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Overview of Biological Methods of Weed Control

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Abstract

Exotic plants in new ecosystems where they may be of no economic importance and where their original biological enemies may be absent become weeds, difficult to manage by crop farmers. They limit the productivity of the lands and hence affect crop development and yield. Efforts towards reducing reliance on herbicides and other methods for environmental, health, economic and sustainability reasons have led to increasing interest in the biological approach to controlling these weeds. This work therefore presents an overview of the biological approach to weed control with focus on the basic concepts, underlying principles, procedures and current practices, cases and causes of failure and successes. Specifically, this chapter has discussed the underlying principles, general procedures, reasons for relatively slow popularity and adoption of biological weed control, examples of successful biological control of weeds with introduced insects and pathogens, when is weed biological control successful?, things to consider when making the choice of agents to be introduced to control weeds and steps to identifying and introducing biological control agents.

Keywords: biological weed control, overview, weed control methods, biocontrol agents

1. Introduction

Sharp increase in international trades and travels over past decades has led to invasive plants becoming a global problem. Plant invasions cause serious threat to the existence of endangered species and the integrity of ecosystems, which cost national economies tens of billions of dollars every year [1–3]. Weeds have been noted by organic horticulture producers as one of the most expensive, time consuming and troublesome activities in production [4]. Weeds are the most significant of the economic and environmental crop loss factors and much of the weedicides applied all over the world are targeted at them. Invasive weeds cause enormous

environmental damage [5]. Also according to [6] weeds disrupt the ecology and the functioning of rangeland plant communities and decrease the quality of services and commodities obtainable from this diverse and important natural resource. In the developing countries, weeding accounts for up to 60% of the total pre-harvest labor input and this is usually by use of simple hand tools [7]. Weeds are generally defined as plants growing where they are not wanted. Popular methods of weed control such as mechanical and chemical are known to be: expensive, energy and labor intensive, require repeated applications, and are unsuitable for managing wide spread plant invasions in ecologically fragile conservation areas or low-value habitats, such as range lands and many aquatic systems. Also mechanical methods cause soil disturbance that may eventually lead to erosion; chemical herbicides cause environmental pollution that pose dangers to human health and wildlife, and certain weed species have developed resistance to some chemical herbicides [1, 8]. Biological approach to weed control dates back from 1795 when *Dactylopius ceylonicus* was introduced to control drooping prickly pear (*Opuntia vulgaris* Miller) over a large area of land; and since then biological control of weeds have been mainly through the classical strategy of introducing natural enemies from areas of co-evolution [9–14].

Biological control agents usually target their specific natural enemy weeds. Recently due to certain favorable environmental [15], health, economic and sustainability reasons; foreign and native organisms that attack weeds are being evaluated for use as biological control agents that may be used to complement conventional methods especially where some weeds have developed resistance to chemical control. Wheeler et al. [16] reported that their international team discovered and tested numerous new species of potential biological control agents that could attack different plant tissues such as defoliators, sap-suckers, stem borers, and leaf- and stem-gall formers. Many successful biological weed control programs in many parts of the world have demonstrated the potency of this approach and support the concept that natural enemies can contribute to the reduction of plant growth and reproduction [17, 18]. Wapshere et al. [19] classified biological approach to weed control as follows: the classical or inoculative method which is based on the introduction of host-specific exotic natural enemies adapted to exotic weeds; the inundative or augmentative method which is based on the mass production and release of native natural enemies usually against native weeds; the conservative method which is based on reducing numbers of native parasites, predators and diseases of native phytophages that feed on native plants; and the broad-spectrum method which is based on the artificial manipulation of the natural enemy population so that the level of attack on the weed is restricted to achieve the desired level of control. According to McFadyen [5] classical method is the predominant method in weed biocontrol. He further explained that classical method involves the introduction and release of agents in form of exotic insects, mites or pathogens to give permanent control, while inundative involves the releases of predators, use of bioherbicides and other integrated pest management which usually are not as widely used as the classical method. Also there are three different techniques for applied biocontrol: (i) conservation—protection or maintenance of existing populations of biocontrol agents; (ii) augmentation—regular action to increase populations of biocontrol agents, either by periodic releases or by environmental manipulation; and (iii) classical biocontrol—the importation and release of exotic biocontrol agents, with the expectation that the agents will become established and further releases will not be necessary.

Louda and Masters [6] stated that despite the positive impact of chemical herbicides in agricultural productivity, complete reliance on chemical control has caused severe problems such as high cost per unit area, decreasing effectiveness, negative impact on plant diversity and increased environmental contamination. He therefore pointed out that the use of biological factors that naturally limit weed populations is one promising alternative. Menaria [20] discussed bioherbicides as an eco-friendly approach to weed management. He explained that the use of chemical herbicides leaves some chemical residues in food commodities which directly or indirectly affect human health. According to him this situation led to the search for alternative methods that are environmentally friendly, and biocontrol has been found a suitable alternative. Green [21] reviewed the potential for control using bioherbicides of four important forest weed species in the UK; including bracken, bramble, Japanese knotweed and rhododendron. They concluded that rhododendron is a suitable target weed for control using wood-rotting fungus as a bioherbicide stump treatment; and this is an approach already developed for weedy hardwood species in South Africa, Canada and Netherlands. Clewley et al. [22] analyzed factors associated with control programs (invasive region, native region, plant growth form, target longevity, control agent guild, taxonomy and study duration) in order to identify patterns of control success. They found out that biological control agents significantly reduced plant size ($28 \pm 4\%$), plant mass ($37 \pm 4\%$), flower and seed production (35 ± 13 and $42 \pm 9\%$, respectively) and target plant density ($56 \pm 7\%$).

2. Underlying principles and procedures for biological weed control

2.1. Underlying principles

The underlying principle behind biological approach to weed control is based on some research works that reported that exotic plants become invasive because they have escaped from the insect herbivores and other natural enemies that limit their multiplication and distribution in their native regions [23–25]; however some other factors may contribute to the tendency for particular plant species to become invasive [26–28]. Therefore biological control involves using specific natural enemies that can diminish the development and reproduction of their prey organism and put some limitations to them [29]. McFadyen [5] stated that the predominant approach to classical biological weed control involves the importation, colonization, and establishment of exotic natural enemies (predators, parasites, and pathogens) to diminish and maintain exotic pest populations to densities that are economically insignificant [30, 31].

2.2. General procedures

Some authors have outlined general procedures to be followed when embarking on classical biological weed control programs as follows: (i) evaluate the ecology, economic impact of the weed and potential conflicts of interest; (ii) survey the organisms that are already attacking the weed in the new habitat in order to distinguish accidentally introduced agents and so eliminate such from future evaluation; (iii) carry out literature search and other forms of survey to identify natural enemies attacking the weed in its native region; (iv) screen the possible biological control agents in the foreign country to determine host range and

Steps	Details
1. Initiation	Data on taxonomy, biology, ecology, economics, native and introduced distributions, known natural enemies, etc., are compiled by initiating scientist or group. An extensive literature review is conducted on the proposed target weed and its relatives, plus known natural enemies. Conflicts of interest identified and resolved if possible
2. Target weed approval	Data in (step 1) submitted to appropriate State and Federal groups for comment; additional data may be required
3. Foreign exploration and domestic surveys	If project approved in (step 2), the center of evolution of the genus of the target weed (if known) and other suitable areas, are searched for natural enemies, particularly where these are eco-climatically similar to the area of introduction. At the same time, the weed should be investigated in the country of introduction for attacking enemies, related plants, etc.
4. Weed ecology and agent host specificity	Ecology of the target weed, its close relatives and its natural enemies is studied in the native area, and the most damaging and apparently selective agents are subjected to several years of host-specificity testing
5. Agent approval	A report on each agent is submitted to appropriate State and Federal bodies to obtain importation and release permits
6. Importation and quarantine clearance	Each agent is imported to the country of introduction where it is reared through at least one generation in quarantine to rid it of its parasites and diseases
7. Rearing and release	After a pure culture of the agent is obtained in (step 6), it is normally mass-reared and released in the field in cages or free at field sites
8. Evaluation and monitoring	Agent is monitored at field sites to determine establishment and degree of stress on target weed, or to determine reasons why the agent did not become established or efficacious
9. Redistribution	To aid spontaneous self-dissemination, agent is distributed to other areas in the target weed's distribution, if needed

Table 1. Summary of steps normally followed when introducing a biological control agent in a classical/inoculative biological control weed program.

specificity, and to remove nonspecific agents from further consideration; (v) carry out further tests of promising candidates in quarantine after introduction to ensure host specificity and eliminate predators, parasites, and pathogens that may have been introduced with them; (vi) embark on mass rearing of host-specific agents; (vii) release the host-specific agents; (viii) carry out post-release evaluation to determine establishment and effectiveness of agents; and (ix) redistribute agents to other areas where control is required [5, 32–34]. Wapshire et al. [19] presented a summary of steps normally followed when introducing a biological control agent in a classical biological control weed program as in **Table 1**.

3. Reasons for relatively slow popularity and adoption of biological weed control

Recent research activities and weed control practices around the world have shown that the old idea derived from untested opinions; that biological approach to weed control is usually very slow, unpredictable, expensive and mostly unsuccessful is totally not true. Apart from the high initial costs, biological approach to weed control has been known to be relatively cheaper

when compared to other methods; however certain factors have slowed down the rate of adoption. These factors include: long time of establishment-usually 20 years or more to ensure success, inadequate or no records of the extent of pre-biological control weed infestations that should serve as a guide for a new biocontrol program, discouraging story of poorly implemented weed bio-control programs. A lot of success stories however have been documented [35]. Lack of information about previous successfully implemented biological control of weeds often lead to untested theories becoming established dogma and this negatively influence the decisions to or not apply it [36]. For instance Mcfadyen [35] stated that it was believed that biological control of trees is difficult, but many examples of trees controlled by insects have been reported [37, 38]. Also classical biological control has been viewed as unsuitable for weeds of annual crops or other frequently disturbed environments [39, 40], however there are many examples of successful control of crop weeds [41, 42].

Some researchers have reported that there are evidences showing that some agents introduced for exotic weed control have attacked non target, native plants [43, 44]; and this situation has raised concerns among biological control workers and weed scientists as well as the governments [5, 43, 45, 46]. Opposition to biological approach to control of weeds has also contributed to slowing down the rate of adoption and practice; this is because some researchers and weed control scientists believe that it is difficult to estimate the cost or the feasibility of biocontrol [47]. Based on a study carried out in South Africa, it was reported that some of the weed biocontrol projects have provided practical solutions to problems e.g. the development of Stumpout for the treatment of wattle stumps and the use of *C. gloeosporioides* for the control of *H. sericea*. However other projects have been less successful and have resulted in the rejection of potential agents for various reasons and these include *C. albofundus* on *A. mearnsii*, *X. campestris* on *M. aquaticum* and *G. nitens* on *R. cuneifolius* [48]. Vurro and Evans [49] identified legislative hurdles, technological and commercial constraints as limitations to the adoption of biological weed control in Europe. Olckers [50] stated that limited budgets in many countries have also helped to slow than the rate of adoption and practice of biological approach to weed control.

4. Examples of successful biological control of weeds with introduced insects and pathogens

One thousand one hundred and forty-four individuals (mostly entomologists and plant pathologists) have ever attended the International Symposia on Biological Control of Weeds (ISBCWs); and out of these, 450–550 weed biological control experts have been actively involved in research and development efforts over the last 50 years mainly from USA, Canada, Australia, South Africa and New Zealand [51]. McFadyen [5] reported that biological approach to weed control has a long history and a good success rate of 94. A comprehensive list of agents and their target weeds have been documented by Winston et al. [52]. Culliney [1] presented potential benefits estimated for some proposed or initiated biological control programs targeting invasive weeds. Frequently cited examples of successful approach to biological weed control are the prickly pear cacti (*Opuntia; spp.*) in Australia, eradicated by an imported moth (*Cactoblastis cactorum*) and rangeland in California, Oregon, Washington, and British Columbia controlled by St. John's wort *Hypericum perforatum* (millepertuis perforé) [53].

Mcfadyen [35] presented a list of 41 weeds which have successfully been controlled using introduced insects and pathogens and another three weeds also controlled by introduced fungi applied as mycoherbicides. He further stated that many of these successes have been repeated in other countries and continents. Julien [11] presented a list of both successful and failed cases of biological weed control; this included the introduction of 225 organisms against 111 weed species, and 178 insects and 6 mites. Palmer et al. [54] reported that 43 new arthropod or pathogen agents were released in 19 projects; and that effective biological control was achieved in several projects with the outstanding successes being the control of rubber vine, *Cryptostegia grandiflora*, and bridal creeper, *Asparagus asparagoides*.

4.1. When is weed biological control successful?

Information collated on weed impacts before the initiation of a biological control program is necessary to provide baseline data and devise performance criteria with which the program can subsequently be evaluated [55]. For avoidance of confusion on when a biological control could be viewed as successful or not, Hoffmann [56] stated that an implementation of a particular biological control will be termed successful when: complete-when no other control method is required or used, at least in areas where the agent(s) is established; substantial-where other methods are needed but the effort required is reduced (e.g. less herbicide or less frequent application); and negligible-where despite damage inflicted by agents, control of the weed is still dependent on other control measures. Complete control does not imply total eradication of the weed; rather it means that control measures are not required anymore specifically against the target weed, and that crop or pasture yield losses will not be attributed mainly to this weed [26, 41]. Substantial control involves situations where control may be complete in some seasons and/or over part of the weed's range, as well as cases where the control achieved is widespread and economically significant but the weed is still a major problem. It is therefore concluded that successful implementation of biological approach to weed control is the successful control of the weed, and not necessarily the successful establishment of individual agents released against the weed [35]. Successful biological control depends on three factors: the extent to which each individual agent can limit the targeted plant; the ecology of the agent as it affects its ability to populate and spread easily in the new environment; and the ecology of the weed, which determines if the total damage that can be caused by the agent can significantly reduce its population [57]. Because agents always need some surviving predator plants to complete their life cycle, biological control will not usually totally eradicate their target weeds. In essence a successful biological control program reduces the potency and population of the target weed and usually in conjunction with other control methods as part of an overall integrated weed management scheme which is recommended.

5. Things to consider when making the choice of agents to be introduced to control weeds

Gassmann [58] reported that selection of potential agents in the last decades has been mainly based on the population biology of the weed, impact studies of agents on the plant and the

combined effect of herbivory and plant competition. Palmer et al. [54] stated that agent selection is highly dependent on the type of weed, its reproductive system, on the ecological, abiotic and management context in which that weed occurs, and on the acceptable goals and impact thresholds required of a biological control program. Generally, factors to be considered in selecting agents include the following: the agent must target a particular plant species, must have high level of predation and parasitism on the host plant and its entire population, must be prolific, must be able to thrive in all habitats and climates where the weed exists and should be able to spread easily and widely, must be a strong colonizer, the overall cost of introducing the agent must be cheaper compared to other control methods, the technology that will be involved in introducing and managing the agent must be as simple as possible, must as much as possible maintain natural biodiversity, sufficient number of individuals must be released, plant phenology (effect of periodic plant life cycle events) must be favorable [59]. To be considered a good candidate for biological control, a weed should be non-native, present in numbers and densities greater than in its native range and numerous enough to cause environmental or economic damage, the weed should also be present over a broad geographic range, have few or no redeeming or beneficial qualities, have taxonomic characteristics sufficiently distinct from those of economically important and native plant. Furthermore, the weed should occur in relatively undisturbed areas to allow for the establishment of biological control agents, cultivation, mowing and other disturbances can have a destructive effect on many arthropod biocontrol agents. Inundative biocontrol agents such as bacteria and fungi are less sensitive to these types of disturbances so may be used in cropland.

5.1. Steps to identifying and introducing biological control agents

The study of insect attributes and fitness traits, the influence of plant resources on insect performance, and the construction of comparative life-tables, are the first steps towards an improvement of the success rate of biological weed control [58]. Generally, steps to identifying and introducing biological control agents include: (i) identify target weeds; (ii) identify control agents and determine the level of specialization; (iii) apply controlled release of the agents; (iv) apply full release and determine optimal release sites; (v) for the case of classical methods, monitor release sites; (vi) apply redistribution for the case of classical methods (vii) and maintain control agent populations.

6. Conclusion

The following conclusions are drawn from this study:

- i. In recent times, biological and integrated weed control is gaining popularity over the traditional methods of mechanical and chemical because the latter have been noted to be more expensive, energy and labor intensive and require repeated applications.
- ii. Mechanical methods cause soil disturbance and possible erosion while chemical herbicides lead to pollution of the environment and the aftermath

- iii. Some weed species have developed resistance to some chemical herbicides and biological control readily comes as a viable alternative
- iv. Classical method of biological weed control has been the most popular and widely adopted and practiced; it involves the introduction and release of agents in form of exotic insects, mites or pathogens to give permanent control
- v. Inundative method of biological weed control involves the releases of predators, use of bioherbicides and other integrated pest management which usually are not as widely used as the classical method.
- vi. Biological weed control is presently widely adopted in the USA, Canada, Australia, South Africa and New Zealand.
- vii. The biological approach to weed control holds great prospects for sustainable, environmentally friendly and economically viable control of exotic weeds and should be explored further through research, development and legislation.

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