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Impact of climate change on weed threat

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Abstract

Natural events and human activities are believed to be contributing to an increase in average global temperatures. This is caused primarily by increase in greenhouse gases. In future decades, when climate change effects are more consistently felt, weed management requirements in agriculture and non-agricultural situations will change. Control of weeds is likely to be more difficult and more expensive under climate change. Some well known invasive species are likely increase their bio-geographical ranges, and other, relatively mild species may become aggressive invaders. Several studies have focused on the impact of climate change on crop productivity, but less attention has been given to the impact on weed management, particularly herbicide efficacy and its subsequent effects on the development of herbicide-resistant weeds. The mitigation of climate change vulnerability can be mitigated by storing carbon in soils which reduces atmospheric levels of carbon. Climate change has severe direct and indirect impacts on biodiversity and is predicted to be a dominant driver of future biodiversity loss; at the same time, the loss of biodiversity magnifies the adverse effects of climate change. Other management changes such as using cover crops, crop rotations instead of monocropping, reducing or eliminating fallow periods and avoiding burning of crop residues can lead to carbon sequestration in soil.

Keywords: Climate change, agricultural weeds, greenhouse gas, herbicides

Introduction

Climate change refers to an increase in average global temperatures. Natural Natural events and human activities are believed to be contributing to an increase in average global temperatures. This is caused primarily by increase in greenhouse gases. As explained by the US agency, the National Oceanic and Atmospheric Administration (NOAA), there are 7 indicators i.e. troposphere temperature, humidity, temperature over ocean, sea surface temperature, sea level, temperature over land and ocean heat content that would be expected to increase in a warming world, and 3 indicators i.e. glaciers, snow cover, sea ice, would be expected to decrease. The term *greenhouse* is used in conjunction with the phenomenon known as the *greenhouse effect*. Energy from the sun drives the earth's weather and climate, and heats the earth's surface; In turn, the earth radiates energy back into space. Some atmospheric gases like water vapor, carbon dioxide and other gases trap some of the outgoing energy, retaining heat somewhat like the glass panels of a greenhouse. These gases are therefore known as greenhouse gases. The greenhouse effect is the rise in temperature on earth as certain gases in the atmosphere trap energy.

Key greenhouse gases emitted by human activities

- Carbon dioxide (CO_2): Fossil fuel use is the primary source of CO_2. CO_2 can also be emitted from direct human-induced impacts on forestry and other land use, such as through deforestation, land clearing for agriculture, and degradation of soils.
- Methane (CH_4): Agricultural activities, waste management, energy use and biomass burning all contribute to CH_4 emissions.
- Nitrous oxide (N_2O): Agricultural activities, such as fertilizer use, are the primary source of N_2O emissions. Fossil fuel combustion also generates N_2O.
- Fluorinated gases (F – gases): Industrial processes, refrigeration and the use of a variety of consumer products contribute to emissions of F-gases, which include hydro fluorocarbons (HFCs), per fluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Anthropogenic greenhouse gas (GHG) emissions since the pre-industrial era have driven large increases in the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Between 1750 and 2011, cumulative anthropogenic CO_2 emissions to the atmosphere were 2040 ± 310 Gt CO_2. About 40% of these emissions have remained in the atmosphere (880 ± 35 Gt CO2); the rest was removed from the atmosphere and stored on land (in plants and soils) and in the ocean. The ocean has absorbed about 30% of the emitted anthropogenic CO_2, causing ocean acidification. About half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years (IPCC, 2014) [13].

Climate change and impact on agricultural weeds

Climate change is a threat to global crisis and its impacts on agricultural weeds have not been well explored. Conventional thinking around carbon pathways in plants and nutrient management in crops could partially solve the climate change implications, but weed problems could also be aggravated in the wake of increasing CO_2 concentration, high temperature, and most significantly by water stress. These conditions might necessitate the adoption of new agronomic practices to enhance weed competitiveness. As crops and weeds share the same nutritional level, the stimulatory or inhibitory behavior of the climate variables on crops should generally hold true for weeds. The majority of plants and crop plants are C3 plants, referring to the fact that the first carbon compound produced during photosynthesis contains three carbon atoms. Under high temperature and light, however oxygen has a high affinity for the photosynthetic enzyme Rubisco. Oxygen can bind to Rubisco instead of carbon dioxide, and through a process called photorespiration, oxygen reduces plant photosynthetic efficiency and water use efficiency. By contrast, C4 photosynthesis evolved in plants in environments with high temperature and light, that tend to have soil moisture limitations unique leaf anatomy and biochemistry enables C4 plants to bind carbon dioxide when it enters the leaf and produce a 4-carbon compound that transfers and concentrates carbon dioxide in specific cells around the Rubisco enzyme, significantly improving the plant's photosynthetic and water use efficiency. As a result in high light and temperature environments, C4 plants tend to be more productive than C3 plants. Examples of C4 plants include maize, sorghum, sugarcane, and millet. However, the C4 anatomical and biochemical adaption require additional plant energy and resources than C3 photosynthesis, and so in cooler environments, C3 plants are typically more photosynthetically efficient and productive. Numerous studies have addressed weed-crop interactions by evaluating the comparative growth and physiology of C3 crops and C4 weeds, and concluded that an elevated CO_2 concentration generally favors the vegetative growth of C3 plant species over those with C4 pathways (Patterson, 1995) [28]. However, not all crops are based on C3 pathways, and not all weeds are C4 based (Ziska *et al*., 2010) [45]. Hence, while the above concept is relevant for C3 cereals such as rice, which compete, in the main, with C4 grassy and broad-leaved weeds, this situation is not universal. There are many C4 crops of economic significance, such as maize, sugarcane and sorghum, which have competition from important C3 weeds, for example, *Chenopodium album* L. (Ziska, 2000) [44]. This implies that weed-related yield losses of C4 crops will tend to increase under elevated CO_2, but this will not occur with C3 crops, as elevated CO_2 will be a crucial factor in realizing the potential benefits of CO_2 fertilization.

An increase in atmospheric temperature has been found to favor weed growth as well as herbicide efficacy. Although there is a dominance of C4 weeds in agriculture, C3 and C3-C4 intermediate pathways of prominent weeds would pose severe crop-weed competition in the years to come. Importantly, due to species interaction, there is a need to study all possible combinations of plant-weed carbon fixation pathways, C3 crops and C3 weeds, C4 crops and C4 weeds, C3 crops and C4 weeds, and C4 crops and C3 weeds, while studying the impact of climate change on crop-weed competitive interactions. Several weeds will exert additional pressure for crop-weed competition under the climate change scenario.

Increasing atmospheric CO_2 and associated changes in climate directly affect

1. Weed diversity
2. Weed physiology and crop-weed interactions
3. Response to weed control methods

1. Weed diversity

- Weed species have a greater genetic diversity than most crops and therefore, under the changing scenario of resources (eg. light, moisture, nutrients, CO_2), weeds will have the greater capacity for growth and reproductive response than most crops.
- Differential response to seed emergence with temperature could also influence species establishment and subsequent weed-crop competition.
- Increasing temperature might allow some sleeper weeds to become invasive.
- The increased temperature and aridity are expected to alter the distribution and impact of weeds.
- However, under high temperature and water stress conditions, C4 plants may exhibit significant growth increase in response to CO_2 enrichment.

Table 1: Major weed species (C3 pathway) and their life form (Patterson, 1995; Mishra, 2003) [28, 24].

Species	English name	Life cycle
Ageratum conzoides	Goat weed	Ephemeral/Broad leaved
Argemone maxican	Mexican poppy	A/ Broad leaved weed
Bracharia spp.	Para grass	P/grass
Chenopodium album	Common lambs quarter	A/ Broad leaved weed
Commelina nudiflora	Day flower	A/grass
Echinocloa colona	Sawan	A/grass
Eichornia crassipes	Water hycinth	Floating aquatic
Elytrigia repens	Quak grass	P/grass
Leptochloa chinensis	Chinese sprangle top	A/grass
Phalaris minor	Little seed canary grass	A/grass
Poa annua	Annual blue grass	A/grass

Rumex acetocella	Red sorrel	A/broad leaved
Rottboellia cochinchinensis	Itch grass	A/grass

P= perennial; A = annual;

Table 2: Major weed species (C4 pathway) and their life form (Patterson, 1985; Mishra, 2003) [24].

Species	English name	Life cycle
Cynodon dactylon	Bermuda Grass	P/Grass
Cyperus iria	Rice field flat sedge	A/sedges
Cyperus rotundus	Purple nutsedge	P/sedge
Dactyloctenium aegyptium	Crows foot	A/grass
Digitaria ciliaris	Crab grass	A/grass
Euphorbia hirta	Garden spurge	A/broad leaved
Imperata cylindrica	Cogon grass	P/Grass
Monochoria vaginalis	Monchoria	P/Aquatic
Elusine indica	Goose grass	A/Grass
Sacchrum officinarum	Tiger Grass	P/Grass
Setaria Glauca	Fox tail	A/Grass

P= perennial; A = annual;

2. Weed physiology and crop-weed competition

- Crop-weed competition is the most important agricultural aspect influenced by CO_2 elevation.
- Different responses in C3 and C4 plants to increased CO_2 and temperature might change their competition ability.
- Most of the world crops are C3 and the noxious weeds are C4.
- Studies indicated that the growth of C3 plants tends to be stimulated more by CO_2 enrichment than the growth of C4 plants.
- By duplicating CO_2 concentration, there was 41% increase in growth of C3 plants compared to 22% in C4 plants (Poorter, 1993) [33].
- Weed dynamics with climate change depends on the species, growth and photosynthetic (C3 and C4) behavior and response to environment
- For the most important species on a worldwide basis, crops have predominantly C3 photosynthesis metabolism and weeds disproportionately have C4 metabolism.
- Among the 18 most troublesome weeds, 14 are C4, whereas of the 86 plants that supply most of the world's food, only 5 are C4, species.

Table 3: Ranges of increase in biomass of C3 and C4 weeds and crops grown under doubled CO_2 (Patterson, 1995) [28].

C-assimilation pathway	Weeds	Crops
C3	95 – 272%	107 – 494%
C4	56 – 161%	98 – 182%

Increase in CO_2 and plant physiology

- Decrease in photorespiration (only in C 3-plants)
- Increase in net photosynthesis increase in overall carbon balance
- Decrease in transpiration by 25-50% (partial stomatal closure)
- Increase in water use efficiency (WUE, g of dry matter / g of transpired water)

Some possible effects of change in the weed / crop competition patterns owing to climate change

- Differential effects of CO_2 on C3 and C4 plants: more beneficial to C3 plants
- 14 of the 18 "world's worst weeds" are C 4 weeds
- 12 of the 15 major crops are C3 crops
- Perennial weeds more difficult to control due to the stimulation of growth of rhizomes and storage organs
- Expansion of warm season weeds to higher latitudes and cooler areas (e.g. *Cassia, Amaranthus, Sesbania, Crotalaria, Rottboellia, Imperata, Panicum, Striga, etc.*)
- Competitive advantage (higher growth rates) of warm season weeds against temperate crops
- In case of similar photosynthetic path way of crop and weed such as sorghum (*Sorghum vulgaris*) and shatter cane (*S. bicolor*), rice and red rice, oat and wild oat, weed growth was favoured by CO_2 enrichment.
- Ziska *et al.*, 2004 [46] reported increase in velvet leaf (*Abutilon theophrasti*) biomass in response to increasing CO_2 and reduced the yield and biomass of sorghum.
- Ziska *et al.* 2006 [47] reported that the vegetative growth, competition and potential yield of sorghum could be reduced by co-occurring of common cocklebur (*Xanthium strumarium*) as the atmospheric CO_2 increases.
- Growth and reproduction of *Parthenium hysterophorus* was increased with CO_2 enrichment (Naidu *et al*. 2008).
- The C4 cereal *Sorghum bicolor* grown under either ambient (350 μmol mol^{-1}) or elevated (700 μmol mol^{-1}) CO_2 in either the presence or absence of the C3 obligate root hemi-parasites *Striga hermonthica* or *S. asiatica* showed that both uninfected and infected sorghum plants were taller and had greater biomass, photosynthetic rates, water-use efficiencies and leaf areas under elevated compared with ambient CO_2 (Watling & Pres, 1997) [43]
- Various studies have shown that the growth of plants with C3 photosynthetic pathway tends to be stimulated more by CO_2 enrichment than is the growth of C4, plants.
- Therefore the future increase in the atmospheric CO_2 concentration might increase the competitive impact of C3 weeds in C4 crops while decreasing the impact of C4 weeds in C3 crops
- Under high temperature and water stress condition, C4 plants may exhibit significant growth increase in response to CO_2 enrichment.
- It has been observed that growth enhancement in response to CO_2 enrichment was greater in soybean (C3) than C4 grassy weeds viz. *Echinocloa crusgalli*, *Elusine indica*, and *Digitaria sanguinalis*.
- Similarly in rice (C_3), elevated CO_2, alone enhanced the crop competitiveness against E. *glabrescens*, but simultaneous increase in CO_2 and temperature favoured *E. glabrescens*.
- The growth, development and reproduction of most troublesome weed *Parthenium hysterophorus* have been found to increase in elevated CO_2 conditions.
- In*creasing* atmospheric CO_2 and associated changes in climate have the potential to directly affect weed physiology and crop weed interactions *vis-à-vis* their response to weed control measures.
- The efficacy of herbicides is greatly influenced by environmental variables such as temperature, soil moisture and atmospheric humidity. Decreasing stomatal conductance with increased CO_2 could reduce the uptake

of both soil and foliar applied herbicides.
- Climate change also alters the efficacy of bio control agents by changing the growth, development and reproduction of target weed.
- Increased root and rhizome growth particularly in perennial weeds due to elevated CO_2 may make the mechanical weed control more difficult

Response to weed control methods

In future decades, when climate change effects are more consistently felt, weed management requirements in agriculture and non-agricultural situations will change. Aggressive growth of C3 or C4 weeds will require more energy and labour intensive management. Control of weeds are all likely to be more difficult and more expensive under climate change. Some well known invasive species are likely increase their bio-geographical ranges, and other, relatively mild species may become aggressive invaders. Increased tolerance of glyphosate was reported in a perennial C3 weed, quack grass (*Elytrigia repens* (L.) Nevski) by Ziska and Teasedale (2000) [44]. Compared to ambient levels of CO_2 (380 μmol mol^{-1}), elevated CO_2 levels (720 μmol mol^{-1}) stimulated the growth of cohorts of the perennial grass at different life stages i.e. young, intermediate and old over. In the case of the old cohort, stimulation of leaf photosynthesis and vegetative plant growth under elevated CO_2 was consistent and high over a long (231 day) period of exposure. In contrast, the stimulation of biomass the intermediate-age and young cohorts was time-dependent. Higher CO_2 levels and acclimation had no effect on glyphosate control of the young cohort of quack grass. However, in this work, glyphosate at 2.24 kg a.i. ha^{-1}, reduced the growth of, but did not eliminate the intermediate and old cohorts grown at elevated CO_2. Plant size at the time of glyphosate application could not explain the differences in response. The authors concluded that sustained stimulation of photosynthesis and growth in perennial weeds could occur as atmospheric CO_2 increases, and such changes would reduce the effectiveness of chemical control.

Although the focus of weed management is shifting toward integrated strategies to reduce the impact of herbicide use on the environment and the development of herbicide-resistant weeds, herbicides remain the mainstay of weed control due to their ease of application and cost-effectiveness. Several studies have focused on the impact of climate change on crop productivity, but less attention has been given to the impact on weed management, particularly herbicide efficacy and its subsequent effects on the development of herbicide-resistant weeds.

Environmental factors that affect herbicide activity

Light

Variation in light intensities changes the anatomy, morphology, and growth of plants, which further affects herbicide performance. Stomatal conductance and leaf cuticle development are positively correlated with light intensity At high light intensity, stomata remain open, thus improving tissue penetration for foliar-applied herbicides. Furthermore, plant branching and leaf thickness increase to reduce the damage caused by excessive light energy and to ensure the proceeding of photosynthesis. Conversely, at low light intensity, plants tend to produce thinner leaves with greater specific leaf area and plant height to capture available light and meet the demand for photosynthesis. These adaptations in plant growth and leaf anatomy influence the amount of herbicide that is absorbed and retained by the plant; for example, higher plant branching increases surface coverage and absorption of post emergent (POST) herbicides, whereas thicker leaves slow the diffusion of herbicides resulting in reduced herbicide activity.

Carbon dioxide

High CO_2 concentrations in the atmosphere are likely to have pronounced effects on weed biology, consequently altering herbicide performance on weeds. One of the most prominent effects of elevated CO_2 levels is the reduction in stomatal conductance. At elevated CO_2 levels, leaf thickness increases and the number of open stomata decrease; thus, reducing the amount of foliar-applied herbicide that is directly absorbed into the plants, thereby protecting the weeds from damage by POST herbicides. Decreased stomatal conductance also results in reduced transpirational flow, which further reduces the uptake of soil-applied herbicides. Common lambsquarters is a C3 weed that has shown higher tolerance to glyphosate as a result of increased growth and biomass at elevated CO_2 (Ziska *et al*., 1999) [48]. Glyphosate efficacy at elevated CO_2 concentrations was also reported to decrease in C4 invasive weeds such as Rhodes grass (*Chloris gayana*), weeping lovegrass (*Eragostis curvula*), and dallisgrass (*Paspalum dilatatum*) owing to increased biomass and leaf area (Manea *et al*., 2011) [23]. Greater CO_2 concentrations may stimulate rhizome or tuber (below-ground) growth relative to aboveground growth in most perennial weeds, which may render herbicide control of such weeds more difficult (Patterson *et al*.., 1999) Ziska *et al.* (2004) [46] reported increased growth and root: shoot ratio of field-grown Canada thistle (*Cirsium arvense*) under elevated CO_2 levels, which resulted in the reduced efficacy of glyphosate because of the dilution effect caused by large stimulation of below-ground growth

Temperature

Temperature has both direct and indirect effects on herbicide efficacy. Temperature can directly affect herbicide performance through its effects on the rate of herbicide diffusion, viscosity of cuticle waxes, and physicochemical properties of spray solutions (Price, 1983) [35]. Higher temperatures may lower the viscosity of cuticular lipids, thereby increasing the permeability and diffusion of herbicides through the cuticle; for example, uptake and translocation of 14C-glyphosate was found to be higher at 22°C than at 16°C in *Desmodium tortuosum* (Sharma and Singh, 2001). Similarly, Roundup Ready Soybean translocated more 14C-glyphosate to meristematic tissues at 35°C than at 15°C, indicating potentially increased glyphosate injury at higher temperatures (Pline *et al*., 1999) [32]. Flumiclorac also showed higher activity on common lambsquarters (sevenfold) and redroot pigweed (threefold) as temperatures increased from 10°C to 40°C (Fausey and Renner, 2001) [12]. Although high air temperatures tend to speed both absorption and translocation of most foliar applied herbicides, in some cases high temperatures also may induce rapid metabolism, which subsequently reduces herbicide activity on target plants (Kells *et al*., 1984; Johnson and Young, 2002) [16, 14]. A threefold increase in the absorption and translocation of mesotrione in velvetleaf and common cocklebur was observed at 32°C. In contrast, mesotrione efficacy on common water hemp and large crabgrass

(*Digitaria. sanguinalis*) decreased by six and sevenfold at the same temperature (Johnson and Young, 2002) [14]. Visual symptoms of injury due to dicamba drift on soybean increased from 0% to 40% as temperature increased from 15°C to 30°C (Behrens and Lueschen, 1979) [7]. Although these effects are observed mainly with foliar-applied herbicides, soil temperature affects the movement and permeability of soil applied herbicides within the plant. High soil temperatures may lower the efficacy of soil-applied herbicides by increasing volatility and microbial breakdown. High temperature had a profound effect on the volatilization of the trial late herbicide from soils. Trial late losses increased from 14% to 60% in sandy soil and 7% to 41% in loamy soil when temperatures increased from 5°C to 25°C (Atienza *et al.*, 2001) [2].

Relative humidity

Relative humidity primarily influences the activity of foliar-applied herbicides through its effects on herbicide uptake. At high humidity, however, the effects of high temperature on droplet drying is reduced due to increased leaf retention time, hence increased herbicide absorption. The efficacy of glufosinate ammonium on green foxtail (*Setaria faberi*) and barley was greater at high humidity than at high temperature (Anderson *et al.*, 1993) [1]. The effects of humidity are much higher on water-soluble herbicides than on lipophilic herbicides. At high humidity, cuticle hydration and stomatal opening increases, this further increases the permeability of water-soluble herbicides into the leaf surface (Kudsk *et al.*, 1990) [19]. The susceptibility of common water hemp and large crabgrass to mesotrione was four and two-fold higher at 85% relative humidity compared with 30%, respectively (Johnson and Young, 2002) [14]. Uptake and efficacy of most herbicides was generally found to be higher when plants were exposed to high humidity after spraying than before, suggesting that delayed droplet drying could be the mechanism for higher efficacy at high humidity levels rather than cuticle hydration (Ramsey *et al.*, 2002) [36].

Precipitation and soil moisture

Precipitation can directly influence herbicide uptake by washing the spray droplets off leaf surfaces or by diluting the herbicide to a less effective form. Herbicide applications are generally not recommended immediately after rainfall because wet leaf surfaces have a higher tendency to bounce off the spray droplets (Spillman, 1984) [42]. Rain fastness is the ability of an herbicide to quickly dry and penetrate into the leaf tissues so it remains effective after rainfall. Herbicides with lipophilic properties usually have better rain fast properties than water-soluble herbicides (Kudsk and Kristensen, 1992) [18]. Ester formulations of auxinic herbicides are absorbed more quickly than amine and salt formulations, which are more susceptible to wash-off. Low levels of precipitation or dew may improve leaf retention and herbicide efficacy by rewetting spray droplets on the surface (Olesen and Kudsk, 1987) [27]. On the other hand, lower precipitation amounts throughout the season may result in water stress conditions that affect both plant growth and herbicide efficacy.

Wind

Wind may have a less pronounced influence on herbicide performance. Nonetheless, windy conditions can interfere with surface application and cause spray drift, thereby reducing spray application efficiency (Combellack, 1982) [10]. Wind reduces herbicide retention by moving spray off and away from plants and particularly affects deposition of smaller droplets on the leaf surface. Furthermore, spray deposits tend to dry rapidly under windy conditions, with a subsequent reduction in herbicide uptake.

Mitigation of climate change with reference to agricultural weeds

Mitigation refers to human actions intended to reduce greenhouse gas sources or enhance carbon sequestration, thus limiting the extent of impact of climate change. Cropland mitigation measures remain unexplored although many adaptation options also contribute to mitigation. Among these measures are:

Soil management practices that reduce weed infestation

Storing carbon in soils reduces atmospheric levels of carbon. The reduction of carbon outputs is achieved by reducing mechanical soil disturbance, which leads to increased mineralization and soil carbon loss, as much as possible. The amount of carbon released from soils depends directly on the volume of soil disturbed during tillage operations. Conversely, intensive tillage with ploughing and powered tools like rotary cultivators leads to uncontrollable carbon loss in soils and to a degradation of soil fauna and biodiversity. Therefore, intensive agriculture that avoids inversion tillage and emphasizes carbon management with conservation agriculture has potential to offset some CO_2 emissions and may be a small but significant player in sequestering carbon and mitigating GHG emissions. Therefore, the less soil is disturbed, the better the conservation of soil carbon. Stopping soil tillage has an important effect on weed populations. When the soil is ploughed, weed seeds are buried, some of them deeply, and then returned to the surface in the following season. The “seed bank” in the soil is difficult to empty if the soil is continually tilled. Good weed control in conservation agriculture (CA) for a few seasons will deplete the weed seed bank in the soil, and if weeds do not set seed again, weed problems will decline rapidly. Conversion of native vegetation to cultivated cropland under conventional tillage system has resulted in a significant decline in soil organic matter content (Paustian *et al.*., 2000; Lal, 2002) [30, 20]. Farming methods that use mechanical tillage, such as the mould board plough for seedbed preparation or discing for weed control, can promote soil C loss by several mechanisms: they disrupt soil aggregates, which protect soil organic matter from decomposition (Karlen & Cambardella, 1996; Six *et al.*, 1999; Soares *et al.*, 2005) [15, 40, 41], they stimulate short-term microbial activity through enhanced aeration, resulting in increased levels of CO_2 and other gases released to the atmosphere (Bayer *et al.*, 2000a; 2000b; Kladivko, 2001) [4, 5, 17], and they mix fresh residues into the soil where conditions for decomposition are often more favourable than on the surface (Karlen & Cambardella 1996; Plataforma, 2006) [15, 31]. Furthermore, tillage can leave soils more prone to erosion, resulting in further loss of soil C (Bertol *et al*., 2005; Lal, 2006) [8, 21].

Promotion of legumes in crop rotations

Few studies have examined the role of crop rotation in weed suppression, and most have looked at crop rotation in conventional agricultural systems with herbicides. Weeds establish most easily when the ground is bare. Plant canopies suppress seed germination of many weed species by reducing the amount of light and the relative amount of red-wavelength light reaching the soil surface. In addition, cover crops compete with any weeds that do emerge. (Beddows, 1973) [6]. Introduction of legumes crops in prevailing crop rotation can also be helpful in future scenario of climate change. Grain legume intercrops may benefit such as better use of resources, weed management, reduction in pest and diseases, increased protein content of cereals, and reduced nitrogen leaching as compared to sole cropping system. This will helpful in cost management and soil fertility enrichment.

Increasing biodiversity

Climate change and biodiversity are closely linked. Climate change has severe direct and indirect impacts on biodiversity and is predicted to be a dominant driver of future biodiversity loss; at the same time, the loss of biodiversity magnifies the adverse effects of climate change. There are several other drivers of biodiversity loss including habitat degradation/destruction and the introduction of invasive alien species to ecosystems. In the same way, biodiversity protection and climate change mitigation go hand – in - hand and are strongly co - dependent. Managing and protecting biodiversity will mitigate the negative impacts of climate change and help humans adapt to it; policies and actions aiming at limiting the effects of climate change will contribute to the protection of biodiversity.

Carbon sequestration

The term “carbon sequestration” is used to describe both natural and deliberate processes by which CO_2 is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments (vegetation, soils, and sediments), and geologic formations. The balance between C added to the soil and C emitted from the soil determines whether the overall C levels in a given soil increase or decrease (Schlesinger, 1995) [37]. Human actions strongly influence the C balance in managed soils. Soil management techniques such as no-till systems may result in lower CO_2 emissions from and greater C sequestration in the soil as compared to management systems based on intensive tillage (Post *et al.* 2004, Lokupitiya *et al.*, 2006) [34, 22] although some recent studies have indicated that no-till systems may simply result in higher C accumulations in the upper 15–20 cm of the soil with no increase in C when the entire soil profile is considered (Bakker *et al.* 2007 and Blanco-Canqui *et al*, 2008) [3, 9]. Other management changes such as using cover crops, crop rotations instead of monocropping, and reducing or eliminating fallow periods can lead to C sequestration in soil (Post *et. al.* 2004) [34]. Sequestration of C tends to be rapid initially with declining rates over time (Silver, 2000) [39]. Most agricultural soils will only sequester C for about 50–150 years following management changes before they reach C saturation (Mosier, 1998) [25].

Avoiding burning of crop residues

Bush burning as a traditional practice of clearing the farm land contributes to the emission of GHGs such as CO_2 and CH_4 which adds to the atmospheric stock of gases thus, increasing global climate change. Stubble burning mainly done by the farmers to quickly clear the field for succeeding crop, kills weeds, including those resistant to herbicide, kills slugs and other pests, can reduce nitrogen tie-up. However, it has a number of harmful effects on the environment like loss of nutrients, pollution from smoke. Hence, there is need to abolish the practice of bush burning and the emission of gases that result from the process. This could be achieved through clearing and raking of the grasses with the use of farm tools or alternatively allowing the grasses to decompose and increase the fertility of the soil. A soil that is fertile would ensure the release of nutrients for better production of crops.

Conclusion

Various studies have shown that the growth of plants with C3 photosynthetic pathway tends to be stimulated more by CO_2 enrichment than is the growth of C4, plants. Therefore the future increase in the atmospheric CO_2 concentration might increase the competitive impact of C3 weeds in C4 crops while decreasing the impact of C4 weeds in C3 crops. Several weeds will exert additional pressure for crop-weed competition under the climate change scenario. The studies reviewed here suggest that any positive impact of climate change on crop growth may be nullified by higher responses from weeds. Weeds tend to show better survival mechanisms under changing climate because of their greater interspecific genetic variation and physiological plasticity. Furthermore, herbicide properties are significantly influenced by environmental conditions before, during, and after application. Current weed management strategies that rely heavily on herbicide usage may have altered effects on these aggressively growing weeds in future climatic conditions. Integrated crop and animal production, use of intermediate and catch crops and cover crops, compost application, crop rotation and diversification, and zero or reduced tillage have potential to improve soil carbon sequestration and reduce greenhouse gas emissions. More adaptive research studies, including complex research conditions, could yield useful solutions for managing yield reduction in the ensuing decades owing to climate change.

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