



Biological Control of Weeds

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Received: 07 Jun 2024; Received in revised form: 10 Jul 2024; Accepted: 17 Jul 2024; Available online: 26 Jul 2024

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Abstract— In response to the mounting environmental and anthropogenic challenges, there has been a notable shift towards adopting biological approaches as pivotal components of integrated and sustainable weed control strategies. Over the course of centuries, the efficacy of employing biological agents for weed management has emerged as a cornerstone in addressing these challenges. This review article aims to delve into the historical evolution and contemporary significance of biological agents in weed control, highlighting their pivotal role in modern agricultural and ecological practices. Our exploration begins with a classical perspective on the biological approach, shining a spotlight on arthropods, particularly insects. A unique angle introduced involves the redistribution of local arthropods as a nuanced method for effective weed control. Transitioning to the bioherbicide section, we delve into the realm of formulated natural products and their diverse formulations, recognizing their pivotal role in biological weed control. However, the landscape of biological weed control is not without its challenges. Financial constraints, side effects, and divergent opinions pose hurdles that warrant attention. Yet, despite these challenges, the narrative maintains an optimistic outlook. The underlying belief is that, in the future, biological methods will evolve to offer not only effective but also sustainable solutions for weed control practices. In essence, this abstract navigates through the historical successes of biological weed control, explores specific facets such as arthropods and bioherbicides, confronts existing challenges, and ultimately anticipates a future where biological methods emerge as more promising and sustainable players in the field of weed control.



Keywords— Arthropods, Bioherbicides, Biological weed control, Sustainable agriculture, Weed control practices

I. INTRODUCTION

Ever since the first cultivation systems were developed for food production, farmers of all generations and areas have been faced with the problems of non-crop plants growing amongst the crops. These non-crop plants, which compete with the crops for moisture, light, nutrients and space, have long been known as weeds. The weeds often cause many problems to farmers as they are difficult to control and are being used as an insult to other humans, inferring lack of courage or strength. Yet thin, spindly and pale weeds often have the resilience and ability to compete with the crop plants (Briese, 1997). A weed can be thought as any plant growing in the wrong place at the wrong time. In crops, weeds can cause problems of severely reduced yields and also affect the efficient use of machinery.

So effective weed control is therefore an essential part of crop husbandry and has traditionally been a labour-intensive operation of controlling the weeds. In less developed countries, the situation of labour shortage still exists where the peak labour requirement is often for hand weeding (Rogers, 1979). If this labour demand cannot be met, then the crop must be grown on a smaller area that would otherwise be economically viable. Some herbicides have also been developed which are a challenge worth combating as in methods of weed control in systems, herbicides are too expensive or ineffective to use. Thus, with the much greater public awareness of food and environmental issues, it is probably worth looking at weed control from a wider perspective especially non-chemical weed control.

II. WEED COMPETITION

At this stage it is worth considering some basic aspects of weed management, before looking in detail at the techniques available for non-chemical weed control. Awareness about the common weeds in the crop fields is important, so operations such as cultivations, sowing and weeding can be timed according to the peak germination periods of the predominant species.

Crop rotations, one option for weed control in the cropping system, should be designed such that the differences in the timing of seedbed cultivations prevent one weed species becoming dominant (Lockhart *et al.*, 1990).

III. WHY ARE WEEDS IMPORTANT?

In a review of crop losses due to pests, it was stated that: overall, weeds produced the highest potential loss (34%) with animal pests and pathogens being less important (losses of 18% and 16%) (Oerke, 2005). Worldwide, 40% of pesticide use is contributed to herbicides, 17% to insecticides and 10% to fungicides. (Jamaludheen *et al.*, 2022).

The problem with weeds: Weeds compete with crops for essential resources such as space, light, moisture, and soil nutrients, consequently leading to yield reduction. It causes health problems to human beings. *For example, Parthenium hysterophorus.* Similarly, morning glory is beautiful in the garden, but when it entwines corn stalks, it can destroy a farmer's crop. Heavy infestation by perennial weeds makes the land unsuitable for cultivation resulting in loss in its monetary value. Aquatic weeds that grow along the irrigation canals, channels and water streams restrict the flow of water. Aquatic weeds form breeding grounds for obnoxious insects like mosquitoes. They reduce recreational value by interfering with fishing, swimming, boating, hunting and navigation on streams and canals. *For example,* water hyacinth is beautiful in floating gardens but can rapidly clog waterways, making navigation impossible.

So, there are many methods of destroying weeds either by burning, pulling out or chopping down and treating them with herbicides. Biological control holds much promise for long-term, economical and environmentally sensitive weed management (Gharde *et al.*, 2023).

IV. BIOLOGICAL WEED CONTROL

Origin: In ancient times, the Chinese discovered that increasing ant populations in their citrus groves helped decrease destructive populations of large boring beetles and caterpillars. That use of a natural enemy to control a pest marked the birth of biological control. Biological control

research and implementation is even more relevant today. As a weed management method, biological control offers an environmentally friendly approach that complements conventional methods (This paragraph sheds light on the origins of biological weed control, which is why ancient techniques are mentioned.) It helps meet the need for new weed management strategies since some weeds have become resistant to certain herbicides. Biological control agents target specific weeds. Moreover, this technology is safe for applicators and consumers.

What is biological control of weeds?

Biological weed control involves use of living organisms, such as insects, nematodes, bacteria, or fungi, to control the weeds. 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. In nature, plants are controlled biologically by naturally occurring organisms called bio agents.

Qualities of bio-agent:

- The bio-agent must be host specific,
- Devoid of predators or parasites,
- Adaptable to environmental conditions with ample reproductive capacity,
- Capable of independent host-seeking,
- Able to either directly kill the weed or prevent its reproduction, in a direct or indirect manner (Smith *et al.*, 2023),

Merits:

- Environmentally benign/eco-friendly since it does not lead to environmental pollution,
- No residual effect,
- Preserves bio-diversity,
- Economical in the long run, although initially monetary investment is high,
- Will not affect non-targeted plants and safer in usage.

Demerits:

- Requires/incurs higher initial cost,
- Multiplication is costlier,
- Control is very slow,
- Weeds are not eradicated, but managed at a lower density,
- The span of activity of bio-agent in most cases is small/narrow, whereas weeds may grow all through the year. For example, *Parthenium hysterophorus*

grows all through the year, but *Zygodium bicolorata*, the bio-agent is active only during rainy season for a period of 2-3 months starting from July.

How does it work?

- Roots provide plants with water and nutrients. Some bio-agents attach to roots and thereby stunt plant growth. Some bacteria release toxins that stunt root growth. Many fungi disrupt the water transport system, which reduces leaf growth. Beneficial insects and nematodes feed directly on the weed roots causing injury which allows bacteria and fungi to penetrate (Khanna *et al.*, 2021).
- Plant leaves capture energy from the sun and store it as sugar. Insects feeding on leaves reduce the leaf area available for energy capture (Mooney, 1972). Fungi and bacteria infecting leaves reduce leaf ability to make sugars. In either case, there is less energy available for weed growth.
- Many weed species survive from year to year by producing seeds. Fungi or insects that attack seeds reduce the number of weed seeds stored in the soil, which in turn reduce the size of weed populations. This lowers the effort needed to control the remaining emerging weeds (Barbercheck, and Wallace, 2021).

Some bacteria and fungi applied as biological control agents do not survive from year to year. These organisms must be applied on an annual basis. This technique is called the "bioherbicide" strategy. With this tactic, biological agents are used in manner similar to chemical herbicides.

V. METHODS OF BIOLOGICAL WEED CONTROL

- Classical/Inoculative Biological Control
- Inundative/Augmentative/Bio-Herbicide Biological Control
- Broad-spectrum Biological Control
- Allelopathy
- Bio-dynamics

Classical/Inoculative Biological Control

Classical/Inoculative biological control involves the release of bio-agents (insects, pathogens) (Evans & Ellison, 1990) just for once in the belief that it will readily adapt to the prevailing climate and multiply enough to keep pace with the multiplication rate of weed in question. Therefore, repeated release of bio-agent is not advocated.

No augmentation and large-scale mass production of the bio-agent are practiced. It has been suggested that some of the introduced, invasive perennial weeds such as giant hogweed (*Heracleum antegazzium*), Himalayan balsam (*Impatiens glandulifera*) and the Japanese knotweeds (*Reynoutria* spp.) would be ideal candidates for classical biological control (Child *et al.*, 1993; Das *et al.*, 2017; Evans & Ellison, 1990; Fowler *et al.*, 1991). The introduction of a classical bio-control agent may not be deliberate. In this approach, a small amount of inoculum (pathogen) or insects, based on the assessment of weed problem and prevailing situation, is initially released in the standing population of weeds and allow it to multiply and feed on the weeds. The rust (*Puccinia lagenophorae*) is of Australian origin where it attacks a range of *Senecio* spp. (*Senecio vulgaris*) (Evans & Ellison, 1990). The rust does not kill the weed but makes it less competitive. Higher yields have been recorded in lettuce experiments with rusted groundsel compared with rust-free plants (Mishra *et al.*, 2021; Paul & Ayres, 1986; Tewari & Chethan, 2018).

Inundative/Augmentative/Bio-Herbicide

Biological Control

Inundative/Augmentative/Bio-Herbicide

biological control involves the culture and release of large numbers of a bio-control agent (inoculum) into the region or field where the target weed needs to be controlled. This inoculum is bio-herbicide. Bio-herbicides are native pathogens mostly fungi and hence called myco-herbicide. It has the advantage that native organisms can be used but there is the same requirement for host specificity (Weidemann & Tebeest, 1990). Several inoculums such as fungi, bacteria, parasitic nematodes, viruses can be applied as sprays in the same way as conventional herbicides. Bio-herbicides are sprayed in every season on the target weed in crop field (Aneja *et al.*, 2017; Keerthi *et al.*, 2019). The bio-agent generally remains active only on concurrent weed population. The specificity of a bio herbicide is increased where the susceptibility of the target organism can be enhanced. This may allow a selected area of a weed to be controlled without affecting nearby plants of the same species. For example, Isolates of *Xanthomonas campestris* pv. *Poae* have some activity against annual meadow grass, *Poa annua* (Imaizumi *et al.*, 1997). In groundsel (*Senecio vulgaris*), plants naturally infected with the rust *Puccinia lagenophorae*, were killed by inoculation with the pathogen *Botrytis cinerea*, while healthy plants were not (Hallett *et al.*, 1990).

Table 1: Mycoherbicides (Bioherbicide) that have been registered and their targeted weeds, October 2008 (Kumar et al., 2018).

Product	Pathogen	Target weeds
Lubao	<i>Colletotrichum gloeosporioides f. sp. cuscutae</i>	Dodder in soybean
DeVine	<i>Phytophthora palmivora</i>	Strangler vine in citrus orchard
Collego	<i>Colletotrichum gloeosporioides f. sp. aeschynomene</i>	Northern joint vetch in rice and soybean
CASST	<i>Alternaria cassiae</i>	Sickle pod and coffee senna in soybean and peanuts
Dr Bio-Sedge	<i>Pucciniacaniculata</i>	Yellow net sedge in soybeans, sugarcane, maize, potato and cotton
BioMal	<i>Colletotrichum gloeosporioides f. sp. Malvae</i>	Round leaved mallow in wheat, lentil & flax
Stumpout	<i>Cylindrobasidium leave</i>	Acacia species in native vegetation and water supplies
Biochon	<i>Chondrostereum purpureum</i>	Woody weeds like black berry in plantation forests
Camperico	<i>Xanthomonas campestris pvpoae</i>	Turf grass in golf courses
Hakatak	<i>Colletotrichum acutatum</i>	<i>Hakea gummosis</i> & <i>H. sericeain</i> native vegetation
Woad Warrior	<i>Puccinia thlaspeos</i>	Dyers woad (<i>Isastinctoria</i>) in farms, rangeland, waste areas and roadsides

Broad Spectrum Biological Control

The oldest example of broad-spectrum biological control is the use of grazing animals and birds to maintain pasture. In aquatic situations, the use of grass carp (*Ctenopharyngodon idella*) and other phytophagous fish has been investigated. In Australia, goats have been used to control blackberry (*Rubus fruticosus* agg.) (Dellow et al., 1988). In cereals, sheep grazing in spring is a traditional practice of many organic growers to aid weed control. Weeding increased grain yield but grazing reduced ear number. It is known that different breeds of livestock vary in their grazing or browsing preferences and abilities and should be taken into account for improved weed control (Soil Association, 2002).

Allelopathy

Within the broadening perceptions of biological control, allelopathy is regarded as a component of biological control (Lovett, 1991). Allelopathy is derived from two Greek words, "allelon or allelo" means "mutual or

each other" and "pathos or patho" means "suffering or to suffer." Molisch (1937) coined the term allelopathy, which includes all stimulatory and inhibitory reciprocal biochemical interactions among plants including microorganisms. The effect is exerted through the release of allelo chemicals by the growing plant or its residues. Allelopathy has been considered a defense mechanism in plants (Lovett, 1982). It makes a significant contribution to the process of plant succession (Numata, 1982). Allelo chemicals may be present in the mucilage around a germinating seed (Kosemura et al., 1993), in leachates from the aerial parts of plants (Tukey, 1966), in exudates from plant roots, in volatile emissions from the growing plant (Charron et al., 1995), and among decomposing plant residues (Bewick et al., 1994). The effectiveness of living mulches, intercrops or smother crops may in part depend on their allelopathic ability. While allelopathic crops or their residues inhibit the growth of certain weeds (Steinsiek et al., 1982), weeds such as fat-hen (*Chenopodium album*) that has allelopathic ability, may also influence the growth of

some crops (Goel *et al.*, 1994; Qasem & Hill, 1989). Weeds can also inhibit the growth of other weeds (Anaya *et al.*, 1988). Allelopathy could be used to manipulate the crop-weed balance by increasing the toxicity of the crop plants to the weeds (Kostina-Bednarz *et al.*, 2023).

There are two types of allelopathy : (**True and Functional**)

- **True allelopathy** involves the release of compounds into the environment and are toxic in the form they are produced.
- **Functional allelopathy** involves the release into the environment substances that are toxic as a result of transformation by microorganism.

Table 2: Allelochemicals and their functions (Vyvyan *et al.*, 2002)

Chemicals	Impact
Sorgoleone and its hydroquinones	Inhibit chlorophyll formation and photosynthetic oxygen evolution
Coumarins and flavonoids	Blocks mitosis, seedling and germination inhibitor
Terpenoids	Germination and growth
Breviones	Etiolation of coleoptile (wheat)
Dehydroazulatin	Rapid leakage of plasama membrane and growth inhibitor
Strigolactones	Germination stimulants
Heliannuols	Enhance growth of monocots and restricts dicots

Biodynamic

The term biodynamic is taken from Greek word bios meaning life and dynamics meaning energy. Hence biodynamic farming refers “working with the energies which create and maintain life” (Rai and Yadav, 2005). There are two main characteristics of BD farming (Dengel, 2004). Firstly, by the use of particular farming inputs made from various herbal, mineral and raw materials processed in complex ways and finally applied in small and minimal doses on soil and crops. And secondly by the observation of rhythms in nature which go beyond the most obvious influences of sun, weather and season, but which include lunar, planetary and stellar constellations. Biodynamic differs from organic farming in a way that biodynamic farms aim to become self-sufficient in compost, manure and animal feeds and moreover an astronomical calendar is used to determine auspicious planting, cultivating and harvesting times (Sharma, 2001). Although not strictly part of biological control, bio-dynamics and related methods are included here because they rely on the use of natural

materials for their effect. The control of perennial weeds by treating them with the potency ashes of those particular weed or their seeds is one area of particular interest to organic farmers. There is little scientific information on how these so-called weed peppers work. The principle is similar to the use of homeopathic medicines. Scherrer (2000) has begun testing the impact of weed peppers on *Solidago alissima* and *S. gigantean* but the treatments are expected to take several years of repeated applications to show an effect. Bio dynamically prepared compost applied to field crops reduced weed numbers but no more than non-biodynamic compost (Carpenter-Boggs, 2000).

Outstanding and Feasible Examples of Biological Weed Control (Hinz *et al.*, 2020)-

- Larvae of *Coctoblastis cactorum*, a moth borer, control prickly pear *Opuntia* sp. The larvae tunnel through the plants and destroy it. In India it is controlled by cochinal insects *Dactylopiusindicus* and *D. tomentosus*.
- Lantana camara* is controlled by larvae of *Crociosema lantana*, a moth bores into the flower, stems, eat flowers and fruits.
- Cuscuta* spp. is controlled by *Melanagromyza cuscutae*.
- Cyperus rotundus*- *Bactra verutanaa* moth borer.
- Ludiwigia parviflora* is completely denuded by *Altica cynanea* (steel blue beetle).
- Herbivorous fish- Tilapia controls algae. Common carp, a non-herbivorous fish controls submerged aquatic weeds. It is apparently due to uprooting of plants while in search of food. Snails prefer submersed weeds.
- Weed like *Parthenium hysterophorus* completely controlled by a Mexican beetle



Larvae of *Coctoblastiscactorum*



Mexican Beetle
(*Zygogrammabicolorata*)

Table 3: Some examples of Biological Weed Control (Monteiro and Santos, 2022)

Bio agent	Weeds
Insect	
Beetles: <i>Octotomas cabripennis</i> and <i>Uroplatagiraldi</i>	<i>Lantana camara</i>
Scale insect: <i>Dactylopiu stomentosus.</i>	Prickly-pear weed - <i>Opuntia</i>
Flea beetle: <i>Agasicleshygrophyla</i>	Alligator weed – <i>Alternantheraphiloxeroides</i>
Fish	
Common carp and Chinese carp	Aquatic weeds
Mammals: Manatee or sea-cow	Water hyacinth
Snails: Marisa sp and other fresh water snails	Submerged weeds like coontail and algae
Fungi: <i>Rhizoctinia</i> blight.	Hyacinth
Mites	
<i>Tetranychu</i> ssp	Prickly pear
Plants: Cowpea as intercrop in sorghum	Effectively reduces the growth of weeds in sorghum

Table 4: Factors Affecting Biological Success (Monteiro and Santos, 2022)

Biotic Factors	Abiotic Factors	Procedural Factors
Plant Community: Host density, Succession	Climate: Temperature, precipitation	Before release: Site selection, colony source, collection method, shipment, sex ratio
Interactions: Predation, parasitism, competition	Site characteristics: Soil, slope, aspect, shade, moisture	Release: Method, Wrong agent or host, timing, life stage, documentation
Biological Organism: Synchronization, physiology, fecundity, behavior, genetic diversity, emigration	Elevation: Temperature, precipitation	After release: Site management, agent detection, vandalism
	Latitude: Season, day length	Personnel: Training, experience, continuity, prioritization, follow-up
	Disturbance: Fire, flood	

Table 5. Exotic natural enemies' field-released for Classical biological control of weeds in India.

Weed (purported year of introduction)	Agents released (year) ^a	Establishment in the field and impact
Terrestrial weeds <i>Ageratina adenophora</i> (Sprengel) R. King and H. Robinson (1900)	<i>Procecidocha resutilis</i> Stone (1963)	Established - minimal control due to parasitoids
<i>Chromolaena odorata</i> (L.) King and H. Robinson (1914)	<i>Apion brunneonigrum</i> Béguin-Billecocq (1972) <i>Pareuchaetes pseudoinsulata</i> Rego Barros (1973 and 1984) <i>Cecidochares connexa</i> (Macquart) (2005)	Not established Recently reappeared Established - too early to assess
<i>Lantana camara</i> L. (1809)	<i>Ophiomyia lantanae</i> (Froggatt) (1921) <i>Teleonemia scrupulosa</i> Stål (1941) <i>Diastematigris</i> Guenée (1971) <i>Salbia haemorrhoidalis</i> Guenée (1971) <i>Octotomascabripennis</i> Guérin-Méneville (1972) <i>Uroplata girardi</i> Pic (1972)	Established - not effective Established - provides minimal Control Not established Not established Established - not effective Established - not effective
<i>Mikania micrantha</i> H.B.K. (1914)	<i>Puccinia spegazzini</i> de Toni (rust pathogen, 2005 Assam and 2006 Kerala)	Established in Kerala - too early

<i>Opuntia</i> spp. (unknown)	<i>Dactylopius ceylonicus</i> (Green) against <i>Opuntia vulgaris</i> Miller (1795)	Established and provided excellent Control
	<i>Dactylopius confuses</i> (Cockerell) against <i>O. vulgaris</i> (1836)	Not established
	<i>Dactylopius opuntiae</i> (Cockerell) against <i>Opuntia elatior</i> Miller and <i>Opuntia stricta</i> (Haworth) Haworth var. <i>dillenii</i> (Ker Gawler) L. Benson (1926)	Established and provided completecontrol of both species
<i>Parthenium hysterophorus</i> L. (1955)	<i>Zygommatibicolorata</i> Pallister (1984)	Excellent control in some areas
Aquatic weeds		
<i>Eichhornia crassipes</i> (Martius) Solms-Laubach (1900)	<i>Neochetinaeichhorniae</i> Warner (1983)	Established - provides good to variable control
	<i>Neochetinabruchi</i> Hustache (1984)	Established - provides good to variable control
	<i>Orthogalumnaterebrantis</i> Wallwork (1986)	Established - alone not very effective
<i>Salvinia molesta</i> Mitchell (1955)	<i>Pauliniaacuminata</i> (Degeer) (1974) <i>Cyrtobagous salviniae</i> Calder and Sands (1983)	Established - uncertain control Established - spectacular control

VI. CONCLUSION

Techniques for non-chemical weed control have been developed to reduce chemical costs in conventional agriculture, in response to environmental pressures and to provide for the needs of organic food production. A wide range of equipment is available to cover the major crops grown. Successful non-chemical weed control requires a well-managed, integrated system and attention to detail. Future work is required to research the effects of heat from thermal techniques on soil microorganisms, weed seed germination and viability. The effects of the different soil/weed combinations on the success of the weeding operation and on the soil structure also needs merit attention.

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