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General Article ______________________________________ *Chapter – 1*

ROLE OF BIOLOGICAL CONTROL IN WEED MANAGEMENT

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Abstract

Implementing other naturally existing living things for controlling their growth, such as insects, fish that eat plants, other animals, disease organisms, and competitive plants, is known as biological control. Although weeds cannot be completely eliminated by biological management, their population can be lowered. Not all weed types respond well to this form of weed control. The most successful biological controls are against introduced weeds. Biological control is the least damaging to the environment, leaves no permanent effects, is relatively cheaper to implement, has a comparatively long-lasting effect, is safe for non-targeted plants, and is especially effective at managing weeds in uncultivated areas. In addition, certain fish, snails, and other creatures devour weed plants and convert them into food.

Keywords: Biological control, Bio-agent, Bio-herbicides, Weed

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Introduction

Numerous plant species are considered weeds in agronomic cropping systems. Weeds play an important role in human affairs in most of the areas on the earth. Weeds have many undesirable attributes like as; reduce crop yields through competition for resources such as sunlight, water, nutrients, and space. It may also harbor insects and provide a host for certain plant pathogens. The major characteristics of weeds are their unwanted occurrence, undesirable features and ability to adapt in to a disturbed environment. Weeds are estimated to reduce world food supplies by about 11.5% annually (Combellack, 1992). Many of our problematic weeds are of exotic origin, having been introduced accidentally. They flourish in the new environment as, they have escaped from the natural enemies which suppress their vigor and aggressiveness in their native lands. Eliminating or reducing the deleterious effects of weeds on agricultural and horticultural crops is the ultimate goal of weed management (Sushil Kumar, 2015).

There are many methods for destroying weeds. But the global need for weed control has been imposed mainly by the chemical industry (Mukherjee and Singh, 2004). After the Second World War, chemical like as; 2, 4-D became known and the farmers eventually got more interested in having better herbicides for effective control of various weeds. Since then, different chemicals development and their extensive use in agriculture went up. However, the public perception gradually changed regarding their use and the interest shifted toward the biological control, especially after the publication of Rachel Carson's *"Silent Spring"* in 1962 and several related reports on the deleterious effects of chemical pesticides on human being, animals and environment. Natural biological control by predators, parasites and pathogens of various agricultural and horticultural crops weeds have been occurring since the beginning of evolutionary process of crop plants. Biological control holds much promise for long-term, economical and environmentally sensitive weed management (Singh, 2004).

In biological control method, it is not possible to eradicate weeds but weed population can be reduced. This method is not useful to control all types of weeds. Introduced weeds are best targets for biological control. The control *Opuntia* spp. (prickly pear) in Australia and lantana in Hawai with certain insect bioagents are two spectacular examples of early period biological control of weeds (Evans, 2002).

Biological Weed Control

"Biological control" a term first used by H.S. Smith (DeBach, 1964), it means uses one living organism to control another. Biological weed control involves using living organisms such as; insects, nematodes, bacteria, fungi to suppress weed population and to keep it at or below desirable level without significantly affecting economically important plants.

According to Alberta (AESA), Manitoba and Saskatchewan Agriculture and food factsheet (2000), biological control includes the classical (inoculative), inundative approaches and herbivore management. Insects, mites, nematodes, plant pathogens, animals, fish, birds and their toxic products are major weed control biotic agents.

1. Classical (Inoculation) approach for biocontrol of weeds includes the release of a relatively small number of control agents. These agents feed on the weed, reproduce and gradually suppress the weed as their population grows. For this approach, arthropods are generally used as control agents. In classical approaches, an exotic biocontrol agent is introduced in a small area of infested zone. In this approach, the control is slow and also dependent on favorable ecological conditions.

The following different steps in classical biological control program

- *Initiation of a Biological Control Program*- Review literature and compile existing knowledge about target weed and its natural enemies.
- *Approval to Work on the Weed*- Seek approval and funds to work.
- *Foreign Exploration*- Locate native range of the target weed and search for natural enemies of the target weed.
- *Survey the Exotic Range of the Weed*- Survey fauna attacking the weed and determine their origin.
- *Ecology of the Weed and Its Natural Enemies*- Study the weed and its natural enemies including their host ranges.
- *Host Specificity Studies*- Prepare lists of test plants and conduct host testing trials.
- *Approval to Import Biological Control Agents*- Submit report of host testing to appropriate authorities to obtain approval to release.
- *Importation*- Obtain certified clean material or eliminate parasites and pathogens before release.
- *Rearing and Release*- Mass rear and make field releases.
- *Evaluation*- Field studies to determine establishment, spread and effect on target weed.
- *Distribution*- Distribute the agents widely; collaborate with other institutions.

One of the most successful examples of classical biological control of weeds is the introduction of a rust fungus, *Puccinia chondrillina*, into Australia to control rush skeleton weed (*Chondrilla juncea*). A plant of Mediterranean origin, it became a serious weed in Australian cereal crops. The fungus, also from the Mediterranean, was introduced, along with three insects, as a classical biocontrol agent. Following the introduction and establishment, the fungus disseminated rapidly and widely and controlled the most common biotype of the weed. It has been estimated that this highly successful biocontrol project has resulted in a cost-to-benefit ratio of 1: 100 in Australia (Cullen, 1985).

The rust fungus attacks one of three forms of the weed, the predominant type. Initially, as the population density of this susceptible type was reduced due to biocontrol, the two other types became more widespread. Therefore, additional rust strains virulent on these more resistant forms were introduced from the Mediterranean and these strains are exerting some degree of control over the resistant forms (Hasan, 1985). This case illustrates a potential problem in using biological control, namely, a shift in the weed population toward more resistant weed biotypes. However, it also illustrates the possibility to counter the presence of natural resistance in weed populations by the introduction of new pathogen strains.

Puccinia chondrillina was also introduced into the western United States to control rush skeleton weed. However, unlike in Australia, it has been only partially successful. Hence, in practice, the rust fungus is utilized along with two insect biocontrol agents, and chemical herbicides in an integrated weed management program. As in Australia, the rust fungus has been the most effective biocontrol agent of the weed (Supkoff *et al.,* 1988).

2. Inundative (Bio herbicides) approach for biocontrol of weed involves large quantities of a control agent, generally a pathogen (a bacteria or fungus that causes disease in a weed) are applied to weeds in much the same manner as herbicides. In this approaches, control agent usually native to the country of application, which is mass reared and released for weed control (Julien and White, 1997).

As stated by Singh (2004), maximum degree of success with classical biological control agents was achieved in biological control of aquatic weeds (55.5%) followed by terrestrial weeds (23.8%). McFadyen (2000) also observed 44 weeds, which were successfully controlled somewhere in the world using various insects and pathogens.

Characteristics of Successful Bio-agent

1. Host-specific

Bio-agents should be host specific and they should not attack other economic plant spp. They should pass the starvation test i.e. they prefer to starve to death rather feed upon other than host weeds. Lantana was controlled by *Teleonemia scrupulosa* insect bio-agent. But in India it is likely to damage teak (*Tectona grandis*) and sesame (*Sesamum indicum*). *Zygogramma bicolarata* is an effective leaf eating bio-agent against Parthenium (carrot grass). But it is found to attack sunflower in India. Plant pathogens are usually very host specific but have been used less frequently than insects in weed biological control because of a fear amongst some biologists and bureaucrats that they might 'host shift' and attack non-target plant species (Harris 1973).

2. Ease of Multiplication

Bio-agent should have high rate and ease of natural reproduction. It is very important for insects, pathogens, snails and competitive plants. But it is not desirable with carp as its increased population compete with natural fish.

3. Feeding Habit

Bio-agents are more efficient in controlling weeds if they attack either flowers or seeds of the weed or bore into the stems than root and leaf feeders. But root-feeding insects are more effective in controlling perennial weeds. Harley and Forno (1992) suggest that for a biological control agent to inflict "critical damage it must either i) attack essential tissues, such as photosynthetic, meristematic or cambium tissues, ii) create an energy imbalance, for example, by stimulating gall production, or iii) have a physiological effect, such as a plant disease increasing stomata1 opening with the result that plants become water stressed.

4. Bioagent Hardiness

Bio-agent should free from its own parasites and predators. Bio-agent should withstand starvation for short or long periods of food shortage when the target weed population is brought to low level. But carp can't survive even a short period of starvation. Theoretically, the better adapted a biological control agent is to its new environment the more abundant it will become. Insects from similar climates and the same variety or subspecies of plant are thus given a higher priority because they are more likely to be preadapted to conditions in the new environment

Bio-control Agents of Weed

1. Insects

The utilization of insects as a biocontrol agent for weed was begun in 1902 against the brush weed, *Lantana camara*, in Hawaii. Entomologists team visited the native land of this weed in Central America and Mexico and succeeded in finding *Crocidosema lantana* (Moth), as the most promising bioagent for this perennial weed (Gupta, 2013).

The first successful biocontrol of weed in India occurred unintentionally by the insect *Dactylopius ceylonicus.* It was imported in 1795 from Brazil to produce high quality commercial dye. It was established on *Opuntia vulgaris* in North and Central India bringing about suppression. Gradually, areas that were uncultivated due to prickly pear, became suitable for cultivation (Sushil Kumar, 2015). After its success, in 1865 *D. ceylonicus* was introduced into Sri Lanka from South India, where it controlled *O. vulgaris* in large area. This was the first example of intentional transfer of a natural enemy for biological control of weeds (Sushil Kumar, 1993).

The most successful example for biological control of weeds in India is that of *Parthenium hysterophorus* (congress grass or carrot grass) which has occupied several thousands of land throughout the country. Based on well documented success by *Z. bicolorata* from the native home of Parthenium and other countries where they were introduced, efforts were initiated in India in 1983 by Dr K.P. Jayanth at Indian Institute of Horticulutral Reseach (IIHR), Bangalore. The beetle, *Z. bicolorata*, is commonly known as the Mexican beetle, but also called as Parthenium beetle (CABI 2020). Since the first release in the field in 1984 at Bangalore, the beetle has well established in most of the south India and many parts of central and north India, in very conservative estimate, it is calculated that the beetle has already spread in about 7 million hectares of amounts to be about 20% area of the land which an estimated 35 million hectares land infested with the Parthenium. Larval and adult feeding on Parthenium results in skeletonization, defoliation and reduction in flowers and seed production. *Z. bicolorata* can cause 100% defoliation of Parthenium, resulting in reduced weed density, plant height, plant biomass, flower production and soil seed bank.

Likewise, water fern (*Salvinia molesta)* affects large water bodies and rice fields in Kerala. It has been controlled by weevil *(Cyrtobagous salviniae)*. The insect is native of South America. This weevil takes about 4-6 months for the completely destruction of *S. molesta*. The young larvae of this insect damage the terminal buds, rhizomes, and petioles of the floating weed (Gupta, 2013).

Water hyacinth is considered to be the most damaging aquatic weed in India. It now occurs in all fresh water ponds, tanks, lakes, reservoirs, streams, rivers and irrigation channels. Exotic natural enemies *like as;* hydrophilic weevils (*Neochetina bruchi* and *N. eichhorniae*) and galumnid mite (*Orthogalumna terebrantis*) for the biological suppression of water hyacinth. It has been successfully controlled in Florida (USA) with hyacinth moth (*Sameodes albigultalis*) which feeds on young leaves and buds of hyacinth (Sushil kumar, 2011 and Gupta, 2013).

S. N.	Natural Enemies/ Bio-agent for Weed	Weed Plant Affected	Reference
1	*Chrysolina quadrigemina*	St. Johnswort weed	Singh, 2004
2	*Microlarinus lypriformis*	Puncturevine	Gupta, 2013
3	*Lantanophaga pusillidactyla*	Brush weed (*Lantana*)	Sushil kumar 2001; Singh, 2004
4	*Mescinia parvula*	Siam weed	Singh 2004
5	*Phytomyza orobanchia*	Broomrape	Singh 2004
6	*Osphronemus goramy*	Aquatic weeds	Singh, 2004
7	*Procecidochares utilis*	Crofton weed	Sushil kumar, 2015
8	*Rhinocyllus conicus*	Musk Thistle	Zimdahl, 2013
9	*Orthogalumna terebrantis*	Water hyacinth	Singh, 2004; Sushil kumar 2011
10	*Teleonemia scrupulosa*	Brush weed (*Lantana*)	Sushil kumar, 2015
11	*Agasicles hygrophyla*	Alligator weed	Gupta, 2013
12	*Paulinia acuminata*	Salvinia	Gupta, 2013

2. Fish

Several herbivorous fish (Grasscarp) also called white amur or Chinese carp (*Ctenopharyngodon idella*), is a greedy feeder of several submerged and emerged aquatic vegetation. The daily aquatic weed consumption of this grass carp is equal to its own body weight, which is about 1 kg when it is one year old. Its body weight reaches up to 32 kg at its full length of 1 meter (Gupta, 2013). In the same way, sea manatee (*Trichechus manatus*) feeds on water hyacinth and other aquatic vegetation (Zimdahl, 2013).

3. Fungi

Microorganisms can be applied to control weeds within a specific area by inundative application of inoculum. This approach is also referred to as the mycoherbicide approach (Charudattan, 1993). This bioherbicide approach involves the spray of specific fungal spores or their fermentation products on the target weed which later release their phytotoxins to destroy the menace. These fungal based preparations are also called mycoherbicide. Plant pathologists and weed scientists have identified approximately more than 200 plant pathogens for the control of weeds. Some cases of fungal bioagents for weed control are presented below.

Hemp sesbania (*Sesbania exaltata*) most troublesome weed in soybean which can easily be controlled by *Colletotrichum truncatum* (Boyette, 1991). *Fusarium oxysporum* applied a potential mycoherbicide for controlling three species of *Striga* spp. *like as; S. asiatica*, *S. gesneroides* and *S. hermonthica* (Marley *et al.,* 2005).

In the same way, *Myrothecium verrucaria* is useful for the control of *Chenopodium amaranticolor*, *Senna obtusifulia*, *Sesbania exaltata, Datura stramonium*, *Carduus acanthoides* and *Euphorbia esula* (Walker, *et al.,* 1997; Yang and Jong, 1995). The toxin trichothecenes produced by *M. verrucaria* inhibit seed germination of the parasitic plant *Orobanche ramose* (Andolfi, *et al.,* 2005).

Sr. No.	Fungal Bioagent	Weed Plant Affected	Reference
1	*Phomopsis amaranthicola* *Aposphaeria amaranthi* *Microsphaeropsis amaranthi*	*Amaranthus* species	Rosskopf, 1997 Heiny *et al.*, 1992 Ortiz-Ribbing *et al.,* 2006.
2	*Drechslera avenacea*	*Avena fatua*	Hetherington *et al.,* 2002.
3	*Pyricularia setariae*	*Setaria viridis*	Peng *et al.,* 2004
4	*Phoma macrostoma*	*Taraxacum officinale* *Cirsium arvense*	Bailey *et al.,* 2003 Zhou *et al.,* 2004.
5	*Dactylaria higginsii*	*Cyperus rotundus*	Kadir *et al.,* 2000.
6	*Plectosporium tabacinum*	*Galium spp*	Zhang, 1999

Among the numerous fungal pathogens for weed control *Phytophthora palmivora* was first used commercially as DeVine in 1981 to control Milkweed vine (Kenny, 1986). Later, *Colletotrichum gloeosporioides* f.sp. *aeschynomene* was developed in the United States in 1982 for the control of northern joint vetch. By the same token, spores of *C. gloeosporioides* (Penz.) Sacco f. sp. *malvae* was used for the control of round leaved mallow in wheat (Mukherjee and Singh, 2004). At present thirteen different bioherbicide products have been launched, out of them only nine bioherbicides are available for sale/purchase in the market globally.

Another approach combining an insect biocontrol agent and a fungus has been used in an attempt to control the aquatic weed water hyacinth (*Eichhornia crassipes*) in Florida USA, by Professor Charudattan. Spores of the fungus *Cercospora rodmanii* are sprayed in small areas to create 'hot spots' of infection. Two previously imported weevils, which attack the inflated petioles of water hyacinth, spread the fungal spores as they move from plant to plant.

4. Bacteria

The bacteria also have the potential for controlling the weed by causing diseases in weeds. Weed control by using bacteria have several advantages due to their rapid growth. Among the different bacterial pathogens *Xanthomonas campestris* developed as bioherbicides to control annual bluegrass (*Poa annua*) and Asteraceae weeds (Johnson *et* *al.,* 1996). Likewise; phytotoxin produced from a crude extract of *Pseudomonas syringae* control the growth of weeds in cranberries (Norman *et al.,* 1994).

Fungi Bio Agents Introduced to Various Countries as Classical Biocontrol Agents of Weed (based partly on Julien 1992)

Pathogen	Target Weed	Target Country	Year of Introduction
Colletotricum gloeosposoides	*Clidemia hirta*	Hawaii	1986
Diabole cubensis	*Mimosa pigra*	Australia	1995
Entyloma compositarum	*Ageratina riparia*	South Africa	1989
Maravalia cryptostegiae	*Cryptostegia grandiflora*	Australia	1993
Phaeoramularia sp.	*Ageratina adenophora*	South Africa	1988
Phragmidium violacaum	*Rubus procerus*	Chile Australia	1973 1991
Puccinia abrupta var. *partheniicola*	*Parthenium hysterophorus*	Australia	1991
Puccinia carduorum	*Carduus tenuiflorus*	USA	1987
Puccinia chondrillina	*Chondrilla juncea*	Australia	1991
Puccinia evadens	*Baccharis halimifolia*	Australia	1996
Sphaerulina mimosa-pigrae	*Mimosa pigra*	Australia	1994
Uromyces galegae	*Galega officinalis*	Chile	1973
Uromyces heliotropii	*Heliotropium europaeum*	Australia	1992
Uromycladium tepperanium	*Acacia saligna*	South Africa	1987

Commercially Available Bio-Herbicides

1. DeVine

DeVine is a fungal product containing chlamydospores of the fungus *Phytophthora palmivora* MWV pathotype was registered in 1981. DeVine was produced in a cooperative venture between the Florida Department of Agriculture and Consumer Services and Abbott Laboratories (Ridings 1986). It is utilized for the control of *Morrenia odorata,* strangler or milkweed vine in citrus groves. This fungus will initiate a root infection in milkweed vine plants that kill the vine in two to ten weeks of application, depending on the size and maturity of the vine.

2. Collego

Collego, was developed as a collaborative effort between a group at the University of Arkansas led by Professor George Templeton, the US Department of Agriculture and the Upjohn Company. Collego is living spores of the fungus *Colletotrichum gloeosporioides* f. sp. *aeschynomene.* Collego is a two compound product. Component A consists of a water soluble spore dehydrating agent and component B is a wettable powder formulation of living fungal spores of *C. gloeosporioides* f. sp. *aeschynomene.* It is a selective post-emergent mycoherbicide for the control of northern joint vetch *(Aeschynomene virginica*) in rice and soybean. It was registered for commercial use in 1982. Collego should be applied to emerge joint vetch plants that are from 20 to 30 ern tall and have not reached the bloom stage. Rice fields should be flooded before application. Soybean fields should be irrigated just prior to application. *C. gloeosporioides* f. sp. *aeschynomene* cause anthracnose disease in joint vetch and produces lesions on the above ground parts of it.

Some Commercial and Experimental Available Bioherbicides
[Boyette (2000); Upadhyaya and Blackshaw (2007)]

S. N.	Weed Host	Pathogen
1.	Spurred anoda *(Anoda cristata)*	*Fusarium lateritium*
2.	Spurred anoda *(Anoda cristata)*	*Colletotrichum coccodes*
3.	Round-leaved mallow (*Malva pusilla)*	*Colletotrichum gloeosporioides* f. sp. *malvae* **(BioMal)***
4.	Annual bluegrass *(Poa annua)*	*Xanthomonas campestris* (**Camperico)***
5.	Spurred anoda *(Anoda cristata)*	*Alternaria macrospora*
6.	Giant rag weed *(Ambrosia trifida)*	*Protomyces gravidus*
7.	Field bind weed (*Convolvulus arvensis)*	*Phomopsis convolvulus*
8.	Jimson weed *(Datura stramonium)*	*Alternaria crassa*
9.	Florida beggarweed *(Desmonium tortuosum)*	*Colletotrichum truncatum*
10.	Sickle pod *(Cassia obtusifolia)*	*Alternaria cassiae*
11.	Common purslane *(Portulaca oleraceai*)	*Dichotomophthora portulacaceae*
12.	Horse purslane *(Trianthema portulacastrum)*	*Gibbago trianthemae*
13.	Hemp sesbania *(Sesbania exaltata)*	*Colletotrichum truncatum*
14.	Eastern black nightshade *(Solanum ptycanthum)*	*Colletotrichum coccodes*
15.	Strangler vine *(Morrenia odorata)*	*Phytophthora palmivora* **(DeVine)***
16.	Velvet leaf *(Abutilon theophrasti)*	*Fusarium lateritium*
17.	Northern jointvetch *(Aeschynomene virginica)*	*Colletotrichum gloeosporioides* f. sp. *aeschynomene* (**Collego)***
18.	Spurred anoda *(Anoda cristata)*	*Alternana macrospora*
19.	Texas gourd *(Cucurbita texana)*	*Fusarium solani* f. sp. *cucurbitae*
20.	Marijuana *(Cannabis sativa)*	*Fusarium oxysporum* var. *cannabis*
21.	Hemp sesbania *(Sesbanla exaltata)*	*Colletotrichum truncatum*
22.	Sicklepod *(Cassia obtusifolia)*	*Fusarium oxysporum*
23.	Sicklepod *(Cassia obtusifolia)* and others	*Alternaria cassiae* (**Casst)***

**** Bold name in the bracket are commercially available formulation***

3. BioMal

It is another *Colletotrichum* based mycoherbicide developed in Canada. Biomal contains spores of *Colletotrichum gloeosporioides* (Penz.) Sacco f. sp. malvae. It is used as post-emergence to control *Malva pusilla* (rounded leaved mallow). 2 x 10^9 spores/L at the rate of 3 x 10^2 L/ha. Control of round-leaved mallow has been achieved in field tests (Makowski and Mortensen 1989).

Biomal infested round-leaved mallow plants show typical anthracnose disease symptoms. Lesions produce on the leaves, petioles and stems of infested plants within 2-4 hrs after application. As the disease progresses, the stems are girdled by lesions resulting in plant mortality.

Limitations

From an economic standpoint, it would be attractive to develop a bioherbicide that can control several closely related weed species even if these weeds are not commonly found in the same locations or crops. The potential to use a bioherbicide in diverse crops and against several weeds might stimulate commercial interest in this technology. Accordingly, attempts are being made to target closely related weeds such as pigweeds (*Amaranthus* spp.), nutsedges (*Cyperus* spp.), and grasses with fungal pathogens that have broad and overlapping host ranges at the generic level (*i.e.,* restricted to several species of a genus) (Rosskopf *et al.,* 1999).

Furthermore, to enhance the effectiveness and acceptability of bioherbicide agents, attempts are being made to combine several host-specific pathogens into a single application. In this "multiple-pathogen strategy", three or more pathogens are combined at optimum inoculum levels and sprayed onto the weeds in post- or pre-emergent applications. The feasibility of this approach has been demonstrated in greenhouse and field trials wherein seven weedy grasses were controlled with three fungal pathogens, *Drechslera gigantea, Exserohilum longirostratum*, and *E. rostratum* applied in an emulsion (Chandramohan *et al.,* 2000).

Innovative techniques and tools have been used to address several main drawbacks in mass production, formulation, shelf life, and application systems. Many more modern techniques and materials are being developed, many of which are easily adapted for particular weed-pathogen systems. The key challenges to classical biocontrol of weeds using plant pathogens include a lack of adequate support. This arises from the erroneous impression held by some institutional and funding agencies that the possible non-target danger is politically difficult to consider, the process of discovery and deployment takes too long, and the outcome of classical biocontrol is often too delayed. But, one only needs to look at the number of successful examples and their cost-benefit ratios to conclude that classical biocontrol is one of the best solutions, particularly for weeds that adversely affect large areas of natural land and water.

Conclusion

Since growing agricultural output has brought up a number of new challenges, future growth is only possible if these challenges are resolved effectively and quickly. In many countries, including India, the rise in crop production from modern farming techniques has reached a plateau, and environmental problems brought on by the excessive use of chemical fertilizers and pesticides are a cause for concern. In order to achieve the purpose of agriculture, biological control can therefore be a viable alternative approach.

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