

## Weed regimes in agro-ecosystems in the changing climate scenario—A review

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### ABSTRACT

Changes in temperature, and the amount, intensity, frequency, and distribution of rainfall, collectively known as climate change, can have beneficial or adverse effects on weeds interfering with agriculture. Implicit in discussion of weed management and climate change is the assumption that we know what to do in relation to soil and crop management, but these strategies might not apply to the unexpected future climate change conditions, particularly weed menace. There is confusion in interpreting weed management for the weather fluctuation in a region, as there is a clear-cut distinction between climate change and climate variability. Soil warming could enhance the availability of certain elements in the soil by faster ion-diffusion rate and the soil-moisture stress could boom weed proliferation. Judicious agronomic practices would partially help to offset weed pressure, but climate may have over-riding influence on weeds, as they share the same trophic level with crops. Implications of climate change would be identical with crops, aggravating the crop-weed competition. Many of the most troublesome weeds in crop ecosystems follow C<sub>4</sub> pathway. As atmospheric CO<sub>2</sub> increases, it is conceivable that competitive ability of weeds could be similar to C<sub>3</sub> crops, such as rice, if there is no dearth of soil moisture and nutrients. From a weed-management perspective, C<sub>4</sub> weeds would flourish under the increased temperature scenario and pose serious yield limitation. It is speculated that reduced water availability due to recurrent/unforeseen droughts would alter the competitive balance between crops and some weed species, intensifying the crop-weed competition pressure. Research conducted indicated that a rise in temperature would benefit C<sub>4</sub> weeds but not the rising CO<sub>2</sub> levels.

**Key word:** Agro-ecosystem, Climate change, Herbicide efficacy, New weed ecology

Uncertainty in agricultural productivity under-climate change scenario can be the result of plant-plant interactions through direct effects of a change in temperature, atmospheric CO<sub>2</sub> etc. or indirect effects at the system level, through shifts in crop-weed interactions (Fuhrer, 2003) and other biotic stresses. Understanding the key dynamics that characterize the interactions of elevated CO<sub>2</sub> with changes in climate variables, with ecosystem remained a priority for quantifying the impacts of climate change on agriculture, particularly weed-management regimes. The quantitative knowledge of nutrient inputs and crop-weed interactions with shifts in climate variables is still unclear (Tubiello *et al.*, 2007) although a few FACE (free air CO<sub>2</sub> enrichment) experiments have been conducted in this regard.

The atmospheric CO<sub>2</sub> concentration is expected to

nearly double to 700 ppm by the turn of the 21<sup>st</sup> century (Houghton *et al.*, 2001) from 280 ppm in 1800. As per our current understanding, vegetation dynamics will be influenced by this change of CO<sub>2</sub> concentration irrespective of whether it is a crop or weed, besides an enhancement in tissue C/N (Kimball *et al.*, 2002). FACE experiments conducted elsewhere in the world indicated that species identity and resource availability were important factors influencing the response of human-engineered agro-ecosystems where crop-weed interactions assume significance to elevated CO<sub>2</sub> (Nowak *et al.*, 2004) as well as temperature.

### *Nutrient cycling in soils and availability to weed-plant complexes*

A comprehensive literature search indicated a change in the functioning and population of soil microbes under elevated temperature and CO<sub>2</sub> conditions as soil microbial diversity dictates the nutrient cycling in the soil-plant system. Although the elevated CO<sub>2</sub> does not directly affect the microbial community, it indirectly influences through the return of vegetation biomass quality and quantity to the soil (Patra *et al.*, 2012).

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A shift in precipitation and air temperature could amplify rhizospheric temperature due to moisture deficit (Kang *et al.*, 2000). On the nitrogen (N) front, increased CO<sub>2</sub> may not directly affect N mineralization *per se* but associated warming (Pendall *et al.*, 2004) could lead to increased solution-phase N, benefitting more to weeds due to temporal advantage in their establishment. A combination of CO<sub>2</sub> and high temperature would enhance carbon supply to below-ground plant parts (Kant *et al.*, 2007), apparently, enhancement in respiration to influence nutrient cycling through faster mineralization of resident soil organic N. While accepting the soil-warming effect on increasing N mineralization, Zhou *et al.* (2011) contradicted the enhancement in C allocation on the below-ground plant parts. Whatsoever be the findings, a change in CO<sub>2</sub> alone could alter ecosystem level nutrient cycling processes (Rakshit *et al.*, 2012). Nutrient availability in the soil has a direct bearing on the crop-weed competitive ability, as weeds always emerge earlier than crops.

#### Enhanced atmospheric temperature

A slight increase in transpiration between 10 and 40°C, but with a constant dark respiration rate was observed by Doley (1977) in Congress weed (*Parthenium hysterophorus* L.). Seeds of *parthenium* weed could germinate at temperature as high as 36°C (Williams and Groves, 1980). Jain (1993) observed that the plants remain in flowering stage throughout the year in Gwalior Madhya Pradesh, except during summer. As it possesses excellent drought-tolerance (Chamberlain and Gittens, 2004), this weed could pose a serious limitation to crop plants under water-scarce conditions. Further, recent evidences (Nguyen *et al.*, 2011) too confirmed that warm conditions promote its reproductive ability, including enhanced dormancy and seed longevity. Germination peaked at 25/20°C in tall waterhemp or roughfruit amaranth (*Amaranthus tuberculatus* L.) and at 35/30°C in redroot amaranth (*Amaranthus retroflexus* L.) and palmer amaranth (*Amaranthus palmeri* L.), but declined above 35/30°C (Guo and Al-Khatib, 2003). The germination rates of summer annuals [prostrate pigweed: *Amaranthus albus* L., palmer amaranth *A. palmeri* L., hairy crabgrass: *Digitaria sanguinalis* (L.) Scop., barnyard grass: *Echinochloa crus-galli* (L.) P. Beauv., common purslane: *Portulaca oleracea* L., and yellow foxtail: *Setaria glauca* (L.) Beauv.], winter annuals (short pod mustard: *Hirschfeldia incana* (L.) Lagr. - Foss. and common sowthistle: *Sonchus oleraceus* L.), and Canadian horseweed: *Conyza canadensis* (L.) Cronquist (summer or winter annual) increased linearly with increased temperatures between 15°C and 30°C (Steinmaus *et al.*, 2000), indicating that these weed species could potentially

compete with crop plants in the altered temperature scenario.

#### Enhanced atmospheric CO<sub>2</sub> concentration

Doubling CO<sub>2</sub> decreased the transpiration by 23% (Cure and Cock, 1986), irrespective of the pathway of C fixation in plants, but the response was soil-moisture dependent. There is evidence that this could preferentially select for invasive, noxious plant species (Ziska and George, 2004) favouring the growth of agronomic weeds (Ziska and Goins, 2006). Plants of *parthenium hysterophorus* grew significantly taller (52%) and produced more biomass (55%) at enhanced atmospheric CO<sub>2</sub> concentration (550 µmol/mol) than ambient concentration of 380 µmol/mol, besides higher water-use efficiency under enhanced CO<sub>2</sub> conditions (Shabbir *et al.*, 2014). This indicated that *P. hysterophorus* weed would be a noxious pest under the climate-change scenario.

It is risky to predict which species will 'win' and 'lose' in high CO<sub>2</sub> conditions on the basis of their photosynthetic pathway or their CO<sub>2</sub> response in the absence of other species (Dukes and Mooney, 1999). Dormancy cycles observed in some species are known to be regulated mainly by soil temperature in temperate environments where water is not seasonally restricted (Batlla *et al.*, 2004), irrespective of their CO<sub>2</sub> response. High temperatures during summer could result in dormancy relief, and low temperatures during winter can induce secondary dormancy. This behaviour of weeds might pose serious limitations in farming in the future.

Ziska (2003) pointed out the possibility of an increase in atmospheric CO<sub>2</sub> during the 20<sup>th</sup> century might have been a factor in the selection of Canada thistle (*Cirsium arvense* L.), field bindweed (*Convolvulus arvensis* L.), leafy spurge (*Euphorbia esula* L.), perennial sowthistle (*Sonchus arvensis* L.), spotted knapweed (*Centaurea maculosa* Lam.), and yellow star thistle (*Centaurea solstitialis* L.) in cropped fields. However, a number of significant impacts associated with temperature and CO<sub>2</sub>, the interaction between these abiotic parameters, invasive biology and agricultural productivity remains inadequately characterized (Ziska *et al.*, 2011). Besides other weeds, weedy rice may become a more problematic weed in the future in India (Chauhan *et al.*, 2014) due to climate change and additional management inputs might be necessary.

#### Combined effect of CO<sub>2</sub> and temperature on weed proliferation

It is reported from the response of C<sub>4</sub> plants like barnyard grass grown under 2 thermo periods (28/22°C and 21/15°C) and 2 atmospheric CO<sub>2</sub> concentrations (350 and 675

microliters per litre) that CO<sub>2</sub> enrichment induced a decrease in the size of the export pool. Low temperature reduced translocation at the normal CO<sub>2</sub> concentration, but reversed at high CO<sub>2</sub> (Potvin *et al.*, 1984). However, the response was species dependent. Another species of barnyard grass (*Echinochloa glabrescens* Munro ex Hook. F.) did not respond to an increase in CO<sub>2</sub> concentration (393 and 594 µL/L) at 27/21°C and 37/29°C (Alberto *et al.*, 1996). The opinions of Rosenzweig and Hillel (1998) that rising temperature and CO<sub>2</sub> levels could make crop plants less competitive with weeds, and a decade later by Wolfe (2008) that weeds would benefit more than cash crops, was found to be true, as *Amaranthus retroflexus* produced more seeds under barley cropping; albeit growth of barley as well as the weed was reduced (Hyvonen, 2011) at southern Finland. Certainly, *A. retroflexus* seed production would be proportional to an increase in temperature. Thus, under high temperature scenarios, the competitive ability of barley to compete with *A. retroflexus* was found to be lessened. The reverse may also hold well with a reduction in weed abundance as a result of climatic change.

#### *New weed ecology and complexes*

The changing climate variables may either increase the distribution range of weed species in response to a change in atmospheric temperature or allow some non-potent weeds to dominate weed abundance as crop-weed interactions may increasingly favour C<sub>3</sub> weeds (Bazzaz *et al.*, 1985). Climate change may introduce new weed species complexes as Martinez-Ghersa *et al.* (2000) opined that many weed populations arise as a result of the evolution of wild-plant colonizers through selection and adaptation to continuous habitat disturbances and pose a multitude of challenges for managing invasive weed species (Kriticos *et al.*, 2003) in the human-engineered crop ecosystem.

Climate change causes extinctions and alters species distributions of flora and fauna, and exerts inescapable impacts on various antagonistic and mutualistic interactions among species (Tylianakis *et al.*, 2008) on the Earth, and weeds are no exceptions. These unwanted plant species, in cultivated and uncultivated fields exhibit a significant threat to the biodiversity of crop-production systems, which interfere with the biodiversity of cultivated crop ecosystems. However, very little attention has been paid to the imbalance created to biodiversity by those plants in a rapidly changing climate (Crossman *et al.*, 2011). Those weed species that inhabit either disturbed habitats (Cray *et al.*, 2013), i.e. agricultural or undisturbed habitats, are characterized by self-sown behaviour with exorbitant growth; multiple resistance to biotic and environmental stresses; high reproductive capacity, multiple dispersal and survival mechanisms; ability to survive under wide envi-

ronmental conditions and/or several competitive strategies pose serious limitations to crop production.

Patterson (1995) predicted that climate change would certainly broaden the arable weed species, for example, Jimsonweed (*Datura stramonium* L.), a potential weed in maize, which needs high temperature for profuse growth (Cavero, 1999) would become a competitive candidate under the climate-change regimes, while warm temperature regimes augmented the abundance of orange hawkweed (*Hieracium aurantiacum* L.) in Australia (Brinkley and Bomford, 2002) through accelerated growth, reproduction, and multiplication.

A damage-niche concept was introduced by McDonald *et al.* (2009) to refer to the suite of factors under which specific weed species are judged problematic to the production of crops, stating that both precipitation and temperature are likely to define the boundaries of the damage niche for common lambsquarters (*Chenopodium album* L.), a summer-annual weed in maize. Obviously, it was not a major competitor to maize under the warmer conditions of the Southern U.S.

#### *Carbon accumulation pathway in weeds*

C<sub>4</sub> photosynthesis has to be considered one of the most convergent of the complex evolutionary phenomena on planet earth (Sage *et al.*, 2011) and most of the world's worst weeds follow this pathway. *Parthenium hysterophorus* exhibited the C<sub>3</sub>-C<sub>4</sub> intermediate photosynthetic pathway (Moore *et al.*, 1987), indicating the widest adaptation to changed climate regimes. Portulacaceae (purslane) family has several agriculturally important weed species with a remarkable diversity in photosynthetic pathways, viz. the C<sub>4</sub> (nicotinamide adenine dinucleotide phosphate - malic enzyme (NADP-ME) and NAD-ME types), C<sub>3</sub>, and C<sub>3</sub>-C<sub>4</sub> intermediacy with different leaf anatomical configurations (Ocampo *et al.*, 2013). *Portulaca oleracea* is a mat-forming summer annual that thrives well in all soil types. C<sub>4</sub> photosynthesis is nature's most efficient answer followed in the genus *Flaveria* (Schulze *et al.*, 2013). In the weedy species (Asteraceae family) of this genus, yellowtops (*Flaveria pubescens* Rydb.), C<sub>2</sub> photosynthesis was found to generate 3-fold elevated leaf CO<sub>2</sub> levels in the C<sub>3</sub>-C<sub>4</sub> intermediate species (Keerberg *et al.*, 2014), which is a concern in the climate-change scenario, as they would become potential competitor to crop plants.

#### *Herbicide efficacy*

It is well known that environmental conditions have a perceptible influence on herbicide efficacy, particularly foliage-applied herbicides (Kudsk and Kristensen, 1992). As early in 1970s, rapid volatilization of surface-applied

á-chloroacetanilide herbicides, viz. alachlor, butachlor, and propachlor, occurred from continuously moist soils exposed to a constant 21°C (Beestman and Deming, 1974), while temperatures (day/night 32/22°C and 26/16°C) were not as critical as that of relative humidity in influencing diphenylether group: Acifluorfen phytotoxicity (Ritter and Coble, 1981) on common cocklebur (*Xanthium strumarium* L.) and common ragweed (*Ambrosia artemisiifolia* L.). However, temperature had a significant effect on the degradation of imazapyr (imidazolinone group), flumetsulam (sulfonanilide family), and thifensulfuron (sulfonylurea group) in soil (Mcdowell *et al.*, 1997).

Environmental temperature is a critical factor in the growth, development and succession of all organisms in the Earth. As herbicides have to be applied on these organisms, temperature or relative humidity has a definite role in the absorption process. Glyphosate (Sharma and Singh, 2001) absorption is one such example on Florida beggarweed [*Desmodium tortuosum* (Sw.) DC], a C<sub>3</sub> weed since warm sunny days were ideal for enhanced efficacy. An increase in temperature or relative humidity increased the efficacy of mesotrione on common cocklebur and velvetleaf up to three-fold (Johnson and Young, 2002). Efficacy of the herbicide pyriithiobac (pyrimidinylthiobenzoic acid group) on palmer amaranth (*A. palmeri* L.) was found to be reduced at temperatures outside 20–34°C (Mahan *et al.*, 2004). Anderson *et al.* (1993) found that relative humidity had the most significant effect on the phytotoxic action of glufosinate-ammonium, since this is attributed to changes in cuticle hydration and droplet drying (Ramsey *et al.*, 2005). Studies carried out under controlled environmental chambers in Australia under varying night/day temperatures of 5/10, 15/20, and 20/25°C showed that wild radish (*Raphanus raphanistrum* L.) grown under cooler temperatures of 5/10°C was poorly controlled with 1,200 g ai/ha glufosinate, whereas 100% mortality was achieved under 15/20 and 20/25°C for the same dose (Kumaratilake and Preston, 2005), indicating the enhanced efficacy of glufosinate under enhanced atmospheric temperature. In short, weed management operations, either chemical or mechanical, could be influenced by climate change (Chauhan *et al.*, 2014).

Impact of climate change on weed regimes is an important subject of discussion in scientific fora for formulating suitable package of practices for optimum production from unit lands. Climate changes may also necessitate the adaptation of agronomic practices, which in turn influence weed growth. As the crop and weed share the same trophic level, the stimulatory or inhibitory behaviour of the climate variables will hold good for weeds too. An increase in atmospheric temperature was found to favour weed

growth as well as herbicide efficacy. Although there is a dominance of C<sub>4</sub> weeds in agriculture, C<sub>3</sub> and C<sub>3</sub>–C<sub>4</sub> intermediate pathways of prominent weeds would pose severe crop-weed competition as a challenge in the years to come. Many more adaptive research studies in addition to FACE research could provide solutions for managing unexpected crop failures in the ensuing decades.

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