

Review Article

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## Climate Change's Impacts on Weeds and Herbicide Efficacy: A Review

Amit Kumar\* and Mukesh Kumar

Department of Agronomy, CCS Haryana Agricultural University, Hisar-125004, Haryana, India

\*Corresponding author

### A B S T R A C T

Climate change is a natural and continuous process. But recent relatively rapid change in climate occurs due to anthropogenic activities which makes alarming attention because it contributes largely to global warming by affecting the greenhouse gases (GHGs) and aerosols. GHGs mainly CO<sub>2</sub>, methane, nitrous oxide CFC11, CFC12, HCFC22 and HFC23 with different global warming potential accumulate in atmosphere and increase in concentration over time creating the so called "greenhouse effect". This effect can alter balance by transmitting incoming solar radiation but absorbing outgoing thermal radiation from surface. Atmospheric CO<sub>2</sub> rose from 280 to 387  $\mu\text{mol mol}^{-1}$  from 1750 to 2007 and expected to reach 600  $\mu\text{mol mol}^{-1}$  by 2050 and 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<sub>2</sub> concentration. Weeds are complex in nature and have significant negative effect on agriculture. Chemical weed control becomes major choice/tool because of its economic, easy to use, greater efficacy, due to scarcity of labour and time saving. Climate component *viz.*, light, CO<sub>2</sub>, temperature, precipitation, humidity, wind, environmental stress etc. affect crop-weed competition and efficacy of applied herbicides. Light stimulates weed seed development and leaf shape. Light is the source of energy for photosynthesis and the rate of photosynthesis determines the rate of phloem translocation of assimilates and subsequent phloem translocation will increase the movement of foliar-applied systemic herbicides. Most crops are C<sub>3</sub> and most weeds are C<sub>4</sub>, and hence weed competition will consequently decrease as CO<sub>2</sub> increases, should not be viewed as universal axiom as there are four major C<sub>4</sub> crops of economic importance (corn, pearl millet, sorghum, and sugarcane), and their many important C<sub>3</sub> weeds. Increasing CO<sub>2</sub> concentration increases the starch concentration in tissue and reduces the protein content leads to less demand of amino acids synthesis which alters the efficacy of ALS inhibitors herbicides. High temperature shortens the growth phases, stimulate stomata conductance and lowers the viscosity of cuticular lipids leads to increase permeability and diffusion of herbicides through the cuticle. Warmer temperature also reduce uptake of herbicides due to rapid drying of droplets. Increasing temperatures may mean an expansion of weeds into higher latitudes or higher altitudes. Increased cuticle thickness and leaf pubescence in response to drought, will also reduce herbicide entry into leaves. At higher humidity leaf retention time of herbicides mainly hydrophilic increases. Blowing wind may cause spray drift or dry up the spray droplet. So there is need to pay special attention and to study the impact of climate factors on weed life, crop-weed competition and herbicide efficacy so that adaptation and mitigation strategies can be developed for changing climate.

### Keywords

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## Introduction

Climate change is continuous process; in past it occurred over hundred or thousand s of years. But recent changes in climate make alarming attention because of its shift occurs only in a few decades. Climate change occurs due to natural and human activities. Anthropogenic activities contribute largely to global warming by affecting the amounts of greenhouse gases (GHGs) and aerosols (small particles). These emissions accumulate in Earth's atmosphere and increase in concentration over time, creating the so-called greenhouse effect, which can alter energy balance by transmitting incoming solar radiation but absorbing outgoing thermal radiation from the surface (Schneider, 1992).

Global warming accompanied by an increase in earth's mean temperature, change in frequency and distribution of precipitation, wind pattern, evapotranspiration, weather extremities such as drought, floods, severe storms and hurricanes (Roeckner, 1992). Atmospheric carbon dioxide (CO<sub>2</sub>) has risen from 280 to 387  $\mu\text{mol mol}^{-1}$  from 1750 to 2007, as a result of continuous anthropogenic activities; the CO<sub>2</sub> concentration is expected to reach 600  $\mu\text{mol mol}^{-1}$  sometime around 2050 (IPCC, 2007). 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<sub>2</sub> concentration (IPCC, 2004). In past 250 years, fossil fuels burning change in land use and agriculture are the major anthropogenic sources that have contributed to GHGs emissions. Shift to modern agriculture is main driving forces contributing about 30% of greenhouse gas emissions (Nitze *et al.*, 2008). CO<sub>2</sub>, methane, and nitrous oxide are the three primary greenhouse gases produced from agricultural sources.

These local and global shifts in climate have started affecting life on earth in number of

ways as well as on food supply by its direct and indirect effect on agriculture. It can be greatest threats to sustain life in coming time. Achieving sustainable production in this changing unpredictable environment, need a holistic approach that focus on not only increasing crop productivity but also evolving strategies for effective pest management particularly weeds.

Weeds are complex in nature and these unwanted plants have significantly negative effect on agriculture, forestry, public health so on. Unlike other random and irregular diseases, insects, pests weeds are relatively constant and pose severe problems in crop production. Yield reduction due to weeds differs accordingly weed spp., crop and management practices. When weed emerges in high density, crop losses due to competition will be highest. Also they contaminate the crop seed and deteriorate quality of produce. Harvesting operation also affected by weeds. They produce allelochemicals and are host the insects-pest and diseases (Boydston *et al.*, 2008). Hence weed control is must and major component for successful crop production. Weed can be managed by cultural, mechanical, biological and chemical methods. Chemical controls by herbicides becomes the major choice/ tool because of its economic, easy to use, greater efficacy, due to scarcity of labours and time saving (McErlich and Boydston, 2013). Weeds compete for light, space, nutrients and moisture. The dynamics of competition between crops and weeds are affected by environmental conditions, and have been shown to change with CO<sub>2</sub> enrichment. Differential responses of C<sub>3</sub> and C<sub>4</sub> plants to elevated CO<sub>2</sub> and temperature may cause shifts in their competitive interactions.

Studies were done on impact of climate change on crop production. But less attention is given to importance of weed management particularly herbicide efficacy and its

subsequent effects on the development of herbicides resisting weeds. Herbicides efficacy changes due to environmental stress and could have severe consequence for crop-weed competition and may contributes to loss in production. To study the impact of climate change on herbicides efficiency it is important to understand how environmental conditions affect herbicides performance. Environmental conditions also affect interaction between plant and herbicides. Factors like light, CO<sub>2</sub>, temperature, moisture, relative humidity, rainfall and wind can affects herbicides efficiency by altering the penetration and translocation of herbicides in target plant or indirectly by changing the growth and physiological characteristics of the plants.

Change in climate can affect agriculture through increase in CO<sub>2</sub> concentration, rise in temperature, variation in precipitation and solar radiation and weather extremities like drought, flood, storms etc. Increase CO<sub>2</sub> concentration has beneficial effects on C<sub>3</sub> plants, but only when other growth limiting factors are at optimum level. Beneficial effect of CO<sub>2</sub> rise can be limit by rise in temperature for example there is no elevated CO<sub>2</sub> effect on C<sub>3</sub> Beans, peanut and C<sub>4</sub> (grain sorghum). Increase in both CO<sub>2</sub> and temperature may induce faster growth in determinant crops like cereals by stimulating photosynthesis and vegetative growth.

In C<sub>3</sub> photosynthetic pathway, CO<sub>2</sub> is first accepted by a sugar, Ribulose phosphate (RuBP) and Ribulose bisphosphate carboxylase catalyzed this reaction. Because of the dual activity of Rubisco (carboxylation and oxygenation), both CO<sub>2</sub> and O<sub>2</sub> compete for the same site on Rubisco, resulting in a 20–60% loss of substrate (carbon) through photorespiration (oxygenation) (Bowes, 1996). Increase CO<sub>2</sub> stimulate carboxylation, thereby reduces the losses of CO<sub>2</sub> by photorespiration. On the other hand C<sub>4</sub> have

alternate CO<sub>2</sub> fixation mechanism. CO<sub>2</sub> initially fixed in mesophyll cells by phosphoenolpyruvate carboxylase (PEPcase), which has a higher affinity for CO<sub>2</sub> than rubisco. The resultant 4-carbon organic acid formed in this reaction regenerates CO<sub>2</sub> in the bundle sheath cells for fixation by Rubisco. Because of this internal mechanism photorespiration is inhibited.

Responses of weeds and crops to increasing CO<sub>2</sub> levels were species-specific. Herbicide efficacy can be negatively affected by elevated CO<sub>2</sub> and effects were dependent on the mode of action of herbicides, on weed species and on competition. Differential response of C<sub>3</sub> and C<sub>4</sub> plants to elevated CO<sub>2</sub> and temperature can have important implications on crop-weed competition as most of the weeds are C<sub>4</sub>. But this fundamental idea that most crops are C<sub>3</sub> and most weeds are C<sub>4</sub>, and hence weed competition will consequently decrease as CO<sub>2</sub> increases, should not be viewed as universal axiom (Ziska 2001, 2003). Clearly, there are four major C<sub>4</sub> crops of economic importance (corn, pearl millet, sorghum, and sugarcane), and many important C<sub>3</sub> weeds (e.g. *Chenopodium album*, *Avena ludoviciana*, *Phalaris minor*, *Eclipta prostrata*, *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.

### **Effect of light**

Light is one of the most influencing environmental factors for plant growth and development. Variation in light intensities changes the anatomy, morphology, and growth of plants, which further affects herbicide performance. Light is the source of energy for photosynthesis, and the rate of

photosynthesis determines the rate of phloem translocation of assimilates. As light intensity increases Net photosynthetic rate also increases and higher photosynthesis and subsequent phloem translocation will increase the movement of foliar-applied systemic herbicides; for example, the efficacy of clethodim and tralkoxydim was reduced in ultraviolet light, which indicates that spraying these grass herbicides later in the day when light intensity is higher may improve their efficacy (McMullan, 1996). Suspended particulate matter in environment due to climate change may cause global dimming effect which interfere the incoming solar radiation. Sunlight degrades some pre-emergence herbicides on the soil surface, and if optimum moisture does not become available within a week after application, poor weed control often results. Light stimulates weed seed development and the brightness and amount of light influences leaf shape.

### **Effect of elevated CO<sub>2</sub> concentration**

Increase CO<sub>2</sub> concentration increases starch concentration in tissue reduces protein content (Bowes, 1996). Less protein concentration leads to less demand of amino acids synthesis which alters the efficacy of ALS inhibitors herbicides. Elevated CO<sub>2</sub> concentration and temperature alter the photosynthetic activity in plants which may subsequently affect the herbicide activity. Ziska *et al.*, (2004) reported increased growth and root: shoot of field-grown Canada thistle (*C. arvense*) under elevated CO<sub>2</sub> levels, which resulted in the reduced efficacy of glyphosate because of the dilution effect caused by large stimulation of below-ground growth. Climate change has shown to reduce plant available nitrogen through elevated CO<sub>2</sub> (Williams *et al.*, 2001; Zhang *et al.*, 2005). The carbon nitrogen ratio of leaves is usually increased under CO<sub>2</sub> enrichment. Availability of nutrients such as nitrogen and phosphorus appears to quickly

become limiting, even when carbon availability is removed as a constraint, on plant growth when ambient CO<sub>2</sub> concentrations are sufficiently increased (Hall and Allen Jr., 1993).

Therefore, unlike in C<sub>3</sub> plants, increased CO<sub>2</sub> concentrations will have less of an effect on the net photosynthetic rates of C<sub>4</sub> plants. In C<sub>3</sub> plants, temperatures above 25°C increase photorespiration and inhibit CO<sub>2</sub> assimilation (Jordan and Ogren, 1984). Increase in temperature has little effect on CO<sub>2</sub> assimilation in C<sub>4</sub> plants because CO<sub>2</sub> pumps in mesophyll cells maintain low photorespiration rates at all temperature.

Hence, C<sub>4</sub> better adapted to heat stress and most of the weeds are C<sub>4</sub> plants and they get competitive advantages over crop plant under stress condition.

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<sub>2</sub> and changing climate compared to other native species (Singh *et al.*, 2016). Higher photosynthesis rate at elevated CO<sub>2</sub> in C<sub>3</sub> plants (rice, wheat) mean they response more favorably to higher CO<sub>2</sub> level than C<sub>4</sub> weeds. Relative yield of C<sub>3</sub> crops are higher than C<sub>4</sub> crops due to rise in CO<sub>2</sub> concentration. Alberto, 1996 studies the interaction between CO<sub>2</sub> and temperature on barnyard grass-rice completion and reported that elevated CO<sub>2</sub> concentration favorers crop at day/night temperature 27/21°C but favours growth of barnyard grass at 37/29°C. At elevated CO<sub>2</sub> NPK nutrient concentration in tissue found greater in rice than barnyard grass which enhance tillering, LAI, and net assimilation rate of rice.

### Effect of temperature

High temperature shortens the growth phase and grain filling duration through pollen sterility, lowering test weight and poor anthesis (Kadam *et al.*, 2014). Temperature causes direct and indirect effect on herbicides efficiency. Higher temperature stimulate stomata conductance, lowers the viscosity of cuticular lipids leads to increase permeability and diffusion of herbicides through the cuticle; for example, uptake and translocation of <sup>14</sup>C-glyphosate was found to be higher at 22°C than at 16°C in *Desmodium tortuosum* (Sharma and Singh, 2001). Similarly, Roundup Ready Soybean translocate more <sup>14</sup>C-glyphosate to meristematic tissues at 35°C than at 15°C, indicating potentially increased glyphosate injury at higher temperatures (Pline *et al.*, 1999). Warmer temperature also reduce uptake of herbicides due to rapid drying of droplets.

Increasing temperatures may mean an expansion of weeds into higher latitudes or higher altitudes. Very aggressive weeds that are currently found in the south are limited in the northern states by low temperatures. Many C<sub>4</sub> grass weeds are serious problems in the southern U.S. but do not occur at problem levels in the U.S. cornbelt. Studies have shown that itchgrass, a profusely tillering, robust grass weed could invade the central Midwest and California with only a 3° warming trend (Patterson, 1995). Witchweed, a root parasite of corn, is limited at this time to the coastal plain of North and South Carolina. With an increase of temperature of 3° it is speculated that this parasite could become established in the Corn Belt with disastrous consequences. The current distribution of both Japanese honeysuckle and kudzu is limited by low winter temperatures. Global Warming could extend their northern limits by several hundred miles. Similarly, under warmer conditions, *Setaria viridis* (L.)

P. Beauv. Germinated later in the (August) season (Dekker, 2003). This was a beneficial temporal non-synchrony with emergence of a maize crop, avoiding crop-weed competition. In contrast, a recent study indicated that this species would be a problematic weed in maize-based cropping systems elsewhere, through synchrony with maize emergence, which is probably due to stimulation by increased temperature (Peters and Gerowitz, 2014).

### Effect of precipitation

Climate change alters the frequency and intensity of rainfall. Precipitation after application of herbicides can wash out the herbicides and reduces efficiency. Moisture is needed for weed seed germination. So weed adaption to these stress have more competitive advantages over crops. Increased rainfall frequency and intensity will have an adverse effect on uptake, retention, and activity of soil-applied herbicides (Bailey, 2004; Rodenburg *et al.*, 2011). Increased cuticle thickness and leaf pubescence in response to drought, will reduce herbicide entry into leaves (Patterson, 1995). Lower precipitation amounts throughout the season may result in water stress conditions that affect both plant growth and herbicide efficacy (Zanatta *et al.*, 2008). Increases environmental stress on crops may make them more vulnerable to attack by insects and plant pathogens and less competitive with weeds (Patterson, 1995). Pereira *et al.*, (2011) found that the efficacy of sethoxydim was lower in goosegrass (*E. indica*) plants grown under water-deficit conditions. Similarly, plantain signalgrass (*Urochloa plantaginea*) plants grown under water stress were not effectively controlled by ACCase-inhibiting herbicides when applied during the later growth stages (Pereira, 2010). C<sub>3</sub> plants are dominant in submerged soils; C<sub>4</sub> plants are dominant in dry land soils. Submergence protects rice

plants from severe competition with C<sub>4</sub> weeds. On the other hand, upland rice and rainfed lowland rice with limited precipitation face severe competition with C<sub>4</sub> weeds (Matsunaka, 1983).

### Effect of environmental stress

Under imposed drought, Patterson (1986) found that CO<sub>2</sub> enrichment reduced the effects of water stress and significantly increased leaf area and total dry weight of the three C<sub>4</sub> grasses: *Echinochloa crus-galli*, *Eleusine indica* and *Digitaria ciliaris*. He concluded that CO<sub>2</sub> enrichment can increase the growth of both C<sub>3</sub> and C<sub>4</sub> plants under water stress, but growth stimulation can be expected to be greater in C<sub>3</sub> plants. Carlson and Bazzaz (1980) reported that doubling the CO<sub>2</sub> concentration from 300 to 600 ppm increased WUE by 55% in sunflower, 54% in corn, 48% in soybean, 128% in common ragweed, 87% in velvetleaf, 84% in jimson weed and 76% in redroot pigweed. They speculated that the greater stimulation of WUE in the weeds than in the crops might convey a competitive advantage to the weeds. Chauhan and Abugho (2013), found that rice could not survive under water stress conditions. By contrast, *Amaranthus spinosus* and *Leptochloa chinensis* (L) survived under water stress conditions and produced a significant number of tillers/branches and leaves even at the lowest soil water content. C<sub>4</sub> plants have higher nutrient use efficiencies than C<sub>3</sub> grasses, and reduced nitrogen availability has been shown to benefit C<sub>4</sub> plants over C<sub>3</sub> plants in tall grass prairie (Bleier and Jackson, 2007).

### Effect of relative humidity and wind

At high humidity, leaf retention time increases mean more penetration. Relative humidity primarily influences the activity of foliar-applied herbicides through its effects on

herbicide uptake. Relative humidity could influence the efficacy of foliar-applied herbicides through interactions between the herbicide droplet, leaf cuticle, and availability of water in or around droplets (Devine *et al.*, 1993). Effect of humidity was higher on hydrophilic herbicides than lipophilic herbicides. Spray droplets dry up due to wind blowing so reduces efficiency. Can interfere with surface application and cause spray drift, thereby reducing spray application efficiency (Combellack, 1982).

Given the importance to herbicide use, it is essential to understand the factors that governs herbicides performance. Successful management not only depends on chemical properties of herbicides used but also on its interaction with the plant and surrounding environments. Herbicides absorption by target plant largely depends on its interaction with atmosphere, soil or soil-atmosphere interface. Foliar applied herbicides are influenced by many environment factors but soil applied herbicides are influenced mainly by soil moisture and temperature. Herbicides efficacy affected by environment factors such as temperature, moisture, relative humidity and solar radiation plant's physiology and its susceptibility to herbicides. Interactions between all these factors further complicate the precise determination of their effects on herbicides performance. Climate change has impact on photosynthesis process that affects herbicides absorption, translocation and metabolism. For example, at low rates, diclofop toxicity to wild oat was higher at a lower temperature (10°C) than at a higher temperature (24°C) (Mulder and Nalewaja, 1978). Plant growth and herbicides performance is significantly affected by change in global climate due to rise in CO<sub>2</sub> concentration and its impact on temperature rise and precipitation. Knowing the effect of climate change on weed growth and herbicides activity is needed to optimize

herbicide application for better weed management in coming days.

So, there is a need to evaluate the effect of changing climate on weed flora, crop-weed competition, herbicide efficacy so that adaptation and mitigation strategies can be developed accordingly. Information generated from these studies will help in identifying the potential of weed control measures under a range of atmospheric and edaphic conditions.

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