1.0-1.6	*Echinochloa crusgalli*	0.95-1.6
6	*Datura stramonium*	1.7-2.27	*Eleusine indica*	1.02-1.8
7	*Phalaris aquatica*	1.48	*Sorghum halepens*	0.56-1.1

Table 4 : Shift in weed flora in India

Crop	Original weed flora	New weed flora
Wheat (first phase)	*Chenopdium spp.,* *Spergula arvensis,* *Anagallis arvensis*	*Phalaris minor,* *Avena fatua,* *Lolium temulentum*
Wheat (Second phase)	*Phalaris minor,* *Avena fatua*	*Lathyrus aphaca,* *Convolvulus arvensis,* *Medicago spp.,* *Cirsium arvense*
Rice	*Echinochloa spp.*	*Cyperus iria,* *Fimbistylis miliacea,* *Sphenoclea zeylanica*

Sugarcane	Broadleaved weeds	Grassy weeds

Higher photosynthetic rates at elevated CO_2 in C3 crops (Rice, Wheat, Soybean, etc.) mean they will respond more favourably to higher CO_2 levels than the C4 weeds (palmer amaranth (A. *palmeri*), water hemp (*Amaranthus rudis*), kochia (K. *scoparia*) (Elmore and Paul, 1983). In contrast, C3 weeds (lambsquarters, velvetleaf (*Abutilon theophrasti*), common ragweed (*Ambrosia artemisiifolia*) and giant ragweed (*Ambrosia tricda*)) will respond more favourably to increased CO_2 levels and offer stiffer competition to C4 crops (Maize, Sorghum, Sugarcane, etc.) (Tang *et al.* 2009)

C3 weeds in C4 crops

- Elevated CO_2 under sufficient water condition will lead to higher C3 weed competitiveness in C4 crops. At elevated CO_2 - Seed yield or total above ground biomass of sorghum was significantly reduced by C3 weeds (Ziska 2003).
- C3 weed dandelion (*Taraxacum officinale*) produced more fertile seeds and larger seedlings under elevated CO_2 (McPeek & Wang, 2007).

CO_2 VS C4 weeds and C4 Crops

Ziska and Bunce (1997) compared the effect of elevated CO_2 levels on the growth and biomass production of six C4 weeds (*Amaranthus retroflexus*, *Echinochloa crusgalli*, *Panicum dichotomiflorum* Michaux, *Setaria faberi* Herrm, *Setaria viridis*, *Sorghum halapense*) and four C4 crop species (*Amaranthus hypochondriacus*, *Saccharum officinarum*, *Sorghum bicolor*, and *Zea mays*). In these C4 species showed a significant increase in photosynthesis. The largest and smallest increases observed were for *A. retroflexus* (+30%) and *Z. mays* (+5%), respectively.

CO_2 VS Soybean - C3 weeds

Ziska (2000) evaluated the outcome of competition between ‘Round-up Ready’ Soybean (*Glycine max*.) and a C3 weed (lambsquarter, *Chenopodium album*) and a C4 weed (Redroot pigweed, *Amaranthus retroflexus*), grown at ambient and enhanced CO_2 (ambient + 250 µL L^{-1}). In a weed-free environment, elevated CO_2 resulted in a significant increase in soybean growth and seed yield, compared to the ambient CO_2 condition. However, soybean growth and seed yield were significantly reduced by the presence of either weed species at either level of CO_2. With lambsquarter, at elevated CO_2, the reduction in soybean seed yield relative to the weed-free control increased from 28 to 39%; concomitantly, the dry weight of lambsquarter increased by 65%.

Conversely, for pigweed, soybean seed yield losses diminished with increasing CO_2 from 45 to 30%, with no change in the dry weight of the weed. This study suggests that rising CO_2 could alter yield losses due to competition from weeds, and that weed control will be crucial in realizing any potential increase in the yield of crops, such as soybean, as climate change occurs (Chandrasena, 2008).

Table 5 : Effect of elevated CO_2 on crop-weed interactions (Ziska, 2000)

Crop-weed interaction	**Ambient CO_2**	**Elevated CO_2**	**Percentage change**
Above ground biomass			
Soybean (C3)	340±13	448±14	+31.8
+C3 weed	261±18	297±29	+14.0
+C4 weed	204±17	329±27	+61.3
Seed yield			
Soybean (C3)	187±8	228±8	+21.9
+C3 weed	135±9	141±15	+4.4
+C4 weed	103±13	158±14	+53.4

(Total aboveground biomass and seed yield (±standard error) at maturity for soybean (g/m row) at ambient and elevated CO_2 (ambient +250 µl /l CO_2) when grown with or without the presence of a C3 weed (*Chenopodium album*) or a C4 weed (*Amaranthus retroflexus*).

CO_2 VS Redroot pigweed

The elevated CO_2 effect on Redroot pigweed (C4 weed), no change in biomass and yield loss in soybean decreased from 30% to 45% in competition with this weed. Growth of redroot pigweed in a sorghum field was favoured by increasing atmospheric CO_2 levels (Ziska *et al*., 2003). *A. retroflexus* is established well under lack of soil moisture with good root system and may takes advantages of elevated CO_2 for increasing the drymatter production of Redroot pigweed (Weller *et al*., 2021). Redroot pigweed was grown with very well germination, growth, and CO_2 exchange rates at high temperatures, whereas the common lambsquarters grown well under low temperature (Chu, *et al.*, 1978; Egley, 1989).

CO_2 with Temperature

The competitiveness could be enhanced in C3 crop (Rice) relative to a C4 weed (*Echinochloa glabrescens*) *with* elevated CO_2 alone but simultaneous increases in CO_2 and temperature still favour C4 weed *spp*.

The competition outcomes between rice and a C4 weed - *Echinochloa glabrescens* L. using replacement series mixtures at two different CO_2 concentrations (393 and 594 µL L-1) under day/night temperatures of 27/21°C and 37/29°C. Increasing the CO_2 concentration, at 27/21°C, resulted in a significant increase in above ground biomass (+47%) and seed yield (+55%) of rice when averaged over all mixtures. For the C4 weed, higher CO_2 concentration did not produce a significant effect on biomass or yield.

When grown in mixture, the proportion of rice biomass increased significantly relative to that of the C4 weed in all mixtures at elevated CO_2 indicating increased 'competitiveness' of rice. However, under elevated CO_2 level and the higher temperature regime, competitiveness and reproductive stimulation of rice was reduced compared to the lower growth temperature, suggesting that while a C3 crop like rice may compete better against a C4 weed at elevated CO_2 alone (Alberto *et al.*, 1996).

CO_2 VS Leaf area and Biomass

Elevated CO_2

- In C3 weeds, leaf area generally responds less than biomass to CO_2 enrichment.
- However, in C4 weeds, leaf area and biomass more responses to CO_2 doubling (Fuhrer, 2003).

Elevated CO_2

- C3 grass species - Increase in tillering and C4 grass species - Increase in leaf area. Increases in CO_2 and temperature could still favour a C4 species (Yin and Struik 2008).

Table 6 : Effects of doubling CO_2 concentration on biomass and leaf area of C3 weeds (Patterson, 1995)

Range of response (% of growth at ambient)				
Scientific name	**Common name**	**Biomass**	**Leaf area**	**No. of reports**
Abutilon theophrasti Medicus	Velvet leaf	100-152	87-117	6
Cassia obtusifolia L.	Sicklepod	138-160	104-134	2
Chenopodium album L	lambsquarters	100-155	122	2
Cirsium arvense (L.) Scop	Canada thistle	121	92	1
Crotolaria spectabilis Roth	Showy crotaloria	167	154	1

Datura stramonium L.	Jimson weed	174-272	146	1
Elytrigia repens (L.) Neveski	Quack grass	164	130	1
Lolium perene L.	Perennial rye grass	134-143	-	2
Phalaris aquatica L.	Harding grass	143	131	1
Plantago lanceolata L.	Buckhorn plantain	100-133	133	2
Plantago major L.	Broad leaf plantain	155	-	1
Poa annua L.	Annual blue grass	100	-	1
Poa trivialis L.	Rough stalk blue grass	103	-	1
Rumex acetosella L.	Red sorrel	131	-	1
Rumex crispus L.	Curly dock	118	96	1

Table 7 : Effects of doubling CO_2 concentration on biomass and leaf area of C4 weeds (Patterson, 1995)

Range of response (% of growth at ambient)				
Scientific name	**Common name**	**Biomass**	**Leaf area**	**No. of reports**
Amaranthus retroflexus L.	Pigweed, red rot	96-141	94-125	4
Andropogon virginicus L.	Broom sedge	81-117	88-129	2
Cyperus rotundus L.	Nut sedge, purple	102	92	1
Digitaria ciliaris (Retz.)	Crab grass	106-161	104-166	2
Echinochloa crusgalli (L.) *Beav.*	Barnyard grass	95-159	95-177	3
Eleusine indica (L.) *Gaertn.*	Goose grass	102-121	95-132	3
Rottboellia cochinchinensis	Itch grass	121	113	1
Setaria faberi	Foxtail, giant	93-135	101-140	3
Sorghum halepense (L.)	Johnson grass	56-110	99-103	3

CO_2 VS Weedy rice

Ziska *et al.*, (2010) & Ziska et al., (2013) found that in case of rice, rice biomass increased with increase in CO_2 from 300 to 400 ppm but did not increase further with increase in CO_2 to 500 ppm, whereas rice yield did not respond to elevated CO_2. Red rice responded linearly in terms of biomass as well as seed production. The elevated CO_2 (700 ± 50 μmol mol^{-1}) had increased the weedy rice germination, growth and biomass (Balbinot *et al.*, 2022)

CO_2 VS Cocklebur

Ziska (2001) reported the effects of elevated CO_2 on the growth of grain sorghum (C4) with and without common cocklebur (X. *strumarium*). At elevated CO_2, biomass and leaf area were higher for common cocklebur and significantly lower for sorghum in competitive mixtures, indicating that growth of C4 crops could be reduced in the presence of C3 weeds as future CO_2 levels increase (Katoh and Esashi,1975; Esashi, *et al*., 1988). The elevated CO2 enhances the imbibed cocklebur seeds (Esashi and Katoh, 1975; Esashi *et al*., 1978, Ishizawa *et al*., 1988).

CO_2 VS Ragweed and Quack grass

Increased CO_2 stimulated ragweed (*Ambrosia artemisifolia) pollen production several* times more than that it stimulates overall growth (Singer *et al*. 2005). Tremmel and Patterson (1993) studied that increased CO_2 ameliorated the high temperature effects on quack grass (*Elytrigia repens)* and increase the growth and reproduction. C3 weeds like lambsquarters or quackgrass are well grown in an elevated CO_2 environment (Tremmel and Patterson, 1994; Ziska et al. 1999; Ziska & Teasdale 2000).

CO_2 VS Crops and weeds

Increasing CO_2 levels can favour either the crop or the weed in the same field. Rising atmospheric CO_2 concentration altered the competition between rice and barnyard grass in favour of rice (Zeng *et al*., 2011). Nitrogen was found to be the limiting factor for biomass increase in rice at elevated CO_2 levels compared with barnyard grass (Zhu *et al*., 2008).

CO_2 VS Rice and Wheat

The effect of CO_2 enrichment on weed species at the Directorate of Weed Science, Jabalpur revealed that a few weed species such as *Dactyloctenium aegyptium* and *E. colona responded to elevated* CO_2, but *Cyperus rotundus and Eleusine indica* did not respond to CO_2 enrichment. Weedy rice (*Oryza sativa L.) were* responds more strongly than cultivated rice to rising CO_2 level with greater competitive ability, suggesting that weedy rice may become a more problematic weed in the future. The growth and biomass accumulation was increased of the C4 weed (*Amaranthus viridis*) under elevated CO_2 (Naidu and Paroha, 2008).

The C3 crop like rice, elevated CO_2 levels may have positive effects on crop competitiveness with C4 weeds. The problems of *P. minor and Artemisia ludoviciana in* *wheat would* aggravate with increase in CO_2 due to climate change. Further, the problem could be aggravated with water scarcity. Due to CO_2 enrichment, the wheat plant could gain biomass against *P. minor.* Under water stress conditions, *P. minor* had advantage over wheat with CO_2 enrichment (Fuhrer, 2003).

CO_2 VS Wild oat

The CO_2 enrichment/elevated CO_2 hastened the seed maturity in *Avena fatua* (*wild oat*) in wheat. The seeds were matured 13 days in advance compared to the plants grown under ambient CO_2 conditions and enrichment of soil seed bank as the wild oat seeds shatter well before the harvest of the crop. The wild oat plants grown at 480 ppm CO_2 produced 44% more seed than 357 ppm (O'Donnell and Adkins, 2001; Johannessen et al., 2005; Granger *et al*., 2012; Momtazi and Miri, 2015; Ziska, *et a*l., 2015; Oraki *et al*., 2016; Ziska, 2017; Balbinot, 2020)

CO_2 VS Noxious or Invasive weeds

The elevated CO2 Increases the growth and development of Noxious *weeds* (Dukes, 2000; Polley *et al*., 2003; Weltzin *et al*., 2003; Salo, 2005). *Cynodon dactylon* in rice and *Convolvulus arvensis* in wheat. These weeds may show a strong response in growth with increase in atmospheric CO_2 (Ziska *et al*., 2004). In India, *Parthenium hysterophorus* had shown remendous growth response to elevated CO_2. Increased flower production of *Parthenium hysterophorus* (C3) and *Amaranthus viridis* (C4) under elevated CO_2 (Naidu, 2013; Waryszak *et al*., 2018). The elevated CO2 recorded in significant changes in drymatter production and morphology of invasive M. *micrantha and W. trilobata* (Song *et al*., 2009). Many invasive plants have been shown to respond positively to elevated (CO_2) when grown individually or in monoculture (Weltzin *et al*., 2003). Examples of these are species that have invaded North America, such as cheatgrass (*Bromus tectorum),* kudzu (*Pueraria lobata) and Japanese* honeysuckle (*Lonicera japonica,* which has also invaded New Zealand and parts of Europe) (Ziska, 2003).

CO_2 VS Worst weed

Many growers recognize that the worst weeds for a given crop are similar in growth habit. There are 14 of the world's worst weeds comes under C4 plants. Eg: Oat - wild oat, Wheat - little seed canary grass, Rice - wild rice growth is more favoured due to increased CO_2 level in the atmosphere (Patterson, 1995; Ziska, 2003).

Weed Response to Increasing Temperature

Climate change involves rising temperatures (Tubiello *et al.* 2007). Temperature is a primary factors influencing the distribution of weeds. Increasing temperatures on weeds shift into higher latitudes or higher altitudes. Under high temperature, plants with C4 carbon fixation pathway (mostly weeds) have a competitive advantage over crop plants. Increased atmospheric CO_2 levels are likely to be accompanied by higher temperature favouring C4 weeds over C3 crops. A similar shift in weed species composition can also be expected under erratic rainfall because of climate change. Due to sudden change in climate, environmental stress on a crop may increase and as a result the crop could become more vulnerable to attack by insect and pathogens, and less competitive with weeds.

The aberrations in weather conditions not only affect crop-weed competition, but also trigger weed seed germination in several flushes causing serious weed management issues. Three flushes of *P. minor* are not uncommon in the wheat fields in northwest India, which are not controlled by a single application of herbicide. Weeds are more responses to increasing temperature because of their wider gene pool compared with crops, which enables them to adapt to diverse environment conditions. Normally the mean temperatures increases over a long period, weeds will expand their range into new areas (Tubiello *et al.* 2007).

Warmer seasonal temperatures and milder winters will extend the distribution of invasive weeds. (Kudzu and Ragweed) (Garrett, 2012). Temperature rises will give competitive advantage to C4 plants than to C3 plants. Hanzlik and Gerowitt (2012) studied that Soybean was more adversely affected by rising temperature than prickly sida (*Sida spinosa) and sicklepod (Senna obtusifolia).*

Temperature VS Weed Phenology

Climate change may bring changes in weed population and in their phenology. The increased temperature had a greater effect on plant Phenological development than elevated CO_2. The increasing temperature by 4°C had advanced the emergence timing of *C. album* and *S. viridis* by 26 and 35 days, and flowering time by 50 and 31.5 days. Increased temperatures strongly affected the biomass accumulation by annual grass species during their reproductive phase as compared with the vegetative phase (Lee, 2011).

INDIA

Sing *et al.* (1991) reported that most of the weeds in rice are of C4 type. *Ischaemum rugosum* are more in Tropical areas. *Rumex spinosus* in wheat of North West India has increased.

AUSTRALIA

The Buffel grass (*Cenchrus ciliaris*) is one of the few weeds in Australia to be extensively assessed for growth response to climate change (growth at 35°C versus 25°C).

The warm temperature increases many C4 weeds, such as *Amaranthus retroflexus* L., *Setaria* sp., *Digitaria* sp., *Sorghum halepense* L., *Paspalum dichotomiflorum* (L.) are expected to expand further north side of Australia (Clements and DiTommaso, 2011). *Hieracium aurantiacum* L. (Brinkley and Bomford, 2002).

CALIFORNIA

Temperature can allows sleeper weeds to become invasive. Very aggressive weeds that are currently found in the lower latitudes are limited in the higher latitudes of California. The Itch grass has profusely tillering at increasing temperature (Bunce and Ziska 2000). The Robust grass weed could was invaded the central Midwest and California with a 3°C warming trend (Patterson, 1995).

European

Due to Warmer the three important Central European C4 weeds in maize like, *Amaranthus retroflexus*, *Echinochloa crusgalli* and *Setaria viridis*. Most of these weeds are late germinators and emerge from early summer to early autumn (Walther *et al.*, 2002). O'Donnell and Adkins (2001) reported that wild oat plants grown at high temperature 23/19°C (day/night) completed their development faster than those grown at normal temperature 20/16°C.

Temperature VS *Striga*

Atmospheric temperature is regarded as an important indicator of weed species distribution in a geographical area. *Striga* species are highly diverse. *Striga asiatica* is relatively insensitive to temperature. Its distribution may be more affected by changes in the geographical range of the host crop than directly by temperature (Mohamed *et al.*, 2007).

Temperature VS *Parthenium*

A higher percentage of *Parthenium* seed germination was observed during summer. Nguyen et al. (2010) have reported that the highest number of *Parthenium* seeds were produced under warm conditions, with a maximum number (60%) of unfilled seeds under cool condition. Warm dry conditions allow reproduction after only 50 days of growth, while cool and wet conditions delay this to after 75 days. Increased temperature enhances growth of *Parthenium*, enlarges canopy size and structure and accelerates population growth rate because of the shortened life cycle (Singh 2011; Toh *et al.,* 2011).

Weed Response to Precipitation

Lantana camara, for example, could expand if rainfall increased in some areas (McFadyen 2008). The drought-tolerant C4 weeds, parasitic weeds that thrive in erratic and low rainfall environments (e.g. *Striga hermonthica*) or temporarily flooded conditions (e.g. *Rhamphicarpa fistulosa*) could benefit. *Striga spp*. problems are also associated with low soil fertility area (Kroschel, 2000).

Competition of cotton with *Abutilon theophrasti* and *Anoda cristata (L.)* increased under drought conditions (Patterson and Highsmith, 1989). A yield reduction due to *Xanthium strumarium* L. was more pronounced in well-watered soybeans compared with water-stressed soybeans (Mortensen and Coble, 1989). An increase in rainfall provided greater competition to wheat growth and yield against *Cirsium arvense* (Donald and Khan, 1992).*Amaranthus spinosus* and *Leptochloa chinensis* (L) survived under water stress conditions and produced a significant number of tillers/branches.

Cheat grass and Yellow star thistle (*Centaurea solstitialis*) are annual weeds survive under drought conditions (Vollmer and Vollmer, 2006). While cheat grass completes its life cycle based on available moisture and yellow star thistle competes with native plants by developing deeper root system (Hatfield *et al*., 2011). Drought and dry soil conditions prolong the weed seed bank longevity.

Flooding

Submergence protects rice plants from severe competition with C4 weeds. On the other hand upland rice and rainfed lowland rice with limited precipitation face severe competition with C4 weeds. Alternate wetting and drying in puddled as well as dry-seeded rice may encourage weeds such as *Livistona chinensis*, *Eleusine indica and Eleusine prostrata*.Tamarisk (*Tamarix aphylla*) Willows (*Salix spp.*) and *Rhamphicarpa fistulosa* are benefit (increase growth) to flooding events (Rodenburg *et al.*, 2010).

Wind

The increasing CO_2 levels may also increase wind dispersal of weed seeds by either increasing the height of the weed plant or by increasing the plant size. Wind dispersed invasive weed species are *Cirsium arvense*, *Sonchus arvensis* L., *Sonchus oleraceus* L., and *Carduus nutans* L (Ziska and Dukes 2011).

Fire

Gamba grass (*Andropogon gayanus*) is reason for fire under extreme weather condition. Fire is a common extreme event in Australia and its frequency and severity is often influenced by extreme weather.

Climate Change: Crop-Weed Interactions

Crop-weed interactions vary significantly in various climatic regions, depending on temperature, precipitation, soil, etc.

A. C3 crop competing with both C3 and C4 weeds where C3 weeds are dominant, whereas in another situation C4 weeds are dominant.
B. C4 crop competing with both C3 and C4 weeds where C3 weeds are dominant, whereas in another situation C4 weeds are dominant.

Table 8: Crop/weed competition outcome at elevated CO_2 conditions (Bunce and Ziska 2000)

Weed species	Crop	Favoured under elevated CO_2	References
Amaranthus retroflexus (C4)	Soybean (C3)	Crop	(Ziska, 2000)
Amaranthus retroflexus (C4)	Sorghum (C4)	Weed	(Ziska, 2003)
Chenopodium album (C3)	Soybean (C3)	Weed	(Ziska, 2000)
Taraxacum officinale (C3)	Lucern (C3)	Weed	(Bunce, 1995)
Albutilon theophrasti (C3)	Sorghum (C4)	Weed	(Ziska, 2003)
Taraxacum and Plantago (C3)	Grasses (C3)	Weed	(Potvin and Vasseur, 1997)

Red rice (C3)	Rice (C3)	Weed	(Ziska *et al.*, 2010)
Echinochloa glabrescens (C4)	Rice (C3)	Weed	(Alberto *et al.* 1996)

Climate Change on Weed Management

Herbicide Efficacy

I. Carbon Dioxide and Temperature

Reduced stomatal conductance can alter the efficacy of both foliar- and soil-applied herbicides. Change in temperature and CO_2 concentration, may alter transpiration, the number of leaf stomata, or the thickness of the leaf, which may affect the absorption and translocation of herbicides.

II. Relative Humidity

Relative humidity could influence the efficacy of foliar-applied herbicides through interactions between the herbicide droplet, leaf cuticle, and availability of water (Devine *et al.*, 1993).

III. Wind

Wind may have a less pronounced influence on herbicide performance. Nonetheless, windy conditions can interfere with surface application and cause spray drift, thereby reducing spray application efficiency

IV. Rainfall

Increased rainfall frequency and intensity will have an adverse effect on uptake, retention, and activity of soil-applied herbicides

Weed management under climate change

- Continue current control options
- Integrated Weed Management (IWM)
- Use control options suitable for current extreme events.
- Develop new control methods adapted for climate change.

Summary

Changes in temperature and carbon dioxide are likely to have significant direct (CO_2 stimulation of weed growth) and indirect effects (climatic variability) on weed biology. In spite of the importance of weed biology in both the environment and in farms, very little is known regarding the impact of these environmental changes on both the reproductive success of agronomic or invasive weeds, and the potential consequences for their management. The growth and reproduction of C3 weeds will increase under changing climatic conditions.

Conclusion

Global climate change factors have serious implications for not only crop and weed growth and also herbicide performance and the effectiveness of chemical weed management. Weeds tend to show better survival mechanisms under changing climate because of their greater inter-specific genetic variation and physiological plasticity.

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