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Crop-weed interactions under climate change

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ABSTRACT

Weeds are major threat to agriculture and biodiversity as they out-compete crops and native species and contribute to land degradation. Changes in geographic distributions, abundances and life-cycles of weeds are the likely outcome of the effect of climate change. Natural evolution and certain specific characteristics such as short life cycles, dispersal mechanisms, may give the weeds a competitive advantage over less aggressive species under changing climate. Climate change may favour certain native plants to such an extent that they then become weeds. The dynamics of competition between weed and crop plants are affected by environmental conditions, and have been shown to change with atmospheric CO_2 concentration, temperature, precipitation and adaphic factors. Invasive weeds like *Lantana* and *Parthenium* may become more aggressive under climate change especially due to increases in atmospheric CO_2. Growth at elevated CO_2 would result in anatomical, morphological and physiological changes that could influence herbicidal uptake rates, besides translocation and overall effectiveness. The physiological plasticity of weeds and their greater intraspecific genetic variation compared with most crops could provide weeds with a competitive advantage in a changing environment. There is a possibility that agricultural weed populations will evolve new traits in response to emerging climate and non-climate selection pressures.

Key words: Climate change, CO_2 effect, Crop-weed interaction

Climate change projections suggest 2.4 to 6.4 ^{O}C increase of global average temperature by the end of 21st century (IPCC 2007). Studies indicate that significant warming is inevitable regardless of future emission reductions. If these forecasts are realized, crops and cropping systems are likely to experience significant changes and it is so for the associated weeds too. Weeds are major threat to agriculture and biodiversity as they out-compete crops and native species and contribute to land degradation. They reduce farm productivity through yield reduction and contaminate the crop produce. Research data strongly suggest that geographic range transformations for agricultural weeds are highly probable outcomes from global climate change (Patterson 1995, Fuhrer 2003). Climate change poses several challenges for managing weeds. Globally, there is a growing list of recent changes in species' distributions, abundances and life-cycles that are highly likely to be due to climate change.

Climate change means more extreme weather events, greater stress on native species, climate driven activities such as introduction of new species/crops. The increased extremes expected with the climate change, such as long drought periods and occasional very wet years, may worsen weed invasion because established vegetation (both native and crop) will be vulnerable, leaving areas for invasion. Weeds with high reproduction and efficient seed dispersal mechanisms may be better able to take advantage of the expected calamities like cyclones and floods. The characteristic of weeds to be able to respond rapidly to disturbances such as climate change, may give them a competitive advantage over less aggressive species. Agricultural adaptations to climate change, including new products and shifts into new areas, will also create more opportunities for weeds.

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Extreme events create conditions congenial for weeds to extend their range and invade new areas or out-compete native species in their existing range. Drought and dry soil conditions prolong the weed seed bank longevity. Under drought the competitiveness of native vegetations get reduced and new weeds get the opportunity to invade. Floods assist in spreading weeds to weed free areas; provide characteristics for new weed invasion by washing away the vegetation and exposing the areas of disturbed soil. Warmer temperatures will force some species to relocate, adapt or perish. Species that are active in summer will develop faster. Warmer climate restrict temperature sensitive species to high altitudes. In plain areas, this effect on distribution range is magnified because species without the ability to move to higher elevations must relocate further in the same altitude. Weeds with efficient dispersal mechanisms are better equipped to shift their range, while species with short life-cycles are better equipped to evolve, and increase their tolerance of warmer temperatures.

Weeds respond to climate change by changes in geographic distribution, changes in the timing/duration of life cycles, changes in the population dynamics, shift in natural habitats and changes in the ecosystem structure and composition (decline or extinction of some species and invasion by other species)

Weed invasion and climte change

Climate change is expected to increase the risk of invasion by weeds from neighboring territories. With the competitive ability, weeds often find an opportunity to establish new populations when natural or desirable plant species decline. Climate change may also favour expansion of range of weeds that have already established but are currently restricted in range. The range expansion can be attributed to evolutionary adaptation (Clements and Di Tommaso 2011 and 2012). Weeds which have higher spread and establishment potential have the potential to invade new areas and increase their range. Weeds that are well-suited to adapt to the impacts of climate change may not only fill gaps left by more vulnerable native plants, they may have an even greater effect by altering the composition of ecosystems and their integrity. In fact, climate change may favour certain native plants to such an extent that they then become weeds. Land management practices such as land clearing, habitat fragmentation and over grazing that clear native vegetation and degrade its condition adversely affect the biodiversity and favour weed invasion by providing opportunities for them to colonise new areas and by reducing the ability of native vegetation to compete with and suppress invading species.

Growth and development of weeds

Weeds have a greater genetic diversity than crops. Consequently if the availability of a resource changes within the environment, it is more likely that weeds will show a greater growth and reproductive response (Trumble 2013). Number of studies showed that the rise in CO_2 induces growth stimulation without any discrimination between desirable (crops) and undesirable (weeds) plants. C_3 weeds (using one of two types of photosynthetic pathway, which responds to higher levels of CO_2 such as *Parthenium hysterophorus* may grow more rapidly under higher carbon dioxide levels and become more competitive (Poorter and Navas 2003 2008 McFadyen, Naidu and Paroha 2008,). CO_2 can affect plant and leaf size, seed size and production, the nutritive value of leaves to herbivores, plant toxicity and pollen production. Due to changing climate, changes in timing of life-cycles are expected that will affect flowering, fruiting and reproduction as the flowering is the most thermal sensitive stage of plant growth (Boote *et al.* 2005). Flowering can be faster, slower or unchanged at elevated CO_2, depending on species. From the studies conducted in OTCs at Directorate of Weed Science Research, Jabalpur, India, it was observed that under elevated $CO_{2,}$ wild oat (*Avena fatua*), seeds matured two weeks in advance compared to the plants grown under ambient CO_2 conditions (Naidu 2011).

Crop-weed competition: effect of CO_2, temperature and moisture stress

Changes in temperature, precipitation and increasing CO_2, all have potentially important consequences for crop/weed interactions, which is evident from a consideration of the basic biology of weeds and crops. Effects of climate change on crop-weed interactions are likely to vary by region and crop. These affects can be assessed by understanding the response of the physiological mechanisms to such factors. The dynamics of competition between weed and crop plants are affected by environmental conditions, and have been shown to change with CO_2 enrichment (Patterson and Flint 1980).

If the high CO_2 fixation rates are coupled with characters such as stoloniferous or rhizomatous spreading roots or the production of many easily disseminated seeds, the result is likely to be a very competitive plant. It was reported that the efficient species become relatively more competitive as light intensity increases. In addition, these species have high optimum temperature for photosynthesis and thus would become more competitive as temperature increases from 20 ^{0}C to 30 ^{0}C or 40 ^{0}C. At mid-day when light intensity and temperature both reach peak values weeds such as *Amaranthus* spp (C_4) and Johnson grass (*Sorghum halepense*, C_4) are expected to fix CO_2 at higher rate than the crops like soybean (C_3) and cotton (C_3). As high temperatures would also create increased evaporative demand, with its high water use efficiency and CO_2 compensation point C_4 photosynthesis is better adapted to high evaporative demand (Bunce 1983).

Some studies have shown that low or high temperatures reduce or eliminate the high CO_2 growth enhancement (Hofstra and Hesketh 1975, Idso 1990, Coleman and Bazzaz 1992), whereas others have shown that CO_2 enrichment may increase the plant tolerance to temperature extremes (Sionit *et al.* 1981, Potvin 1985, Baker *et al.* 1989). Based on the differences in temperature optima for physiological processes it is predicted that C_4 spp. will be able to tolerate high temperatures than C_3 spp. Therefore, C_4 weeds may benefit more than the C_3 crops from any temperature increases that accompany elevated CO_2 levels. Data from the results of the experiments by Alberto *et al.* (1996) suggest that competitiveness could be enhanced in C_3 crop (rice) relative to a C_4 weed (*Echinochloa glabrescens*) with elevated CO_2 alone but simultaneous increases in CO_2 and temperature still favor C_4 spp. An increase in temperature with accompanying soil moisture stress will offset the positive effect of the CO_2 fertilization; the net effect depends on the level of moisture stress. Increased temperatures have the potential to result in more invasive species introductions through expanded habitat range and greater potential for destructive outbreaks (Butler and Trumble 2012, Trumble 2013).

The interaction between CO_2 enrichment and other environmental factors such as water and nutrient availability and temperature may also result in differential response to CO_2 enrichment among weeds and crops (Patterson and Flint 1982, Bazzaz and Carlson 1984). The CO_2 enrichment tends to reduce the deleterious effects of drought (Sionit and Patterson 1985, Trumble 2013). Even under water limited conditions, growth enhancement by CO_2 appears to be greater in C_3 crops than C_4 weeds if the temperature increase is not as dramatic as predicted (Patterson 1986). Deep-rooted, woody plants and legumes are likely to have an advantage over grasses at higher CO_2 levels due to their ability to tap deep water reserves while still competing with grasses for moisture in the shallow soil layers.

Spread of invasive weeds and wake up of sleeper weeds

Invasive weeds are usually non-native, whose introduction results in wide-spread economic or environmental consequences (e.g. *Lantana camara* in India). Many of these weeds have strong reproductive capability. In many cases the impacts of invasive species beneûting from climate change are likely to exceed the direct impacts of climate change.

Invasive species generally benefit from habitat disturbances because they have characteristics that are likely to make them benefit from climate change. Recent evidence indicates that invasive weeds may show a strong response to recent increases in atmospheric CO_2 (Ziska and George 2004). Spread of invasive weed *Parthenium hysterophorus* was reported to be due to its response to climate change especially elevated CO_2 (Naidu 2013). Many invasive weeds are opportunistic breeders with wide climatic tolerance, whereas native communities may be more susceptible to climatic stress, making them vulnerable to invasion. Also, some native species may become invasive where other anthropogenic influences also favour them. Responses to climate change will be specific to individual species and will depend on a range of interacting factors. For example,the potential distribution of *Lantana* under historical climate exceeded the current distribution in some areas of the world, notably Africa and Asia. Under future scenarios, the climatically suitable areas for *L. camara* globally were projected to contract (Taylor *et al.* 2012).

Climate change, as well as the interactions between climate change and other processes (such as land management and new crop/cultivar introductions), may also turn some currently benign species (both native and non-native) into invasive species and may lead to sleeper weeds becoming more actively weedy. Increasing temperature might also allow some sleeper weeds to become invasive. Huge environmental damage and control cost can be prevented if these weeds are eradicated before they become widespread.

Indirect effects of climate change on weed menace

Higher temperatures and other factors are likely to increase pollinators, (insects) breeding cycles and provide more weed pollination there by increase the weed population. As animals, including invasive species, move into new areas in response to climate change, they are likely to spread weeds or create disturbance advantageous for weeds. Climate change will render native species more vulnerable to weeds either directly or indirectly, for example by facilitating the spread of the serious plant diseases. Importing of fodder and grain into drought prone areas can bring new weed problems to the region.

Climate change: challenge to weed management

Tillage is regarded as a global method of weed control in agronomic systems. Elevated CO_2 commonly stimulate the growth of roots and rhizomes more than that of shoots. Increased below ground growth in such species may make manual removal a difficult task as CO_2 rises. Growth at elevated CO_2 would result in anatomical, morphological and physiological changes that could influence herbicidal uptake rates, besides translocation and overall effectiveness. Climate change especially elevated CO_2 reduce the efficacy of foliar applied herbicides. The reasons for the reduced efficacy of the herbicides might be that increasing CO_2 can increase leaf thickness and reduce stomatal number and conductance possibly limiting the uptake of foliar applied herbicides. Greater increases in biomass could result in dilution of applied herbicide and thereby reducing its efficacy (Patterson 1995). If the growth of the weeds is stimulated by the future levels of atmospheric CO_2, the efficacy of the post-emergence herbicides would be reduced because the time spent by the weeds in seedling stage *i.e.* the stage of greatest herbicide sensitivity would be shortened (Ziska *et al.* 1999). At this situation, further applications or additional concentrations of the herbicides may be needed to control such weeds but add to the cost of control. Drought-stressed weeds are more difficult to control with post-emergent herbicides than plants that are actively benefitting. For example, systemic herbicides that are translocated within the weed need active plant growth to be effective. Pre-emergence herbicides or herbicides absorbed by plant roots need soil moisture and actively growing roots to reach their target species.

Natural and manipulated biological control of weeds and other potential pests could be affected by increasing atmospheric CO_2 and climate change. Climate changes could alter the efficacy of the biocontrol agent by changing the growth, development and reproduction of the selected weedy target. Elevated CO_2 and temperature directly alter morphology and reproduction of weeds. Change in C: N ratio may alter the feeding habits and growth rate of herbivores. Direct effects of CO_2 on increasing starch concentration in leaves and lowering nitrogen contents could also affect the biocontrol by altering the behavior and growth rate of herbivores.

Conclusions

Ecological systems are complex, with many factors being influenced by changing climate and land management practices. Weeds are both impacting on and being impacted on by factors such as land clearing, drought, fire and climate change. Many factors other than climate substantially influence actual species distributions including competitive exclusion, dispersal limitations, and patterns of disturbance. The physiological plasticity of weeds and their greater intraspecific genetic variation compared with most crops could provide weeds with a competitive advantage in a changing environment. Agronomic practices for particular crops are not static in time and space; new classes of herbicides, cultivars, tillage innovations, use of irrigation, and seed cleaning practices can all influence the geographic distribution and crop damage caused by agricultural weeds. For example recent introduction of glyphosate resistant crops can significantly change weed community composition (Harker *et al.* 2005). There is a possibility that agricultural weed populations will evolve new traits in response to emerging climate and non-climate selection pressures. (Clements *et al.* 2004). Reducing the impacts of weeds and preventing new weeds are essential to increasing the resilience of ecosystems and giving native species the best chance to deal with the adverse impacts of climate change. If weed species can be identified as favored due to emergent climate conditions in a given region, expanding or newly introduced populations can be targeted for control before they become well established.

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