Impact of climate change on Weeds and Weed management – A review

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ABSTRACT

Climate change, mostly indicated by Global Warming is resultant of increasing greenhouse gases like CO_2, Methane, N_2O, Ozone, CFC etc. Atmospheric CO_2 has already risen from 285 ppm to 380 ppm during the 20th century with observed increase from 1950s. Scientists agree that the planet's temperature has risen by 0.5 degree Celsius since 1900 and will continue to increase at an increasing rate. The sea level has been rising at the rate of 2mm a year since the beginning of 20th century. Droughts and floods have become more common. Changes in climatic factors would alter the nature of vegetation and agriculture and it is true especially with the increasing atmospheric CO_2 concentration. Most of the earth's plants respond positively to the atmospheric CO_2 enrichment by increasing their photosynthetic rates and biomass production. It is the point of contention, however, that weeds may be more responsive to the ongoing rise in atmospheric CO_2 than non-weeds, and therefore they may increase their dominance in agro-ecosystems. In this situation, weeds compete with crops for nutrient, water and light and can considerably reduce yields and quality of crops. In some cases, weeds can pose a human health problem or cause disturbance to the harvest. Hence, the impacts of climate change on weeds and weed management practices are more important aspects in future as that of crop cultivation.

Key words: Climate change, atmosphere, weeds, weed management, human health.

As the global demand for power and agricultural land intensifies, fossil fuel burning and deforestation will continue to increase the concentration of carbon dioxide in the atmosphere. Since the mid-1950s, records of carbon dioxide concentration [CO_2] obtained from the Mauna Loa observatory in Hawaii have shown an increase of about 20% from 311 to 375 parts per million (ppm) (Keeling and Whorf, 2001). It is being predicted that the earth's average surface temperature may increase as high as 5.8^{o} C during the 21st century. The Change in global climate change associated with global warming and increasing atmospheric CO_2 likely to influence the weed dynamics in different ecosystems. Weeds have a greater genetic diversity than crops. Consequently, if a resource (light, water, nutrients or CO_2) changes within the environment, it is more likely that weeds will show a greater growth and reproductive response. Climate change has significant direct and indirect effect on weed biology. An increase in CO_2 and temperature may allow new weeds to become more problematic or existing weeds to expand their geographical locations. Changes in temperature, wind speed, soil moisture and atmospheric humidity can influence the effectiveness of herbicides. Biological control of pests by natural or manipulated means is likely to be affected by increasing atmospheric CO_2 and climate change. Climate as well as CO_2 could alter the efficacy of weed bio control agents by potentially altering the development, morphology and reproduction of the bio control agents. Hence, Climate change will likely have major impacts on weeds and weed management.

Regarding weeds and climate change, the most important points are:

1. Increased carbon dioxide (CO_2) effect on weeds
2. Increased temperature on weeds

Change in rainfall and evaporation effect on Weeds

Effect of increased carbon dioxide (CO_2) on weeds

Most of the plants obtain carbon, as the major constituent for photosynthesis from atmospheric carbon dioxide (CO_2) and more of CO_2 usually benefits plant growth. Weeds are having greater genetic diversity than crops. Hence, weeds will show a greater response in growth and reproductive ability based on the changes in CO_2 concentration in the environment. The mechanisms that contribute for better response of weeds to elevated CO_2 have been reported as (i) plant architectural differences by virtue of leaf area (Ziska, 2003) and (ii) altered reproductive allocation with particular reference to incorporation of carbon and nitrogen in seeds and increased differential abundance in community of seeds (Smith *et al*. 2000). Besides increased branching and leaf area, higher pollen production from rag weed (*Ambrosia artemissifolia*) that is detrimental to human health (Ziska and Caulfield, 2000) and higher spine production in *Cirsium avvense* (Ziska, 2002) are also reported. Response to elevated CO_2 by three weed species *Mikania mikrantha*, *Wedelia trilobata* and *Ipomea cairica* are reported by Song *et al*. (2009) in China. Many of the weeds which reproduce by vegetative means (roots, stolons, etc.) show a strong response to recent increases in atmospheric CO_2 (Ziska and George, 2004).

Effect of rising CO_2 on weed biology

In addition to the direct CO_2 fertilization effect, climatic change particularly precipitation and temperature will have significant effects on weed biology. Weeds are plants that are generally recognized as objectionable or undesirable to human activities. However, there are biological similarities of such plants, including colonization of disturbed environments, vigorous growth, prodigious seed production, and seed longevity (Baker, 1974). Increasing day and night temperatures with a doubling of CO_2 can either decrease leaf area and biomass (Coleman and Bazzaz, 1992) or have no effect (Tremmel and Patterson, 1993) in velvetleaf (*Abutilon theophrasti*), a common agronomic weed. Similarly, CO_2 enrichment and temperature did not interact for two C_4 weed species (*Echinochloa crus-galli* and *Eleusine indica*) (Potvin and Strain, 1985). Alternatively, spurred anoda (*Anoda cristata*) biomass increased at 700 ppm when day and night temperatures increased from 26/17 to 32/23°C (Patterson *et al.*, 1988). However, because of the indirect effect of CO_2 on stomatal aperture, elevated CO_2 can still stimulate plant photosynthesis and growth even if water is limiting (Chaudhury *et al.,* 1990). For some C_4 weeds, increased photosynthesis and growth at elevated CO_2 may only occur under dry conditions, presumably due to increased water use efficiency (WUE, the ratio of carbon gained to water lost) of the weeds. Although water shortages should not limit the response to elevated CO_2, no assessment on CO_2 response under flooded conditions is available for weedy species. Overall, the greater range of responses observed for weeds with increasing atmospheric CO_2 than the crop species because of weeds have a greater genetic diversity and physiological plasticity (Treharne, 1989).

Effect of increased temperature on weeds

Increasing atmospheric temperatures could trigger some weeds in warm season crops. A rise in temperature by 3ºC of average temperature was shown to enhance biomass and leaf area of itch grass (*Rottboelliia cochinchinensis*) by 88% and 68%, respectively (Patterson *et al.,* 1979). Increase in temperature due to global warming might trigger weed migration. Increasing temperatures could also trigger northward migration of cogon grass (*Imperata cylindrica*) and witch weed (*Striga asiatica*) (Patterson, 1995a). The crop-weed competition could also be influenced by the varying magnitudes of response to the rising temperature and floral reproductive ability of weeds (Ziska and Reunion, 2007). Crop losses due to weeds left uncontrolled are considerably higher in the south than in the north of U.S and this is attributed to the presence of perennial invasive weeds like itch grass that are restricted in the northern states by low winter temperatures (Bunce and Ziska, 2000). In Australia, the increase in mean temperature is expected to be associated with range extension of tropical prickly acacia *A. nilotica* to south (Kriticos, *et al.* 2003).

Higher mean annual temperatures are shown to favour assimilate partitioning towards root biomass in the introduced exotic species *P. juliflora*, in Southern India (Kathiresan, 2006a). Hyvonen *et al.* (2010) suggest climate change with particular reference to increasing temperature would increase the risk of population establishment of new weed species in northern regions of Europe. A definite warming trend is expected to increase the chances for the establishment of weed species with the higher atmospheric temperature.

Effect of Soil Temperature on weeds

Soil temperature plays a key role in promoting seed germination (Schonbeck and Egley, 1980). In India, Carpetweed *Trianthema portulacastrum* invading in irrigated upland ecosystems is shown to be more invasive with synchronised mass seed germination, with increasing soil temperatures (Kathiresan, 2006b). Hence, Soil temperature could mainly serve for the purpose of thermal induction of seed germination of weeds.

Changes in rainfall and evaporation impact on Weeds

Rainfall and evaporation pattern of a region influences the weeds directly by interrupting the physiological functions involved in the process of seed dormancy and germination and by imparting the seed mortality due to excessive drying or soaking. On larger populations, precipitation extremes could tilt the weed-crop competition that would be reflected on declining crop productivity (Patterson, 1995b). Meteorological data from Annamalai University reported, in the tail end of Cauvery river delta region (Tamil Nadu), that the average annual rainfall during the last 20 years has increased by 233 mm and the annual evaporation has come down by 453 mm. The wetland rice fields are recently dominated by weeds like *Leptochloa chinensis* and *Marsilea quadrifolia*. These two weed species dominated over the native weed such as *Echinochloa sp.* (Kathiresan, 2005) due to the change in rainfall and evaporation pattern.

Climate change impact on weed distribution

Increasing temperature may alter the distribution of weeds into higher latitudes or higher altitudes. High-latitude temperature limits of tropical species are set by accumulated degree days (Patterson *et al.*, 1999), while low-latitude temperature limits are determined in part by competitive ability (Woodward, 1988). Many of the weeds associated with warm-season crops are originated in tropical areas expand towards north with warming (Patterson 1993). For example, North ward expansion of weeds, such as cogon grass (*Imperata cylindrica*) and witch weed (*Striga asiatica*), is also anticipated (Patterson 1995b), although warming may restrict the southern expansion of some exotic weeds such as wild proso millet (*Panicum miliaceum*) due to increased competition (Patterson *et al.,* 1986). One of the more interesting examples is potential northward expansion of *Pueraria lobata* (kudzu), a ubiquitous invasive weed. Approximately 15 years ago, the latitudinal distribution of *Pueraria lobata* in USA was limited to areas of the Ohio Valley and the Mason-Dixonline by low winter temperatures (Sasek and Strain, 1990). Interestingly, recent observations have noted kudzu populations were higher due to increasing winter temperatures. Alternatively, greater increases in night time relative to day time temperatures projected with global warming could decrease seed production to a greater extent in crop relative to weed species Eg. *Vigna unguiculata* (Ahmed *et al.,* 1993) with subsequent competitive effects. Due to climate change, many of the weeds associated with warm-season crops are originated in tropical areas and expand towards north with warming.

Climate change impact on photosynthesis

Elevating CO_2 stimulates net photosynthesis in plants with the C_3 photosynthetic pathway by raising the CO_2 concentration gradient from air to leaf and by reducing the loss of CO_2 through photorespiration. Ribulose bisphosphate carboxylase/oxygenase (Rubisco), is the principle enzyme that incorporates carbon into the plant from CO_2. Under the elevated concentration of CO_2 increases net carbon uptake and reducing CO_2 lost via photorespiration. In this condition, Oxygen competes with CO_2 for active sites of the Rubisco enzyme. The competition between O_2 and CO_2 for active sites is temperature sensitive. The stimulation of net photosynthesis by elevated CO_2 should increase as the temperature increases. Thus plants having C_3 photosynthetic pathway (95% of all plant species), with increasing CO_2 and temperature associated with climate change should be favourable for increased growth. Alternatively plants with the C_4 photosynthetic pathway (4% of all known plant species) have an internal mechanism for concentrating CO_2 around Rubisco; therefore, increases in external CO_2 concentration should have little effect on net photosynthesis in C_4 plants (Ghannoum *et al.*, 2000). However, one of the most consistent responses of both C_3 and C_4 species to elevated CO_2 is a decrease in stomatal conductance (Eamus, 1991). The decrease in stomatal conductance can result in significant increases in water use efficiency (dry matter obtained/H_2O transpired). Hence, under water-limiting conditions, elevated CO_2 should result in significant increases in photosynthesis and biomass for both C_3 and C_4 plant species.

Climate change impact on crop-weed interactions

Increasing levels of CO_2 will directly influence plant physiology, through its effect on photosynthesis, transpiration and respiration, which seem to be the only processes by which elevated CO_2 can be sensed directly by plants and ecosystems. However, climatic change, especially increased CO_2 affects C_3 and C_4 plants differently and leads to different combination of crop-weed interactions. They are 1. C_4 weeds in C_3 crops, 2.

C_3 weeds in C_3 crops, 3. C_3 weeds in C_4 crops and, 4. C_4 weeds in C_4 crops. Under Optimal temperatures the growth of C_4 plants are generally higher than C_3 plants (Flint & Patterson, 1983), but with higher CO_2 under the optimum temperature increases growth of many C_3 plants (Bunce and Ziska, 2000). Tang *et al.*, (2009) recently showed that barnyard grass (*Echinocloa crus-galli*) in combination with a mycorrhiza also benefits from elevated CO_2 levels. In drought situations C_4 weeds might also have advantages over C_3 crops under elevated CO_2 (Ward *et al.*, 1999). Under the elevated CO_2, the C_3 weed *Abutilon theophrasti [Medicus]* increased the biomass, reduced the yield and biomass of C_4 crop Eg. Sorghum (Ziska, 2003). Only two studies have actually quantified changes in crop yield with weedy competition as a function of rising CO_2 (Ziska, 2000b, 2003). In these studies, two crop species, one C_3 (soybean), and one C_4 (dwarf sorghum) were grown with lambsquarters (C_3) and redroot pigweed (*Amaranthus retrojlexus*, C_4) and velvetleaf (C_3) and redroot pigweed(C_4), respectively, at a density of two weeds per meter of row. Although, soybean yield losses were less from pigweed, all other crop-weed interactions resulted in increased yield loss at elevated CO_2. A survey of experimental results on 27 non-crop C_3 species revealed that biomass accumulation increased from 79% to 272% under elevated CO_2 (Patterson, 1995). CAM plants react to elevated CO_2 similar to C_3 plants with enhanced growth, if water supply is sufficient. If not they will respond like C_4 plants (Isreal and Nobel, 1994). Due to the differential responses of seed emergence and climate change could influence the weed species establishment and subsequent weed-crop competition. Hence, climatic change, especially increased CO_2 affects C_3 and C_4 plants differently and leads to different combination of crop-weed interactions.

Climate change impact on weed management

Chemical control

Chemical control is the principal means of weed management in most of the developed countries. Temperature and precipitation are known abiotic factors that can affect chemical application rates and overall efficacy (Patterson, 1995). Changes in temperature, wind speed, soil moisture, and atmospheric humidity can influence the effectiveness of herbicides (Muzik, 1976). Rising CO_2 could reduce the foliar absorption of pesticides and reducing stomatal aperture or number, or by altering leaf or cuticular thickness. In addition changes in transpiration could limit the uptake of soil-applied pesticides.

In weed control, the timing of application could also be affected and decreases the chemical susceptibility of the weeds in the seedling stage under the elevated CO_2 condition. For perennial weeds, increasing CO_2 could stimulate greater below ground growth (rhizomes, tubers, and roots), diluting the active ingredient and making chemical control more difficult and costly. At the biochemical level, CO_2 could alter herbicide-specific chemistry in such a way as to directly reduce the efficacy of the active ingredient. For example, glyphosate inhibits aromatic amino acid production through the shikimic acid pathway; if higher the CO_2 reduces the protein content per gram of tissue (Bowes, 1996), this would result in less demand for aromatic amino acids. In this aspect, limited numbers of studies are conducted. One such study revealed that rising CO_2 levels can decrease the chemical efficacy in the control of annual and perennial weeds (Ziska and Runion, 2007). For Canada thistle, CO_2-induced reductions in efficacy of glyphosate application were related due to greater carbon allocation to roots and a reduction in the systemic effect of the herbicide. In this way, climate change will have a significant impact on chemical management either directly or indirectly. Increased spraying frequency could overcome CO_2-induced reductions in efficacy but could increase residual effects within the environment (Ziska *et al.*, 2004). Increased use of herbicides for control of weeds carries further risks for human and animal health because it could increase the presence of these chemicals in the environment.

Mechanical control

Mechanical method is the principal means of controlling weed populations, and the one most widely used in developing countries for removal of the undesired plant. In mechanical method, tillage (by animal or mechanical means) is regarded as a global method of weed control in agronomic systems. Elevated CO_2 could lead to further belowground carbon storage with subsequent increases in the growth of roots or rhizomes, particularly in perennial weeds (Rogers *et al.*, 1994). Consequently, mechanical tillage may lead to additional plant propagation in a higher CO_2 environment, with increased asexual reproduction from belowground structures and negative effects on weed control (e.g., Canada thistle).

Biological control

Biological control of pests by natural or manipulated means is likely to be affected by increasing atmospheric CO_2 and climatic change (Froud-Williams, 1996). Climate as well as CO_2 could alter the efficacy of the bio control agent by potentially altering the development of morphology and reproduction of the target pest. Direct effect of CO_2 would also be related to changes in the ratio of C: N and alterations in the feeding habits and growth rate of herbivores. As pointed out by Patterson (1995a), warming could also result in increased over wintering of insect populations and changes in their potential range. Although this could increase both the biological control of some weeds, with subsequent in direct effects on crop-weed competition. Whether this will result in a positive or negative result remains unclear.

CONCLUSION

Before industrialization, around the year 1750, levels of CO2 in the air were at 280 ppm; in 2005 it reached 380 ppm, and a level of 560 ppm can be expected by the end of the 21st century. 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. Temperature and precipitation are primary abiotic variables that control vegetative distribution and the geographical distribution with subsequent effects on their growth, reproduction and competitive abilities of weeds. Since the availability of water to agriculture will be greatly reduced in future, the importance of rainfed and dryland agriculture will result in shift in weed flora and development of problem weeds which are difficult to control such as weedy rice, Orobanche, Striga, etc., besides reduced the efficacy of herbicides due to moisture stress. Changes in temperature, wind speed, soil moisture and atmospheric humidity can influence the effectiveness of herbicides. Clearly, any direct or indirect impacts from a changing climate will have a significant impact on weed biology and chemical management of weeds. Increase in temperature due to global climate change may affect weed competitiveness and crop-weed interactions. Biological control of pests by natural or manipulated means is likely to be affected by increasing atmospheric CO_2 and climate change. Climate as well as CO_2 could alter the efficacy of weed bio control agents by potentially altering the development, morphology and reproduction of the bio control agents. Increase in CO_2 and temperature in the atmosphere allows new weeds to become problematic and expand their geographical distribution. Hence, new management strategies may be needed to combat them.

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