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Biological control of weeds: A review

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Abstract
Weeds are one of the main constraints to agriculture and cause 10-80% crop yield loss besides reducing product quality and leading to health and environmental hazards. Traditionally, weed control in India has been largely dependent on manual weeding. However, increased labour scarcity and costs are encouraging farmers to adopt labour and cost saving options. In comparison to various weed management strategies, biological control offers an innovative approach to address this problem. Biological management of weeds includes the use of living organisms to decrease the effect of weeds to keep at or below desirable level without significantly disturbing the crop plants. It includes use of insects, pathogens, nematodes, parasitic plants and competition plants affecting the adoption of weed biological control and the challenges to promote them are being studied in this article.

Keywords: Biocontrol, constraints, herbicide, management, weeds

Introduction

Weeds are those notorious plants, which restrict the growth and productivity of the major crop, competing for light, soil moisture, minerals and other nutrients restricting them to exhibit their full yield potential as well as reducing the quality of the final produce (Roa and Nagamani, 2010, 2013; Roa *et al.*, 2015) [26-27]. In severe conditions, weeds can have more baleful effect than fungi, nematodes or any other insect-pests on the crop (Gharde *et al.*, 2018) [9]. Weeds are responsible for almost one- third yield losses as recorded around the world (DWSR, 2013) [6]. Nearly about 34% of the potential yield of the major crops like wheat, rice, maize, potatoes, soybean and cotton is threatened by the weed competition worldwide, whereas 16% and 18% of the total yield loss is contributed by phyto-pathogens and insect-pest, respectively (Oerke, 2006) [21]. A survey conducted by Indian weed scientists predicts that weeds can lead to an estimated yield loss ranging from 10% to a maximum of 100% (Roa *et al.*, 2014). A wholesome amount of US $13 Billion is lost, with a decline of 10% in the potential yields of food grains (Yaduraju, 2012) [31]. If the loss by weeds can be minimized, it will be enough to tackle the issue of malnutrition in the world.

The weeds everywhere not only become yield reducers but also harm the biodiversity and have negative impacts on the human and animal health. Breathing problems and skin allergies like contact dermatitis, eczema, asthma, etc. are caused by a worldwide weed named *Parthenium hysterophorus* L. (Aneja *et al.*, 1991) [3]. The environment also gets severely affected by weeds. Not only this, weeds are primary hosts to agricultural insect-pests, pathogens and microorganisms. Weeds being the major constraint, hence, an effective and efficient management system is the need of the hour keeping in mind that the ever-growing population of the world demands increased crop productivity of food grains. For the same, managerial methods have been developed and the process of development of a much sustainable method to control the weed menace is under process. Weeds can be controlled or managed by an integrated approach starting from prevention, eradication and control (Rana and Rana, 2016; Kelton and Price, 2009) [25, 15]. Among all the methods, herbicide usage is most commonly used and fastest method of eradicating the weed menace, but herbicidal application causes some negative effects such as adsorption on the soil particles leading to soil pollution; chemical residues leaching down to ground water causing water pollution; food we eat, gets contaminated; residues in the feed and fodder affects some non-targeted organisms. Due to the continuous and excessive usage of chemical herbicides, resistance is being developed among the already existing weed population (Rao and Nagamani, 2010) [26].

The herbicidal residues degrade the soil productivity and affect the soil microbial population (Rana and Rana, 2016) [25]. Above all these facts, the application of herbicides is expensive; the cost of buying the chemical (herbicides) from market as well as the cost of labor for its application in the field. For a small-scale farmer who is struggling to make a livelihood, it becomes burdensome to invest so much in such control measures where he has to spend more than what he earns back from it. Therefore, a more sustainable and effective management is needed to control the weed menace in the world.

Biological control is the most sustainable method among all other methods of weed management. This method of weed control is yet to be explored fully, but the scientists are working on it to find more control measures for the weed population that already exist in nature. A report stated that around 202 agents have been released against 56 weed species in Australia, 85 agents against 30 weed species in Canada, 53 agents against 23 weed species in New Zealand, 103 agents against 51weed species in South Africa, and 199 agents against 74 weed species in USA (Schwarzländer *et al.*, 2018).

Crop cultivars differ in their allelomimetic behaviors, from which superior cultivars can be successfully selected and used as a practice to control weeds (Wu *et al.*, 1999; Olofsdotter *et al.*, 2002) [30, 22]. The allelomorphic crops can be grown in the main field. For this one must exhibit proper knowledge about the important stages in the crop (when it releases the allelochemicals) and sensitive stages of the targeted weed (Inderjit *et al.*, 2005; Olofsdotter *et al.*, 1999) [14, 23].

Some viewpoints are there that weed biological control is risky and biological control agents may mutate or evolve or develop into new strains and feed on other plants, such as crops. There are also perceptions that the weed could be controlled by utilizing organisms where the weed is a problem. Other factors also affect opportunities for funding for biological control which may include the lack of resources and capacity, awareness on the impacts of invasive plants, regulations, processes, and infrastructure to facilitate the importation of biological control agents (Julien *et al*., 2007; Witt *et al*., 2014; Barratt *et al*., 2018).

Acquaintance of Biological Weed Management

Although 91 countries have undertaken weed biological control, there is still some scepticism about the discipline, even in those countries that have undertaken weed biological control previously, and/or have undertaken insect biological control (Cock *et al*., 2016). Common concerns are that weed biological control agents may attack other plant species once the weed is controlled, biological control agents could mutate and start attacking other plant species, or that they may evolve to attack other plant species. Such views are often based on the perception that after biological control “eradicates” the weed, the agent may then attack other plant species. These views reflect a lack of knowledge in the principles of weed biological control, which involves the use of co-evolved organisms collected from the target weed in its native range.

Herbicides are also widely used to manage weeds in some countries, especially in intensive cropping in Asia. However, while the negative impacts of herbicide use on human health and the environment have been well-documented, herbicides are still used indiscriminately in many regions (Igbedioh, 1991). Though widely used, both manual and herbicide control practices are costly and not sustainable, particularly in perennial ecosystems, such as plantations and grazing lands.

Biological Weed Control by using Plant Pathogen

Biological control of weeds by using plant pathogens has gained acceptance as a practically safe, environmentally beneficial, weed management method applicable to agroecosystems. The interest in this weed control approach from public and private groups and support for research and development effort are the upswing (Charudattan, 2001). The science of using plant pathogen to control weeds is almost as old as the science of plant pathology (Templeton *et al.*, 1979; Wilson, 1969) [8]. Wilson (1969) described previous efforts to use pathogens for control of cactus, mistletoe, aquatic and agronomic weeds, and weedy trees that represent a continuous effort in biological control of weeds from 1890 through 1969. Cockayne (1910) reported that fungi had been investigated as "weed controllers" in many parts of the world but without success. Cunningham (1927) reported that "natural control" of weeds with plant pathogens had received "much attention in recent years" for eliminating weed without direct labour or monetary expense and described modest efforts to control weeds with pathogen in New Zealand. This type of control of weeds/plants by one sp. in agro-ecosystem now-a-day is known as allelopathy for harmful as well as beneficial effects.

Biological control of weeds with fungi involves: classical biological control (CBC) and inundative biological control (IBC). CBC follows the enemy release hypothesis. This hypothesis says that plant species in exotic habitats are fitter and more competitive than the indigenous flora as they lack their full complement of coevolved natural enemies, thereby enabling some species to become invasive and dominant. The CBC strategy is to reduce competitiveness of the target weed by introducing coevolved (obligate) fungal pathogens into the exotic-invaded region, thereby restoring the natural balance. A full history of the fungal CBC agent is a prerequisite before it is sanctioned to release by the relevant authorities in the receiving country. IBC, on the other hand is based on the development of a product or mycoherbicide. It involves incorporating an indigenous necrotrophic fungal pathogen which can be mass-produced and formulated, and applied in the same manner as a chemical herbicide. The success rate has been high, and the prospects are encouraging in case of CBC. Conversely, IBC remains a minor player on the weed management stage typically in non-agricultural systems at a targeted niche only (Evans, 2013) [7]. Some fungi which are applied as biological control agents do not survive year after year. For this reason, they must be applied on an annual basis. This technique is called the "bioherbicide" strategy. With this tactic, biological agents are used in similar manner to chemical herbicides.

Table 1.

Pathogen	Weed target	Phytotoxin	Mode of Action	Reference
Cantharellus cibarius	*Eichhornia crassipes*	5-Methyl-Trp	Trp synthase	Hsiao *et al.*
Alternaria tenuis	*Galium aparine*	Tentoxin	CF1 ATPase	Meiss *et al.*
Preussia fleischhakii	*Arabidopsis thaliana*	Cyperin	Protoporphyrinogen oxidase and Lipid synthesis	Dayan *et al.*
Alternaria alternata	*Lemna pausicostata*	AAL-toxins	Ceramide synthase	Abbas *et al.*
Fusarium spp.	*Lemna pausicostata*	Fumonisins	Membrane functions and lipid stability	Abbas *et al.*
Gibberella fujikuroi	*Arabidopsis thaliana*	GA mimic	GA3	Hedden *et al.*

Biological Weed Control using insect pest

The release of insects to combat an invasive weed is paying off, according to a recent study. Lantana was the first on which insect pest were used to control it in the Hawaii (Sankaran T, 1990) [29]. In the case of exotic weeds classical biological control is best suited. The environment of origin of the weeds are evaluated properly and the insect pest to be applied to control them are observed and are released for the control in the new environment. Scientists from the USDA's Agricultural Research Service released arundo scale insects (*Rhizaspidiotus donacis*) and arundo gall wasps (*Tetramesa romana*) several years ago as part of a biocontrol program to kill a weed called "giant reed" (*Arundo donax*) along the Rio Grande in Texas. *Larinus planus* was found to threatened thistle, *Cirsium pitcheri* (Havens *et al*. 2012) [10]. In the 1920s the cactus feeding pyralid Cactoblastis cactorum (Berg) was first used as a classical biological control agent against non-native prickly pear cactus (*Opuntia* spp.) in Australia (Dodd 1940; Mann 1970) [5, 17]. In India, 40000ha of land infested with Opuntia dillenii was recovered by releasing *Dactylopius tomentosus,* cochineal scale insect as bioagent. This insect did not attack other species of Opuntia (Narayanan, 1954) [20].

Zygogramma is a large genus of leaf beetles in the subfamily Chrysomelinae, which includes approximately 100 species and most of the species are very affective on weed control. The mexican beetle (Zygogramma bicolorata) is found to have great potential to bring about permanent reduction in the density of Parthenium hysterophorus, which was accidentally introduced in India in 1956 (Muniappa, 1980). This beetle was found most active on P.hysterophorus during May to Sepetember in Uttaranchal, India (Pandey *et al*, 2001) [24].

Conclusion and Future Prospects

For the fact that over 270 weed species are resistant to herbicides, biological control has taken a vital role in future integrated weed management programs. Some of the world's most important weeds have been controlled using weed biological control method which has a proven track record over 100 years. Till date, only a fraction of the effective biological control agent have been found in the countries where the target weeds are highly present. This creates a vast opportunities to the researchers and scientist to expand the use of the biological agents to control the weeds by discovering specific biological control of organisms or combinations of organisms that are effective and safe method for weed management in crops. Above this, the indiscriminate use of broad-spectrum chemicals has resulted in the development of herbicide resistance, outbreak of new and exotic weeds, reduction in biodiversity of natural enemies, and contamination of food and ecosystem. For this, biological weed control measures have been systematically encouraged to shift to the sustainable way of management.

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