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CLIMATE CHANGE AND ITS POSSIBLE IMPACTS ON WEEDS

Mool Chand Singh, S.C. Dubey and N.T. Yaduraju[1]
ICAR-National Bureau of Plant Genetic Resources, New Delhi-110 012, India
[1]International Crop Research Institute for Semi-Arid Tropics, Patancheru-502319, India
E-mail: mcsingh@nbpgr.ernet.in

Abstract: Weeds have been winner and will be winner in future climate change conditions because of more adaptive power and more diversity. Weed population will change with climate change and risks of invasiveness may increase. Effectiveness of current management practices may be affected. Most studies evaluated effect of single factor (elevated CO_2) and only few studies have evaluated the interaction of multiple factor of change. Research is needed to assess the interactive effects of multiple climate change factors simultaneously to help prediction how weed problems may change in future with changing climate in order to develop flexible integrated weed management practices which are based on a foundation of knowledge of weed biology and ecology.
Keywords: Climate change, Crop-weed competition, Elevated CO_2, Temperature, Weeds.

Introduction

Climate change is now a widely accepted phenomenon. 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 21st century, it will reach to the levels of 600-700 ppm, if current emission trends continue (IPCC, 2001). Climate models projected that the global earth surface temperature is likely to rise in a range of 1.1 to 6.4°C during the 21st century due to the rising CO_2 concentration (IPCC, 2004). There are concerns that global CO_2 enrichment will affect 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 increase in photosynthesis (Kendall *et al.* 1985) and decrease in photorespiration and respiration (Bruce and Caulfield, 1991; Ziska and Bunce, 1993), and different species differ in their response to elevated CO_2 concentrations (Poorter, 1993). It is postulated that competition between plants will change with different responses to elevated CO_2 and temperature (Hunt *et al.,* 1991). Generally, it is reported that plants with C_3 photosynthetic pathways are expected to benefit more than C_4 from CO_2 enrichment but inverse is true with rising temperature. This

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differential response of C_3 and C_4 plants to elevated CO_2 and temperature can have important implications on crop/weed competition as most of the weeds are C_4. But this fundamental idea that most crops are C_3 and most weeds are C_4, and hence weed competition will consequently decrease as CO_2 increases, should not be viewed as universal axiom (Ziska 2001, 2003). Clearly, there are four major C_4 crops of economic importance (corn, pearl-millet, sorghum, and sugarcane), and many important C_3 weeds (e.g. *Chenopodium album, Avena ludoviciana, Phalaris minor, Eclipta prostrate, Ammania baccifera* etc.). Therefore, it is important to examine crop/weed competition case by case to develop effective weed management practice for the emerging species in the changing climate scenario. Climate change may bring changes in weed population and in their phenology. 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. Climate change may also likely have a direct or indirect impact on the chemical, mechanical and biological control methods by reducing their effectiveness on weeds. Very limited studies have examined the impact of climate change on weeds in India, therefore, the overall goal of this review paper is (1) to address the anticipatory changes in weed biology and dynamics with climate change in order to develop flexible integrated weed management practices which are based on a foundation of knowledge of weed biology and ecology and (2) to stimulate research interest in the area of climate change and weeds to predict possible impacts on weeds. Specifically, the paper aims to discuss the effects of climate change on 1) crop-weed competitive interaction under single (CO_2 or temperature) or multiple factors (e.g. CO_2 and temperature or CO_2); 2) invasiveness; and 3) weed management.

Impact of Climate Change on Agricultural Weeds

Effects of elevated CO_2 concentration

Direct physiological effects of elevated CO_2 on photosynthesis and plant growth have been well documented. Plants with C_3 photosynthetic pathways are expected to benefit more than C_4 from CO_2 enrichment (Patterson and Flint 1980). This differential response of C_3 and C_4 plants to elevated CO_2 can have important implications on crop/weed competition as most of the weeds are C_4. Therefore, it can be argued that because of C_4 photosynthetic pathway of many weed species, they will show smaller response to elevated CO_2 relative to crops which are mostly C_3. But in agricultural setting, weeds with both C_3 and C_4 photosynthetic pathways are present (Table 1). Hence, if a C_4 weed species is less responsive to elevated CO_2 concentration; it is likely that C_3 weed species present in the crop will respond more to elevated CO_2. Moreover, clearly, there are four major C_4 crops of economic importance (corn, pearl-millet, sorghum, and sugarcane). 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. Some of the examples of crop/weed competition with similar and different photosynthetic pathway have been discussed below under elevated CO_2 situation.

Table 1: Important C_3 and C_4 weed species of rice and wheat crops in India.

Crop	**C_3 weeds**	**C_4 weeds**
Rice	Weedy rice, *Scirpus* spp, *Monochoria*, *Eclipta prostrata*, *Ammania baccifera*	*Echinochloa* spp, *Cyperus* spp., *Leptochloa chinensis*, *Bracharia*
Wheat	*Chenopodium album*, *Phalaris minor*, *Avenafatua*, *Convolvulus arvensis, Canada thistle*	*Cynadon dactylon*

Impact on crop/weed competition of C_3 crop (rice) versus C_3 weed (red rice)

This study was conducted in the U. S. by Ziska *et al.,* (2010). They 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 (Figure 1). Red rice responded linearly in terms of biomass as well as seed production. These results suggest that under elevated CO_2 concentrations, red rice will be more competitive than rice crop and will produce more seed than at current CO_2 concentration.

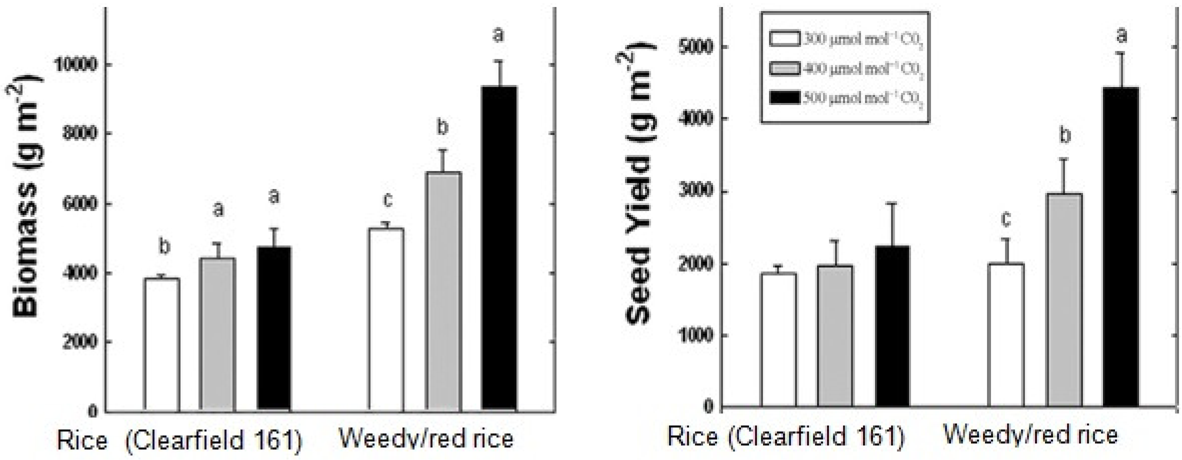

Figure 1. Biomass and seed yield of rice (C_3 crop) and red rice (C_3 weed) under elevated CO_2 conditions (Source: Ziska et al., 2010).

Impact on crop/weed competition of C_3 crop (soybean) versus C_3 (*Chenopodium album*) and C_4 (*Amaranthusretroflexus*) weed species

This study was also conducted in the U. S. by Ziska (2000). He found that soybean biomass (32%) and yield (23%) increased at elevated CO_2 (ambient + 250 ppm) when grown in monoculture (Figure 2). But when soybean was grown in competition with *Chenopodium album* (C_3) weed, soybean biomass and yield reduction increased from 23% and 28% at ambient CO_2 to 34 and 39% at elevated CO_2, respectively due to 65% increase in *C. album* dry weight. Conversely, soybean yield diminished from 45% to 30% at elevated CO_2 compared to ambient CO_2 when grown in competition with *A. retroflexus*. These results suggest that under elevated CO_2, *C. album* would be benefited more than soybean and could become more dominating weed. In contrast, *A. retroflexus* would be less benefitted with rising CO_2 and soybean will likely have competitive advantage when grown in competition with this species.

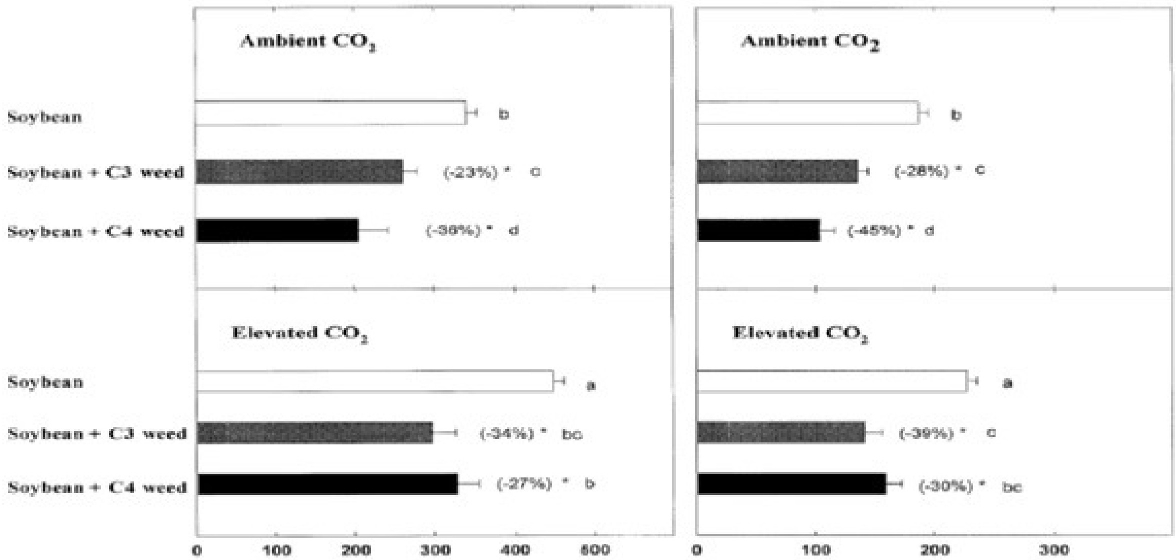

Figure 2. Soybean biomass and yield at ambient and elevated CO_2 when grown in monoculture and in competition with C_3 (*Chenopodium album*) and C_4 weed (*Amaranthus retrofluxus*). (Ziska, 2000).

In general, under elevated CO_2, it is likely that only when weed is C_4 and crop is C_3, crop is likely benefitted, whereas in all other cases weeds will likely get competitive advantage over crop (Table 2).

Table2. Crop/weed competition outcome at elevated CO_2 conditions (Modified from Bunce, and Ziska, 2000)

Weed species	Crop	Favored under elevated CO2	References
Amaranthus retroflexus (C_4)	Soybean (C_3)	Crop	(Ziska, 2000)
Amaranthus retroflexus (C_4)	Sorghum (C_4)	Weed	(Ziska, 2003)
Chenopodium album (C_3)	Soybean(C_3)	Weed	(Ziska, 2000)
Taraxacum officinale (C_3)	Lucern (C_3)	Weed	(Bunce, 1995)
Albutilon theophrasti (C_3)	Sorghum (C_4)	Weed	(Ziska, 2003)
Taraxacum and Plantago (C_3)	Grasses (C_3)	Weed	(Potvin and Vasseur, 1997)
Red rice (C_3)	Rice (C_3)	Weed	(Ziska *et al.,* 2010)
Echinochloa glabrescens (C_4)	Rice (C_3)	Weed	(Alberto *et al.,* 1996)

Effects of elevated temperature on crop and weeds

The general assumption is that rising temperature will give competitive advantage to C_4 plants than to C_3 plants. In a study the crop (soybean) was more adversely affected by rising temperature than prickly sida (*Sida spinosa*) and sicklepod (*Senna obtusifolia),* two weed species (Figure 3).

Effects of both elevated CO_2 and elevated temperature on crop weed competition

Despite prediction that both atmospheric CO_2 and air temperature will rise together, very limited studies have been conducted to assess the possible interaction effects of these two global change factors on weeds and crop/weed competition. Most studies have focused mainly on the response of plant species to elevated CO_2. The outcome can be totally different when both factors are taken together compared to when consider only one factor. For example, in a study conducted by Alberto *et al.* (1996), rice had competitive advantage over C_4 weed (*Echinochloa glabrescens*) when considered elevated CO_2 only, whereas when considered both elevated CO_2 and elevated temperature, C_4 weed (*E. glabrescens*) had competitive advantage over rice crop. Therefore, more studies of interacting effects of elevated CO_2 and temperature are needed to help predict how weed problems may change in future.

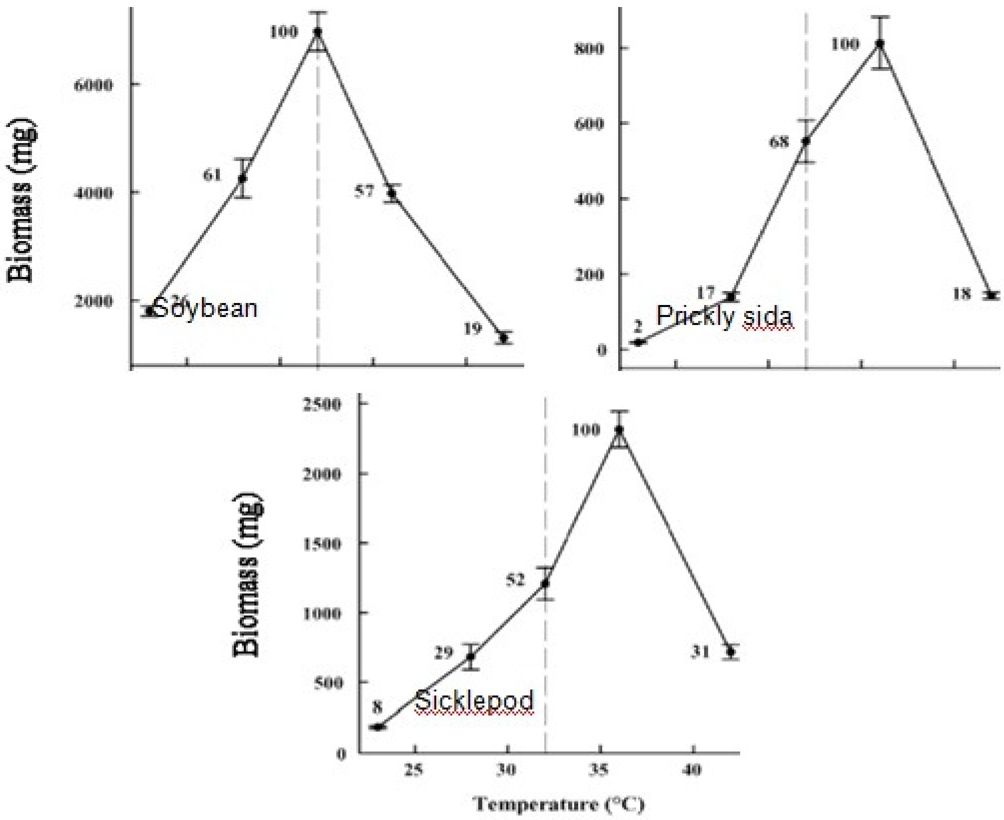

Figure 3. Effects of elevated temperature on crop and weed species (Source Tungate *et al.*, 2007).

Shift in weed population

It is likely that dominant weed species in a given crop may change with change in climate.C_3 weed may dominate under elevated CO_2 conditions, whereas, under both elevated CO_2 and temperature C_4 may dominate. Climate change may bring changes in weed phenology and biology which can further lead to shift in weed flora. Many weed species may expand their range and spread to new areas. It is therefore, important to predict changes in weed flora with climate to develop adaptive management practice.

Impact of climate change on invasive weeds

Intentionally or unintensionally, human have moved many weed species outside of their native ranges to new area where some of these non-native species have become invasive often with detrimental effects on native species and managed ecosystems (Mack *et al*., 2000; Wilcove, 1998). It is predicted that changing climate (rising CO_2 and temperature, and altered precipitation) will alter the impacts of these invasive plants on native and managed ecosystems (Hellmann *et al*., 2008; Dukes, 2000). Most of these climate change factor may likely increase the risks of invasion (Bradley *et al.,* 2010). This is mainly because (1) invasive species are generally well suited to novel environment which is created by climate change, and (2) invasive plants are more successful in environment with high resource availability provided by elevated CO_2. However, recent studies highlighted that it is very difficult to predict the impact of climate change on invasiveness. It is because, in one hand, changes in temperature and precipitation creating novel environment which could benefit invasive species. But on the other hand, they do not consistently increase resource availability, especially elevated temperature and altered precipitation (Bradley *et al.* 2010). Published results have shown both increased and decreased invasion risks associated with climate change (Table 3). It is therefore, critical to assess the response of invasive plants to multiple simultaneous climate change factors (e.g. CO_2, temperature and precipitation) to predict the risks of invasiveness.

Table 3. Likely impact of climate change on risks of invasiveness.
(Source: 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

Impact of climate change on current weed management practices

It is predicted that climate change can reduce the effectiveness of current weed management practices (Ziska *et al*., 1999). Chemical control is the most common form of weed control. Changes in temperature, wind speed, soil moisture and humidity can influence the efficacy of herbicides. For example, drought can lead to thick cuticle development which in turn can reduce the herbicide entry in the plant. Ziska *et al*. (1999 and 2004) also found that rising atmospheric CO_2 concentrations can reduce the glyphosate efficacy. Mechanical control of perennial weeds is also likely be adversely affected by elevated CO_2 conditions. For example, the greater amount of root growth observed at elevated CO_2 in Canada thistle, meaning more asexual propogules (Figure 4). Since Canada thistle propogate asexually, hence, disking/harrowing would result in greater weed infestations. Hence, tillage practices may have to adapt accordingly. However, we have almost no data on mechanical control as a function of rising carbon dioxide levels.

Similarly, climate change could alter the efficacy of weed bio-control agent by affecting the development, morphology, and reproduction of target bio-agent. Overall, it is clear that changing climate or rising CO_2 will likely alter weed management.

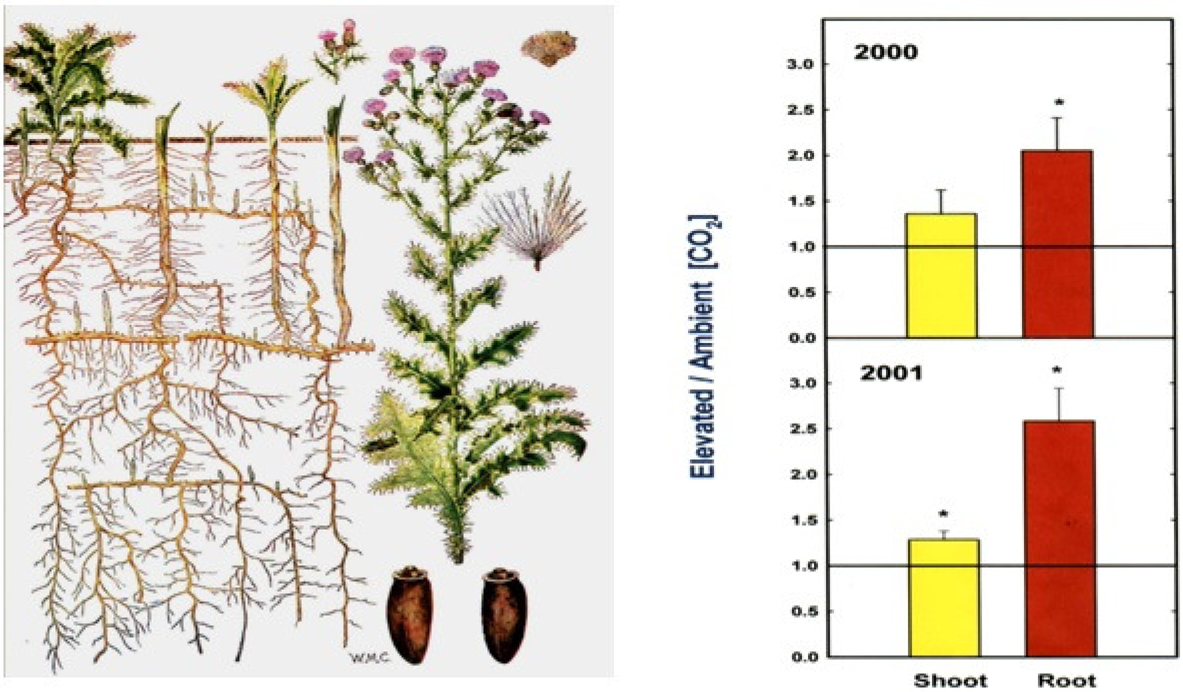

Figure 4. Shoot and root biomass at elevated CO_2 relative to ambient CO_2 (Source: Ziska *et al.,* 2004)

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