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Review Article

Review on Impact of Climate Change on Weed and Their Management

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Abstract: The global climate is changing; along with measuring temperature and CO_2 level changes that are considered major drivers of climate change, there is also increasing attention being given to its impact on agricultural production systems (including weeds). Climate conditions exert a significant influence on the spread, population dynamics, life cycle duration, infestation pressure and the overall occurrence of the majority of agricultural pests. Weeds are among the agricultural pest that can be influenced by climate change. It is expected that climate change will bring about a shift in the floral composition of several ecosystems at higher latitudes and altitudes, as changes in temperature and humidity will be reflected on flowering, fruiting and seed dormancy. Changes in atmospheric CO_2 levels, rainfall, temperature and other growing conditions will affect weed species 'distribution and their competitiveness within a weed population and within crop. Any factor which increases environmental stress on crops may make them more vulnerable to attack by insects and plant pathogens and less competitive with weeds. Many of these weeds reproduce by vegetative means and recent evidence indicates that as a group, these weeds may show a strong response to recent increases in atmospheric CO_2. Changing and increment of temperature is one main characteristics of climate change which may affect existing plants (weeds shift) and allow some other plants (weeds) to replace native and will be expand in to new areas which is not existed before. Even under drought condition some weeds produce allele-chemical that made weeds to thrive well and compete with crop. An increase in root: stem, with increases in the growth of roots or rhizomes, particularly of perennial weeds, may make it harder to control some weeds that regrow from root fragments left after mechanical tillage. The direct impacts of climate change will be either on the biology of the biological control agent and/or on the ability of the host plant to resist, tolerate or compensate for the presence of the herbivore or plant pathogen. Increased temperature would be expected to increase the rate of life cycles of both the biological control agents and the weeds. Increased water stress will affect the host plant's development, and through this, the development of biological control agents, so they might be less effective in drier situations.

Keywords: Weed, Weed Control Methods, Temperature, CO_2 and Precipitation

1. Introduction

Global change stressors, including climate change, variability and changes in land use, are major drivers of ecosystem alterations. Climate is the principal determinant of vegetation distribution from regional to global levels. The global climate is changing; along with measuring temperature and CO_2 level changes that are considered major drivers of climate change. Although much attention is paid to potential effects of climate change on fascinating mega fauna, such as polar bears, there is also increasing attention being given to its impact on agricultural production systems, including weeds [1] [2] [3].

Climate conditions exert a significant influence on the spread, population dynamics, life cycle duration, infestation pressure and the overall occurrence of the majority of agricultural pests [4]. It is expected that it will bring about a shift in the floral composition of several ecosystems at higher latitudes and altitudes, as changes in temperature and humidity will be reflected on flowering, fruiting and seed dormancy. Moreover, weeds are among the agricultural pest that can and will be influenced by climate change. In general, any direct or indirect consequence of increasing CO_2 or climate change, which differentially affects the growth or fitness of weeds and crops, will alter crop weed competitive interactions [5]. Moreover it also exert a significant influence on the spread, population dynamics, life cycle duration, infestation pressure and the overall occurrence of the majority of agricultural pests [6] [7].

Furthermore, change in atmospheric CO_2, rainfall and temperature will affect weed species distribution, and prevalence within weed and crop communities. Climate change may also necessitate adaptation of agronomic practices, which in turn influence weed growth and proliferation of certain weed species [8]. An increase in extreme events, such as cyclones, storms and associated floods which are the main characteristics of climate change may increase the dispersal of weed species with efficient seed-dispersal systems (wind, water and birds) will disperse more quickly than weeds that rely on vegetative dispersal move seeds or pollen which enable them to invade new ecosystems [5]. In addition to effect of climate change on composition of weed flora and distribution it can also influence effectiveness of weed management. It is also hypothesized to change along with the change of environmental conditions. Therefore the objective this paper is to review the effect of climate changes on weed floral composition, distribution and some weed control methods.

2. Discussion

2.1. Climate Change and Agricultural Pests

The earth is warmed largely by short wave radiation (0.15-4.0 µm) emanating from the sun which has a high temperature 6000°C. The earth's intercepts only a part of this radiation and the warmed earth's surface re emits its own radiation [9].

Atmospheric gases, particularly water vapor, CO_2 and other trace gases reabsorb terrestrial radiation leaving the earth at a particular wavelength, while being transparent to incoming solar radiation. The effect is to warm the earth's surface to an average of 15°C which allow life on the earth to be first establish. This is the natural greenhouse effect of the atmosphere, so called because of it is similar to the effect produced by the gases inside an actual greenhouse [10]. Over the last two centuries, coinciding the coming decades, global change will have an impact on food and water security in significant and highly uncertain ways, and there are strong indications that developing countries will bear the burden of the adverse consequences, particularly from climate change [11].

Climate conditions exert a significant influence on the spread, population dynamics, life cycle duration, infestation pressure and the overall occurrence of the majority of agricultural pests including weeds [4]. Weeds are among the agricultural pest that can and will be influenced by climate change.

2.2. Climate Change and Weeds

2.2.1. Weed Floral Composition and Distribution

The impacts of climate change on single species and ecosystems are likely to be complex. In the case of aggressive weed species of tropical and sub-tropical origins, which are currently restricted to Mediterranean environments, future climatic conditions may lead to an expansion of their potential range into temperate regions. However, in contrast to crops, weeds are troublesome invaders, ecological opportunists and resilient plants with far more genetic diversity. Weed populations include individuals with the ability to adapt and flourish in different types of habitats. Any factor which increases environmental stress on crops may make them more vulnerable to attack by insects and plant pathogens and less competitive with weeds. The geographical and seasonal distribution of pests likely will change as the climate changes. The physiological plasticity of weeds and their greater intra specific genetic variation compared with most crops could provide weeds with a competitive advantage in a changing environment events such as cyclones, flooding, drought and fires (from high temperature) will become more common and weeds will be the first to gain a stronghold after these events [5].

Table 1. *Potential impacts of climate change on weeds significant to agriculture.*

Common name	Scientific name	Expect impact
Blackberry	*Rubus fruticosus L. agg.*	Expected to retreat south wards and to higher altitudes because it is sensitive to higher temperature and drought
Chilean needle grass	*Nassella neesiana* (Trin. & Rupr.) Barkworth	Expected to increase its ranges because it highly invasive (long lived, seed dispersal by wind and water) and drought tolerant.
Gorse	*Ulex europaeus* L.	Expected to retreated southwards because it is drought sensitive
Lantana	*Lantana camara* L.	Expected to continue its moves southwards into high rainfall zone of northern new south wales.
Mesquite	*Prosopis glandulosa* Torr.	Some risk that it may move into lower rainfall areas because it is very drought tolerant
Parthenium	*Parthenium hysterophorus* L.	Not suited to winter dominant rainfall areas, may move into summer dominant high rainfall (> 500mm) region
Serrated tussock	*Nassella trichotoma* (Nees.) Hack.ex Arechav.	Expected to retreat southwards and to higher altitude because it is sensitive to temperature As drought tolerant plant, it should become more invasive in an areas where temperature allows
Prickly acacia	*Acacia nilotica*	Expected to move southwards and into arid areas

[12]

There are also mitigation and adaptation mechanism to climate change which might affect the composition and distribution of weeds (sleeper weeds will come to flourish).

2.2.2. Weed Biomass

i. Carbon Dioxide

CO_2 is the sole source of carbon for photosynthesis and at present 96% of all plant species slack optimal CO_2. The current atmospheric CO_2 concentration is sub-optimal for photosynthesis in C_3 plants. However, plants with C_4 photosynthetic pathway have an internal mechanism for concentrating CO_2 at the site of fixation [13].

Weeds have a greater genetic diversity than crops. Consequently, if a resource (light, water, nutrients or carbon dioxide) changes within the environment, it is more likely that weeds will show a greater growth and reproductive response. It can be argued that many weed species have the C_4 photosynthetic pathway and therefore will show a smaller response to atmospheric CO_2 relative to C_3 crops. However, this argument does not consider the range of available C_3 and C_4 weeds present in any agronomic environment. That is, at present, the U.S. has total of 46 major crops; but, over 410 "troublesome" weed species (both C_3 and C_4) associated with those crops [14]. Hence, if a C_4 weed species does not respond, it is likely that a C_3 weed species will. In addition, many growers recognize that the worst weeds for a given crop are similar in growth habit or photosynthetic pathway; indeed, they are often the same uncultivated or "wild" species, e.g. oat and wild oat, sorghum and shatter cane, rice and red rice. To date, for all weed/crop competition studies where the photosynthetic pathway is the same, weed growth is favored as CO_2 is increased [15].

[16] Observed significant increase in photosynthesis and decrease in stomata conductance in C_3 weed (*Chenopodium album*) but no change in *Amaranthus retroflexus* (C_4 weed) at elevated CO_2 level. Many of these weeds reproduce by vegetative means (roots, stolons, etc.) and recent evidence indicates that as a group, these weeds may show a strong response to recent increases in atmospheric CO_2 [17]. How rising CO_2 would contribute to the success of these weeds in situ however, is still unclear.

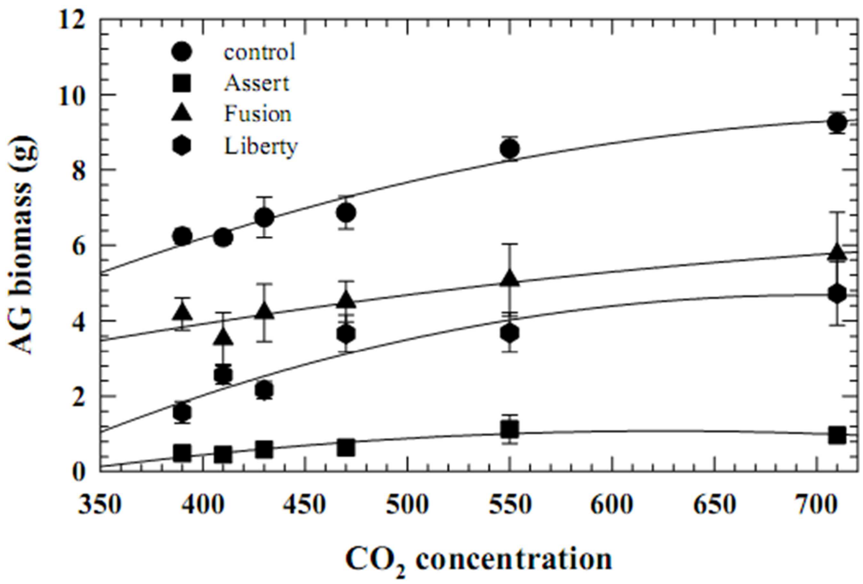


Figure 1. *Effects of increasing CO_2 levels on above-ground biomass production of wild oats under different herbicide application [18].*

ii. Temperature

Temperature determines type, distribution and life cycle duration of plants in particular area. Changing and increment of temperature is one main characteristics of climate change which may affect existing plants (weeds shift) and allow some other plants (weeds) to replace native and to expand in to new areas which is not existed before. Increasing temperatures may mean an expansion of weeds into higher latitudes or higher altitudes. Studies have shown that itch grass, a profusely tillering, robust grass weed could invade the central Midwest and California with only a 3° warming trend [19]. Witch weed, 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°c 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 [15].

iii. Precipitation

Response to drought in agronomic conditions is dependent on species and cultural conditions. Any factor which increases environmental stress on crops may make them more vulnerable to attack by insects and plant pathogens and less competitive with weeds. Even under drought condition some weeds produce allele-chemical that made weeds to thrive well and compete with crop [19].

The C_4 photosynthetic pathway provides its greatest advantage under hot, arid high light conditions. C_4 plants have higher water use efficiency than C_3 plants. Competition between C_3 and C_4 weeds has been examined in relation to soil moisture regime [20], C_3 plants are dominant in submerged soils; C_4 plants are dominant in dry land soils. Submergence protects rice plants from severe competition with C_4 weeds.

On the other hand, upland rice and rainfed lowland rice with limited precipitation face severe competition with C_4 weeds. Under imposed drought, [21] found that the effects of water stress and significantly increased leaf area and total dry weight of the three C_4 grasses: *Echinochloa crus-galli, Eleusine indica* and *Digitaria ciliaris*. The Author also concluded that CO_2 enrichment can increase the growth of both C_3 and C_4 plants under water stress, but growth stimulation can be expected to be greater in C_3 plants.

Weeds of rangelands like cheat grass (*Bromu stectorum*) and yellowstar thistle (*Centaurea solstitiali s* L.) depend largely on available soil moisture forseed germination. Prolonged or heavy winters that greatly enrich the soil moisture favor increased seed production of both the species [19]. Interestingly, both species are also drought adapted. The adoption of cheat grass for drought evidence is shorter life span whereas, deeper root system to endure drought helps star thistle, compared to other native species. Increase in snowfall or a change in snowfall variability is suggested to exacerbate the invasion of forbs in mixed-grass prairie ecosystem which in turn could influence the forage availability [22]. Soil moisture stress promoted greater herbivore tolerance for the invasive *Alternan theraphiloxeroides* and decreased it for the native congener *A. sessilis* [23].

2.3. Weed Management Under Climate Change

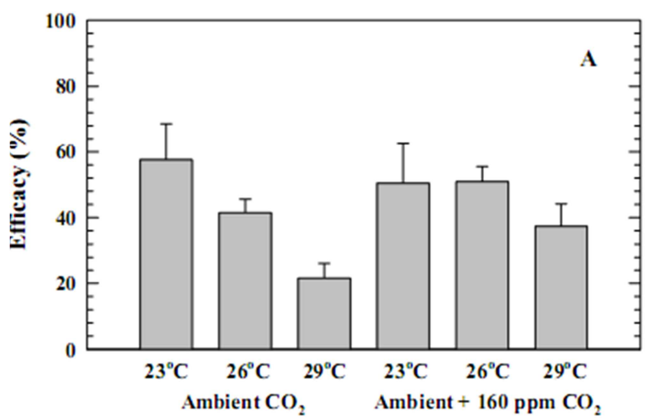
Effectiveness of weed management is also hypothesized to change along with environmental conditions. Weeds that are under moisture stress can respond by thickening their leaf cuticles, slowing down vegetative growth and flowering rapidly. Drought stressed weeds are more difficult to control with post-emergent herbicides than plants that are actively growing for example, systemic herbicides that are translocate within the weed need active plant growth stage to be effective. Pre-emergent herbicides or herbicides absorbed by plant roots need soil moisture and actively growing roots to reach their target sites. Occurrence of drought has the potential to reduce the effectiveness of pre-emergent herbicides [5]. Overall; there are strong empirical reasons for expecting climate and/or rising CO_2 to alter weed management. Adaptation strategies are available, but the cost of implementing such strategies (e.g. new herbicides, higher chemical concentrations, new bio control agents) is unclear.

2.3.1. Chemical Weed Control

Clearly, any direct or indirect impacts from a changing climate will have a significant effect on chemical management. Changes in temperature, wind speed, soil moisture and atmospheric humidity can influence the effectiveness of applications. For example, drought can result in thicker cuticle development or increased leaf pubescence, with subsequent reductions in herbicide entry into the leaf. These same variables can also interfere with crop growth and recovery following pesticide application. Overall, pesticides are most effective when applied to plants that are rapidly growing and metabolizing, i.e. those free from environmental stress. Environmental factors such as temperature, precipitation, wind and relative humidity influence the efficacy of herbicides [18].

Most of the herbicides required optimum temperature for their activity (function). But prolonged high temperature after application (pre plant pre and post emergent herbicides) the efficiency and selectivity may affected. That means at high temperature, selective herbicides may become nonselective. There are an increasing number of studies [24] that demonstrate a decline in chemical efficacy with rising CO_2. But some scholar suggest that as CO_2 increases the growth and development of some weeds (C_3) will increase and plant can develop immunity that can tolerate or detoxifying mechanism (high tissue volume). Recent work with Canada thistle grown in monoculture under field conditions suggested a greater root to shoot ratio and subsequent dilution effect of glyphosate when grown at elevated CO_2 [25]. The scholar pointed out CO_2 does reduce efficacy of the herbicides. However, then additional work is needed to determine herbicide specificity, concentration and application rates as possible means of adaptation.

Furthermore, there is the possibility that increased CO_2 and temperature will reduce the effectiveness of herbicides, requiring an increase in frequency of application and concentration of herbicide to obtain adequate control [26]. Similarly although the effects of elevated atmospheric CO_2 concentrations on weed/crop/herbicide interactions are not well known, a recent study [18] showed that elevated CO_2 levels diminished the efficacy of the widely used herbicide glyphosate. If these effects are common and widespread, they will have a significant impact on agriculture. Moreover, according to [5] weeds that are under moisture stress can respond by thickening their leaf cuticles, slowing down vegetative growth and may flower rapidly. Drought stressed weeds are more difficult to control with post-emergent herbicides than plants that are actively growing for example, systemic herbicides that are translocate within the weed need active plant growth stage to be effective. Pre-emergent herbicides or herbicides absorbed by plant roots need soil moisture and actively growing roots to reach their target sites. Occurrence of drought has the potential to reduce the effectiveness of pre-emergent herbicides.



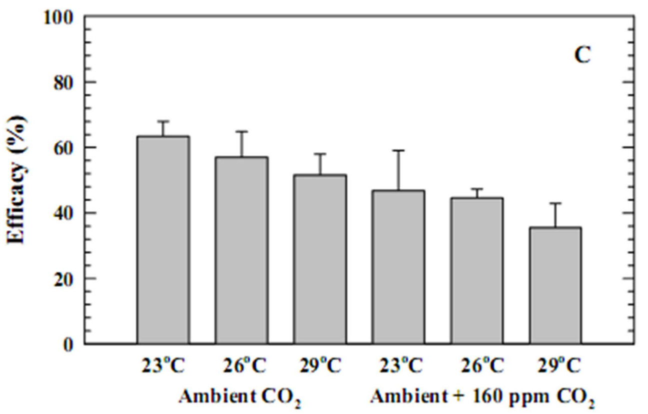


Figure 2. *Herbicide efficacy of Fusion (A), and Liberty (C) applied to wild oats grown at different temperatures at ambient or ambient + 160 ppm CO_2 [18].*

In general different scholar at different time suggests their own idea on the possible effects of climate change on chemical weed control methods. These are

(1) Greater root to shoot ratio leading to subsequent dilution effect on glyphosate when grown at elevated CO_2 (e.g. Canada thistle, [25].
(2) Decreased stomatal aperture or number, cuticle thickening, development or increased leaf pubescence with subsequent reductions in herbicide entry into the leaf.
(3) Altered transpiration leading to reduced uptake of soil herbicides.
(4) Changes to the wetting and drying of soil profiles affecting microbial activity and herbicide degradation.
(5) Increased temperatures affecting the efficacy and selectivity of herbicides [27] [28].
(6) Increased growth rate implying narrower temporal windows in which to apply herbicides before crop yield losses from weed competition and before weed set.
(7) High temperatures, low relative humidity and unsuitable wind conditions reducing the window of spraying opportunity [1].

2.3.2. Mechanical Weed Control

A standard means of controlling weed populations, and the one most widely used in developing countries is mechanical removal. Tillage (by animal or mechanical means) is regarded as a global method of weed control in agronomic systems. Under heavy frequent rainfall carrying out of tillage and other mechanical weed control methods will very difficult due to logging of soil and under condition undertaking of cultivation will help to reduce soil moisture which may decrease the growth of crop plant and make less competitive with weeds. Elevated CO_2 could lead to further below ground carbon storage with subsequent increases in the growth of roots or rhizomes particularly in perennial weeds [29]. Consequently, mechanical tillage may lead to additional plant propagation in a higher CO_2 environment, with increased asexual reproduction from below ground structures and negative effects on weed control [25].

2.3.3. Competitive Species

Cultural control methods (fire, competitive crops, cultivation etc.) have a place in both agricultural and environmental weed control. These weed control methods either change successional processes (by cultivation or fire) reducing plant competition for some species, or can involve direct competition between a crops and weed germinating at the same time. The impact of climate change on plant competition may become apparent through changes in the root: stem. An increase in root: stem, with increases in the growth of roots or rhizomes, particularly of perennial weeds, may make it harder to control some weeds that regrow from root fragments left after mechanical tillage (e.g. Canada thistle (*Cirsiumarvense*), [25]. Examples of weeds that may respond in a similar manner are skeleton weed (*Chondrilla juncea*), and silver leaf nightshade (*Solanumelae agnifolium*) [26].

2.3.4. Biological Control

Biological control involves the introduction of host-specific agents, usually insects or fungi, for the control of a weed species. The biological control agents have evolved to feed only on the target plant [28] (Darren, 2010). Most bio-control systems perform best under a stable environment. However, in addition to the forecast increase in mean temperatures, a CO_2 and shift in rainfall distribution climate variability is expected to increase. Extreme weather events such as droughts, flood and even unseasonal frosts are predicted to occur more frequently. While many species have mechanisms to cope with extremes, they require time to acclimatize and/or enter the resistant state. The relative vulnerability of the host plants, and biocontrol agents to extremes of temperature, desiccation or flooding will determine whether the drought or flood will be followed by a weed or pest outbreak [30] (Gerard *et al*., 2010). Moreover, according to [30] increases in CO_2, changes in water availability and increases in temperature will alter plant phenology, growth and distribution, all of which will have flow on effects on the plant herbivores and those that prey on them. Aspects of plant life cycle events controlled by temperature, such as the timing and duration of seed germination, bud burst, and flowering, are likely to change with warmer temperatures, subject to photoperiod and water availability. Similarly, the degree that individual species benefit will depend on how well the life cycle events are synchronized to ensure optimum survival. Changes in host plant quality in response to elevated CO_2, drought or flooding may also cause shifts in herbivore and natural enemy fitness. In general, elevated CO_2 leads to a decrease in the nutritional value of plants. There is a tendency for foliage feeders to consume more plant material (greater damage), but to grow and develop more slowly, and have reduced fecundity and survival.

The direct impacts of climate change will be either on the biology of the biological control agent and/or on the ability of the host plant to tolerates or compensate for the presence of the herbivore or plant pathogen. Increased temperature would be expected to increase the rate of life cycles of both the biological control agents and the weeds. Increased water stress will affect the host plant's development, and through this, the development of biological control agents, so they might be less effective in drier situations. Increase in greenhouse gases will also affect the herbivore plant relationship so impacts at both the spatial and temporal scales are possible [26]. Changes in temperature can influence production of plant defense compounds against plant herbivores. It is known that levels of many insect-resistance allelochemicals increase during drought [30].

At the spatial scale, the effects of moisture and temperature are likely to play out through differential changes in the preferred distribution of the agents and target weed. For example, an increase in temperature may enable biological control agents from subtropical areas to survive on weeds in more temperate regions. Some examples are the agents of aquatic weeds such as salvinia (*Salvinia molesta*) and alligator weed (*Alternanther aphiloxeroides*), and the agents of terrestrial weeds such as prickly pear cactus (*Opuntia* spp.) which may be favored in southern regions of their distribution. Understanding of the agent's and the weed's physiology, capacity for evolution, and dispersal is needed to determine the potential for a weed to migrate under climate change and "escape" their control agents [26].

CO_2 could alter the efficacy of weed bio-control agents by potentially altering the development, morphology and reproduction of the target pest. Direct effects 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 [19], warming could also result in increased overwintering of insect populations and changes in their potential range. Although this could increase both the biological control of some weeds, it could also increase the incidence of specific crop pests, with subsequent indirect effects on crop-weed competition. Overall, synchrony between development and reproduction of biocontrol agents and their selected targets is unlikely to be maintained in periods of rapid climatic change or climatic extremes.

According to [26] who list the range of possible impacts (based on generally polyphagous invertebrate herbivores) identified in a meta-analysis of CO_2 induced changes on plant chemistry and herbivore performance. The impacts included:

(1) Significantly decreased herbivore abundance (-21.6%).
(2) Increased: relative consumption rates by herbivores (+16.5%) development time (+3.87%); and total consumption (+9.2%).
(3) Significantly decreased: relative growth rate (-8.3%); conversion efficiency (-19.9%); and pupal weight (-5.03%).
(4) No difference between herbivore associations.
(5) Plants showed significantly larger biomass (+34.4%), increased C: N (+26.57%), decreased N concentration (-16.4%), increased tannins (+29.9%), and other phenolics.

3. Conclusion

Climate conditions exert a significant influence on the spread, population dynamics, life cycle duration, infestation pressure and the overall occurrence of the majority of agricultural pests. Weeds are among the agricultural pest that can and will be influenced by climate change. Changes in atmospheric CO_2 levels, rainfall, temperature and other growing conditions will affect weed species distribution and their competitiveness within a weed population and within crop. Climate conditions exert a significant influence on the spread, population dynamics, life cycle duration, infestation pressure and the overall occurrence weeds. It can be argued that many weed species have the C_4 photosynthetic pathway and therefore will show a smaller response to atmospheric CO_2 relative to C_3 crops. Rising global temperature may give competitive advantage to C_4 plants than C_3. This differential response of C_3 and C_4 plants will alter crop weed interaction because of the fact that majority of weeds are C_4 and most of the food grain crops are C_3. Higher levels of carbon dioxide could stimulate the growth of some weed species and greater production of rhizomes and tubers in perennial weeds which can make weed management very difficult. Effectiveness of weed management is also hypothesized to change along with environmental conditions.

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