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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(8): 1307-1310

www.thepharmajournal.com
Received: 08-05-2022
Accepted: 14-06-2022

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Weed management problems and prospects under changing climate scenario

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Abstract
It has become increasingly challenging for agricultural researchers to feed the world's growing population due to the rapidly changing climatic conditions. The environmental factors *viz.,* enhanced carbon dioxide concentration, rising temperature and shifting of rainfall pattern can alter the growth and physiology of weedy plants. These singularities also affect regional and local climates, resulting in significant influences on the agricultural systems of a particular region. In comparison to C_4 plants, higher CO_2 levels may give C_3 plants comparative benefits through greater photosynthesis, biomass production, and yield. On the other hand, plants with C_4 photosynthetic pathways are projected to gain more from an increase in global temperatures than C_3 plants, which resulted in weed species shift in a particular agroecosystem. These changes could modify weed management options to manage or control invasive and more tolerant weed species. The efficacy of herbicides and any other single weed control measures will not address the current situation, the focus should be on sustainable weed management in both natural- and agro-ecosystems to manage such invasive and troublesome weeds. This review has presented a holistic idea to the current research and has shown key deficiencies which need further attention to combat global climate change.

Keywords: Weeds, climate change, temperature, herbicides, biological control

1. Introduction

In recent decades, climate change has caused significant impacts on the agricultural ecosystem. It is evident that food security, be either availability, accessibility, utilization and system stability is mainly dependent on the region's climate conditions. To sustain food grain production and food security for the increasing population in the world, there is an urgent need to discover vulnerabilities and adaptive measures in managed ecosystems (Ramesh *et al*., 2017) [16]. The growth of all plant species, including weeds and crops, is significantly impacted by changes in weather conditions. Rising atmospheric CO_2 and temperature are anticipated to have an impact on food security through both direct and indirect effects on agricultural production, sustainability, and water availability (Chauhan *et al*., 2014) [3].

The predominance of weed species within weed and crop ecosystems will alter as a result of climate change. Agronomic techniques may need to be modified as a result of climate change, which in turn affects weed growth and the spread of specific weed species. At the more subtle level, it is recognized that weeds are aggressive, troublesome, and competitive elements within croplands. Contrary to other pests, weeds share a similar trophic level with crop plants, and by competing for scarce resources they cause enormous crop yield losses (Tesfay Amare, 2016) [18]. Weed species with effective seed-dispersal systems (wind, water, and birds) will disperse more quickly to invade new ecosystems. Climate change led to increased extreme weather events, such as cyclones, storms, and associated floods, which may increase the dispersal of weed species. In addition to having an impact on the distribution and composition of weed flora, climate change can also affect weed management practices.

2. Climate change nexus weeds

2.1 Weeds *vs* carbon dioxide

According to climate predictions made by the Intergovernmental Panel on Climate Change (IPCC), CO_2 atmospheric concentration will rise (730–1000 $mmol^{-1}$) by the end of the 21st century (Varanasi *et al*., 2015) [20]. The results of the experiment revealed that application of cyhalofop-butyl @ 1.09 l ha^{-1} reduced the herbicide efficacy on multi-resistant (MR) *E. Colonum* plants grown under high CO_2 by about 50% compared to MR plants under ambient conditions (Reffati *et al*., 2019).

Laforest *et al*. (2017) [6] recorded that resistance to herbicides belonging to ACCase inhibitors in *Digitaria sanguinalis* L. is due to overexpression of ACCase. The other researchers also reported reduced herbicide efficacy under elevated carbon dioxide for weed species having C_3 and C_4 pathways (Manea *et al*., 2011) [7].

2.2 Weeds *vs* Temperature

The distribution of weed species in a given region is significantly influenced by the atmospheric temperature. Its increase could change cereal crop stands as well as weedy vegetation's competitive behaviour and weed proliferation. According to Tubiello *et al*. (2007) [19], the increased temperature coupled with elevated CO_2 may favor C_4 weeds over C_3 weeds (Mohamed *et al*., 2007) [10]. Under elevated temperature conditions, significantly higher efficacy was observed in sensitive plants by application of cyhalofop-butyl compared to multi-resistant genotypes of *E. colonum*. These include the rate of water absorption and transpiration, the rate of leaf development, cuticle thickness, stomatal number and aperture (Reffati *et al*., 2019). The activity of mesotrione on Palmer amaranth declined when the temperature increased from 25 to 40 °C. The results reported by Matzrafi *et al*. (2016) [8] on the reduction in the activity of pinoxaden (an ACCase inhibitor) on *Brachypodium hybridum* and other grasses under high temperatures. The increase in current temperatures can cause weed species such as *A. retroflexus, Setaria* spp., *Digitaria* spp., *P. dichotomiflorum*, and *S. halepense* are expected to extend their distribution range to locations further north (Peters *et al*., 2014) [15]

2.3 Weeds *vs* Precipitation

Weed species and other management factors show an impact on crop growth and development under varied rainfall conditions. Crops may become more susceptible to attack by biotic and abiotic factors and less competitive with weeds if any element makes the environment more stressful for them. Some weeds even develop allele chemicals that enable them to grow and compete with crops during stress conditions. Many studies suggested that C_4 and parasitic weeds like *S. hermonthica* would thrive better in extended drought periods. Weeds like *Rhamphicarpa fistulosa* (Hochst.) Benth. will thrive in areas with an abundance of water. Hydromorphic weeds would gain from a shift in rainfall patterns, whereas C_4 weeds would benefit more from prolonged droughts than C_3 weeds (Ramesh *et al*., 2017) [16]. Certain weed species *viz.*, competition of cotton with *Abutilon theophrasti* Medic. and *Anoda cristata* (L.) Schltdl. increased under severe drought conditions (Patterson and Highsmith, 1989) [14] and according to Mortensen and Coble, (1989) [11] A yield reduction due to *Xanthium strumarium* L. was more pronounced in well-watered soybeans compared with water-stressed soybeans.

3. Weed management vs climate change

In general, climate change affects the cropping system's weed management options due to changes in atmospheric temperature, elevated CO_2 and varying levels of precipitation and prolonged drought spells. The weeds may withstand such changes in environmental factors over crop plants. The competition will be severe for growth resources between plants and weed species as the abundance of weed species are present in the seed bank. Weed management under changing climate parameters is only left with a few options. In response to moisture stress, weeds may thicken their leaf cuticles, slow down their vegetative growth, and produce more flowers quickly. For example, systemic herbicides that are translocated within the weed need an active plant growth stage to be effective, making it more difficult to treat drought-challenged weeds using post-emergent herbicides than plants that are actively growing. For pre-emergent herbicides or herbicides absorbed by plant roots to reach their target areas, the soil must be moist and the plants must be actively producing roots. Drought can lessen how effective pre-emergent herbicides are.

3.1 Cultural methods

Management of weeds species through cultural practices is the best ecological technique. Cultural practices *viz.*, growing competitive crops, hand hoeing, stale seedbed, crop rotation have a place in both agricultural and environmental weed control. These weed control techniques may alter successional patterns, which lessens plant competition between crops and weeds that are competing at the same time. However, certain weed perennial weed species are difficult to control that regrow from root fragments left after mechanical tillage (e.g. Canada thistle (*Cirsium arvense*), (Ziska *et al*., 2004) [21]. Examples of weeds that may respond in a similar manner are skeleton weed (Chondrilla juncea), and silver leaf nightshade (*Solanumelae agnifolium*) (Darren *et al*., 2010) [4].

3.2 Chemical weed management

Under the current scenario, chemical weed management is the viable option to control the broad spectrum of weed species at the least cost. The efficacy of herbicides will depend on the time of application and climate factors (Ziska, 2020) [22]. Herbicide coverage, persistence, mode of action, efficacy, and selectivity may be affected by climatic variables such as temperature, CO_2, soil moisture, wind speed, etc. (Bailey, 2003) [2]. Higher temperature and precipitation could affect the selectivity and efficacy of pre-and post-emergence herbicides (Medd *et al*., 2001) [9].

Under higher temperatures than optimum resulted in even a selective herbicide may become non-selective. Moreover, elevated temperatures than normal may lead to a shorter application window before the onset of the crucial crop-weed competition period. The research results reported by Patterson *et al*. (1999) [13] opined higher temperatures increase metabolic activity which resulted in higher efficacy of applied herbicides. The effectiveness of flumetsulam against *Raphanus raphanistrum* and clodinafop-propargil against *Avena* spp. (Medd *et al*., 2001) [9] are both clearly impacted by temperature.

According to Patterson and Flint (1990) [12] elevated CO_2 levels reduced the efficacy of applied herbicides in perennial weeds, which are more abundant in nature and difficult to control. Greater increases in biomass will result in dilution of herbicide applied, making weed control more difficult and costly. There are an increasing number of research studies on the declining chemical efficacy of herbicides with rising CO_2. In Canada thistle (*Cirsium arvense* L. Scop.), increased CO_2 levels induced root and shoot growth which resulted in failure to kill roots and regeneration of the whole plant (Ziska, 2020) [22]. The reduced efficacy of the widely used herbicide glyphosate due to elevated CO_2 has been confirmed by many researchers (Medd *et al*., 2001) [9]. Moisture stress or drought has the potential to reduce herbicide efficacy. Different consequences of drought-like decreased stomatal aperture, cuticle thickening, and increased leaf pubescence might limit herbicide entry into the leaf with a subsequent reduction in herbicide efficacy (Bailey, 2003) [2]. Reduced uptake of soil-applied herbicides due to altered transpiration under drought conditions is documented.

3.3 Biological weed management
To manage the weed biological agents such as insects, fungi and other bioagents present in the ecosystem. These bioagents should be host specific and have introduced feed only on the target weed plant (Darren, 2010) [4]. The majority of the bioagents require stable environmental factors to perform better and control the weeds in the region. However, under changes in climatic factors *viz*., increased temperatures, elevated CO_2 and shift in rainfall distribution the ability of bioagents to feed on targeted weeds will be altered. It is anticipated that extreme weather occurrences including droughts, floods, and even unseasonal frosts would happen more frequently. Although many species have the ability to withstand extremes, it takes time for them to adapt or reach a resistant condition. Whether a drought or flood will be followed by a weed or pest epidemic depends on how susceptible the host plants are to temperature, CO_2 levels and flooding extremes and how resistant the biocontrol agents are to these conditions. (Gerard *et al*., 2010) [5].

4. Weed shift and management
In Agroecology systems, weed species shift is a significant result of climate change that has an impact on weed control methods and agricultural productivity. Due to changes in the atmospheric variables, some of the plant species will adapt to the new changes while other new species will be more dominant in the changing environment. The new dominant weed species in the agroecology system is difficult to control or manage with the existing weed management options. Pautasso *et al*. state that plant species have three ways to prevent extinction: (i) migration to a favorable climate through dispersion mechanisms; (ii) acclimation to changes in climate conditions by utilizing their phenotypic plasticity; or (iii) adaptation to changes in climate conditions through evolutionary changes.

According to Anwar *et al*. (2020) [1] expansion of weed species *Pueraria lobata,* distribution in the United Nations was limited to the Ohio Valley and the Mason–Dixon line by low winter temperatures but has now spread to northern areas. Patterson *et al*. (1999) [13] reported that itch grass (*Rottboellia cochinchinensis* (Lour.) W.D. Clayton), might invade the central Midwest and California with only a 3 °C warming trend. Due to climate change, many weed species which are troublesome in nature are distributed to different croplands An expansion in the geographic range of *Lonicera sempervirens* L. and *Pueraria lobata* (Lour.) Merr. are a few examples of invasive weeds spreading to cropland areas because of climate change (Anwar *et al*., 2020) [1]. In Australia, lowland weed species like lantana (*Lantana camara* L.) are expected to move into higher altitude areas (Bailey *et al*., 2003) [2]

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