ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com
Journal DOI: 10.21474/IJAR01

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Weeds - its causes and management through biological means

Vikas Tandon[1], *Ankush Kumar[2], Saurbh Soni [3] and Munish Sharma[4]

1. Ph.D. Scholar, Department of Entomology, CSK Himachal Pradesh Agricultural University, Palampur, India.
2. Ph.D. Scholar, Department of Agronomy, Forages and Grassland Management, CSK Himachal Pradesh Agricultural University, Palampur, India.
3. Ph.D. Scholar, Department of Entomology, CSK Himachal Pradesh Agricultural University, Palampur, India.
4. Ph.D. Scholar, Department of Soil Science, CSK Himachal Pradesh Agricultural University, Palampur, India.

Manuscript Info

Manuscript History:

Received: 18 May 2016
Final Accepted: 22 June 2016
Published Online: July 2016

Key words:
Weed, Biological control, Organisms and Management

Corresponding Author

Ankush Kumar

Abstract

Weeds affect human affairs in most of the areas of the earth. The major characteristics of weeds are their unwanted occurrence, undesirable features and ability to adapt to a disturbed environment. Weeds compete with crop species, lower yields, increase labour requirements and ultimately, increase food costs for the consumer. Biological control as a general term refers to the introduction of organisms into an ecosystem with the intention of controlling one or more undesirable species. Biological control includes the classical (inoculative), bioherbicides (inundative) approaches and herbivore management. Insects, mites, nematodes, plant pathogens, animals, fish, birds and their toxic products are major weed control biotic agents. Biological agents, mainly insects provide excellent biological control of prickly pear (*Opuntia elatior* and *O. vulgaris* by *D. ceylonicus* and *D. opuntiae)*, water fern (*Salvinia molesta* by weevil, *Cyrtobagous salviniae*), water hyacinth (*Eichhornia crassipes* by weevils *Neochetina bruchi* and *N. eichhorniae* and galumnid mite *Orthogalumna terebrantis*) and *Parthenium hysterophorus* by chrysomelid beetle *Zygogramma bicolorata*. Some introduced bioagents were not a big success but provided partial control like in case of *Lantana* by agromyzid seedfly, *Ophiomyia Lantanae*, tingid lace bug, *Teleonemia scrupulosa, Diastema tigris, Uroplata girardi*, *Octotoma scabripennis* and *Epinotia lantanae*. Nevertheless, India has now caught up with the rest of the pioneers in the field by recently introducing a host-specific plant pathogen, *Puccinia spegazzinii* against mikania weed (*Mikania micrantha*) and thereby became the eighth country in the world to practise CBC (Classical Biological Control) of weeds with plant pathogens. As this technology moves forward, their use will become even more probable for growers searching to diversify their weed management system. It will usually require a long period of research and a high initial investment of capital and human resources.

Introduction:-

Increasing worldwide demand for food (due to increasing global population which is predicted to be 9.0 billion by 2050) - the greatest challenge of our time. So that modern agricultural practices to be adopted to ensure; a secure food supply and at the same time ensure that it is done in a sustainable way. The food production is checked by various categories of pest. It is estimated that diseases, insects, and weeds together annually interfere with the production of, or destroy, between 31 and 42% of all crops produced worldwide (**average total losses of 36.5%**). In India weeds causes losses up to 45 %, Insects – 30 %, Diseases – 20 % and others 5% (**TNAU 2014**).

What is Weed?

Weeds are unwanted and undesirable plants which interfere with the utilization of land and water resources and thus adversely affect human welfare. They can also be referred as plants out of place. Any plant or vegetation excluding fungi interfering with the objectives or requirement of people called weed (**Jethro tull, 1731**).

Weeds: Causes:-

- Compete with the desired plants for the resources that a plant typically needs, namely, direct sunlight, soil, nutrients, water and space for growth
- Provide hosts and vectors for plant pathogens giving them greater opportunity to infect and degrade the quality of the desired plants
- Provide food or shelter for animal pests such as seed-eating birds
- Irritation to the skin or digestive tracts of people or animals, either physical irritation via thorn, prickles or chemical irritation *via* natural poisons or irritants in the weed
- Cause root damage to engineering works such as drains, road surfaces, foundations, blocking streams and rivulets

List of Invasive Weed species present in India (Viraktamath, 2002)

S. No	Common Name	Scientific Name	From	Year	Introduction As
1.	Siam weed	*Chromolaena odorata*	Central america	1800	Ornamental plant
2.	Water hyacinth	*Eichhorina crassipes*	Brazil	1800	Ornamental plant
3.	Lantana	*Lantana camera*	Central America	1809	Ornamental plant
4.	Prickly pear	*Opuntia* spp	Australia	1863	Hedge crop
5.	Vilayati babul	*Prosopis juliflora*	Mexico	1877	Royal Plant
6.	Mile-a-minute weed	*Mikania micrantha*	Malaysia	1940	Ground cover crop
7.	Parthenium	*Parthenium hysterophorus*	USA	1951	Contamination with wheat
8.	Gehun ka mama, Mandussi	*Phalaris minor*	Mexico	1961	Contamination with wheat
9.	Crofton weed	*Ageratina adenophora*	Mexico	1967	
10.	Johnson grass	*Sorghum halepense*	USA		Forage crop

Methods of weed management:-

- Cultural method
- Physical method
- Chemical method
- Biological method

Biological control of weeds:-

Biological control as a general term refers to the introduction of organisms into an ecosystem with the intention of controlling one or more undesirable species (**Charudattan, 2001; Bailey et al. 2010).** Biological weed control involves: using living organisms, such as insects, nematodes, bacteria, or fungi, to reduce weed populations.

Origin of biological weed control:-

By 1925, Australia was struggling with 60 million acres of grazing land heavily infested with prickly pear cactus. Hundreds of square miles were virtually impenetrable to humans or animals. A small moth from Argentina (*Cactoblastis cactorum*) was imported and released. The moth larvae burrowed into the cactus, grew and multiplied and within 10 years had decimated the prickly pear population. Today, the cactus covers only 1% of the area it occupied in 1925.

How does it work?

1. Roots:-

- Some biological control agents attach to roots and thereby stunt plant growth

- Some bacteria live on root surfaces and release toxins that stunt root growth
- Many fungi infect roots and 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

2. Leaves:-
- Insects feed on leaves and reduce the leaf surface available for energy capture
- Fungi and bacteria infect leaves and reduce the ability of the leaf to make sugars

3. Seeds:-
- Fungi or insects attack seeds and reduce the number of weed seeds stored in the soil, which in turn reduce the size of future weed populations
- This lowers the effort needed to control the remaining emerging weeds

Management of different weed species through biological means:-
Alligator weed (*Alternanthera philoxeroides)*: The alligator weed was introduced to the United States from South America. This aquatic weed spreads rapidly and causes many problems in lakes and rivers. The weed takes root in shallow water causing major problems for navigation, irrigation and flood control.

Management:-
Three South American insects were released in the 1960s to control alligator weed:
(**1**) **Alligator weed flea beetles** (**2) Alligator weed thrips (3) Alligator weed stem borer**
1) **Alligator weed flea beetle** (*Agasicles hygrophila*): This beetle has been imported from Argentina and first released in Florida and consumes the leaves and parts of the stems of the aquatic form of alligator weed.
2) **Alligator weed thrips** (*Amynothrips andersoni*): Native to Argentina and was first released in 1967. Leaf damage by the thrips affects the plant by stunting its growth and reported to be most successful.
3) **Alligator weed stem borer** (*Arcola malloi*): Small brown moth from Argentina that was released in 1971. The larvae mine inside the stem and cause the plant to wilt and die.

Carrot Weed (*Parthenium hysterophorus*):-
It is known as white top and congress grass. Parthenium is native of Mexico. It can produce thousands of small white capitula each yielding five seeds on reaching maturity. *Parthenium* has invaded about 35 million hectare of land throughout India **(Kumar and Varshney, 2010).** It degrades natural ecosystems by reducing biodiversity **(Holm et al. 1997)** and can cause serious allergic reactions in man and animals **(Chippendale and Panetta 1994; Kumar, 2012).**

Management:-
A beetle native to Mexico, *Zygogramma bicolorata*, was first introduced to India in 1984. It has become widespread and well-established, and is capable of defoliating and killing this weed. The early stage larvae feed on the terminal and auxiliary buds and move on to the leaf blades as they grow. An insect density of one adult per plant caused skeletonization of leaves. The flower feeding weevil *Smicronyx lutulentus* (Coleoptera: Curculionidiae) and the stem boring moth *Epiblema strenuana (*Lepidoptera*:* Tortricidae) (**Singh, 1989; Kumar, 2009).**

Lantana (*Lantana camara*):-
It is a small perennial shrub which can grow to around 2m in height. It is toxic to livestock such as cattle, sheep, horses and goats. The active substances causing toxicity in grazing animals is **pentacyclic triterpenoids** which results in liver damage and photosensitivity. *L. camara* also excretes chemicals (**allelopathy**) which reduce the growth of surrounding plants by inhibiting germination and root elongation. Current estimates suggest that *Lantana* has invaded more than 5 M ha in Australia, 13 M ha in India and 2 M ha in South Africa (**Bhagawat et al. 2012).**

Management:-
In 1921, the agromyzid seedfly, ***Ophiomyia lantanae*** was introduced from Hawaii and released in south India for the suppression of *L. camara* **(Julien and Griffiths 1998).** Tingid lace bug, ***Teleonemia scrupulosa,*** a native of Mexico was introduced from Australia in 1941 but the insect 'escaped' quarantine and by now it has spread to all the lantana stands in the country. *Teleonemia scrupulosa* does not attack teak or any other economic plant in India under field conditions (**Kumar, 1993; Kumar and Saraswat 2001).**

1) ***Teleonemia scrupulosa***: It sucks sap, mainly found on the underside of the tender leaves. The initial effect of its feeding is the yellowish (or) brownish discoloration and stunted growth in the shoot apex followed by curling up, blighting and falling of leaves resulting in a burnt appearance. Flowers and fruits dropped and the maturity of the fruits delayed.
2) ***Orthezia insignis***: Restricted to the ventral side of the leaves mostly abundant along the mid rib feeding on the plant sap. The fully grown coccids cause burnt appearance and severely checking the growth. Both the tingids and coccids, due to their intense sap sucking in the tender shoots, suppressed the vigor of *Lantana* bushes and impeded their reproductive potential.

Leafy spurge (*Euphorbia esula*):-

Leafy spurge is an erect plant that grows 1 to 3 feet tall. Leaves are bluish-green with smooth margins. Umbel flowers are surrounded by heart shaped showy, yellow-green bracts. It can reduce cattle carrying capacity of rangeland or pastures by 50 to 75 percent. Leafy spurge is difficult to control due to its extensive root system. Leafy spurge is Eurasian perennial that was introduced into North America in the 19th century. It infests several million hectares of rangelands and riparian areas in the United States and is a serious pest across the Northern Great Plains. Cattle and horses avoid leafy spurge because its milky latex may cause sickness and even death. Leafy spurge has a number of biological characteristics that have caused it to be difficult to control with herbicides. Classical biological control is envisioned as a potentially valuable spurge management tool in North America.

Management:-

Nine insects have been released in the United States against leafy spurge and six insects have become established in North Dakota, including a gall midge, a stem/root boring beetle and flea beetles. The flea beetles have been the most important in reducing leafy spurge density. Releases of five species of flea beetles (*A. flava*, *A. czwalinae*, *A. lacertosa*, *A. abdominalis*, and *A. nigriscutis*) began in 1985 in North Dakota**.** By 1996, *A. lacertosa* and *A. nigriscutis* had established in almost every country and are the most important in reducing leafy spurge infestations.

Aphthona flava:-

Adult flea beetles are small (3-4 mm) and orange or orange-brown in colour. *A. flava* adults feed on leafy spurge foliage and flowers, and high populations may defoliate spurge plants. Newly-hatched larvae burrow into the soil and begin feeding on very small leafy spurge roots. Larvae feed on progressively larger roots and root buds as they develop.

Mile-A-Minute Weed (*Mikania micrantha*):-

M. micrantha originates in South and Central America where it is widespread but not often a significant weed problem. It also grows along streams and roadsides, in or near forests, forest plantations, pastures, fencelines, tree crops (immature rubber, oil palm and cocoa, and to a lesser extent tea, coffee and fruit trees) and waste areas **(Parham, 1962; Adams et al. 1972).**

Management:-

Barreto and Evans (1995) identified a strain of the rust *Puccinia spegazzinii* from Trinidad has been identified as having great potential. It was found to be highly pathogenic to all the major weed biotypes and is specific to *M. Micrantha.* It attacks not only the leaves but also the petioles and stems, leading to ring-barking and death, whereas other potential agents only cause severe damage to the leaves **(Kumar et al. 2005; Ellison et al. 2006).**

Prickly Pear (*Opuntia elatior,O. stricta* and *O. vulgaris)*:-

It is Native to the Caribbean region. Flowers are yellow, mostly on the margins of the fleshy segments. Fruit are egg-shaped with a depressed top, purple when ripe and edible. Prickly pear plays host to the fruit-fly, providing a food source to a serious pest. Dense infestations of the plant hinder access to water and reduce available fodder for fauna. The barbed bristles of the prickly pear readily penetrate human skin and are difficult to remove, causing severe irritation. Dense infestations of this weed can form an impenetrable barrier, posing as a high nuisance to people by restricting direct access. Due to the spiny nature of the plant, it may affect some recreational activities.

Management:-

The first successful classical biological control was achieved in India when cochineal insect, *Dactylopius ceylonicus* was introduced from Brazil in 1795 in the mistaken belief that it was the true carmine dye producing insect, *D. coccus* **(Singh, 1989).** *D. ceylonicus* later readily established on drooping prickly pear, *Opuntia vulgaris* (its natural host) in north and central India bringing about spectacular suppression of *O. vulgaris. D. ceylonicus*, being restricted

to *O. vulgaris*, proved a failure when introduced and distributed in south India to suppress *O. Stricta.* In 1926, *D. opuntiae*, a North American species, was imported from Sri Lanka and its colonization resulted in spectacular suppression of *O. stricta* and related *O. elatior* **(Singh, 1989; Julien and Griffths 1998).**

Purple Loosestrife (*Lythrum salicaria*):-

Purple loosestrife is an aggressive, herbaceous semi-aquatic plant native to Europe. It is a hardy, upright perennial that grows to 2 metres. Stems are 4-sided and woody with several stalks per plant. The numerous flowers with 5-6 petals,pink-purple in colour and develop. On the terminal spike of each stem reproduction is both by seed and root fragments. Each plant is capable of production up to 2.5 million seed. An attractive but invasive perennial, purple loosestrife has become established in a wide range of habitats including river banks, lake and pond shores, irrigation ditches and roadsides. It was originally introduced to North America in the 1800's as an ornamental. Purple loosestrife has now naturalized and spread across Canada and the northern US. This invasive plant is found in shallow wetlands where it aggressively degrades and crowds out the natural vegetation required by wildlife. Purple loosestrife is a vigorous competitor and can crowd out other vegetation including native species. The natural foods and protective cover required for wildlife survival is lost. This may result in the loss of wildlife species or displacement from their natural habitat.

Management:-

Biological control has played a more important role in reducing loosestrife infestations in Minnesota, where several thousand acres are infested at nearly 2,000 locations statewide and herbicides are ineffective in areas of severe infestations**.** Four insects have been released in the United States for the control of purple loosestrife namely black-margined loosestrife beetle (*Galerucella calmariensis*), golden loosestrife beetle (*Galerucella pusilla*), root-boring weevil (*Hylobius transversovittatus*)**,** flower-feeding weevil (*Nanophyes marmoratus).*

Loosestrife beetles, *Galerucella calmariensis* and *Galerucella pusilla* adults and larvae impact plant growth and reproduction by feeding heavily on the plant's leaves, stems and buds. Adults feed on young plant tissue causing a characteristic "shot hole" defoliation pattern. The loosestrife root weevil, *Hylobius transversovittatus* adults feed on plant foliage and the larvae feed within the roots. The loosestrife seed weevil, *Nanophyes marmoratus*, adults and larvae impact the plants by feeding on unopened flower buds.

***Galerucella calmariensis*:-**

The black-margined loosestrife beetle is cylindrical in shape and mid brown in colour. When seen from above it often has two blackish lateral lines down either side and larvae are yellow speckled with black and resemble small caterpillars. Larval feed on buds and shoots reduces the growth of the plant and its ability to flower and produce seed.

***Galerucella pusilla*:-**

Light brown in colour and the body has fine, dense hairs, parallel sides, is 3-4 mm long and about half as wide, with a slight narrowing toward the head. *G. pusilla* is also punctate, but less coarsely so than *G. calmariensis*.

Water Fern (*Salvinia molesta*):-

Salvinia molesta, commonly known as **giant salvinia** or **kariba weed** is an aquatic fern, native to south-eastern Brazil. First observed in 1955 in Vole Lake (Kerala), assumed the pest status since 1964 and affects large water bodies in Kerala including rice fields. *S. molesta* form dense vegetation mats that reduce water-flow and lower the light and oxygen levels in the water. This stagnant dark environment negatively affects the biodiversity and abundance of freshwater species, including fish and submersed aquatic plants. *Salvinia molesta* invasions alter wetland ecosystems and cause wetland habitat loss. *Salvinia* invasions also pose a severe threat to socio-economic activities dependent on open, flowing and/or high quality waterbodies, including hydro-electricity generation, fishing and boat transport. In Kuttanad area alone, which is considered the rice bowl of Kerala, some 75,000 acres of canals and another 75,000 acres of paddy fields are affected by this weed.

Management:-

The weevil, *Cyrtobagous salviniae* was imported from Australia in Bangalore in 1982 and more than 75 economically important plants belonging to 41 families were tested for host specificity. Within 11 months of the release of the weevil in the lily pond the salvinia plants collapsed and the lily growth which was suppressed by competition from salvinia resurrected**.** The control of salvinia also brought back the aquatic flora of Kerala back to

the pre-salvinia days (**Joy et al. 1995**). *Phoma glomerata* and *Nigrospora sphaerica* were found potential pathogen for the biological control of Salvinia **(Sreerama et al. 2007**).

Cyrtobagous salviniae:-
The weevil is 2 mm long and shiny black in colour and adults feed on growing salvinia tips and grubs feed on roots, before tunnelling into buds and stems. These tunnels cause salvinia plants to sink and die.

ater Hyacinth (*Eichhornia crassipes*):-
Water hyacinth is a free-floating perennial aquatic plant native to tropical and sub-tropical South America. It ranks among the top ten weeds and has spread to at least 50 countries around the globe. After first introduced into Bengal around 1896 as an ornamental plant, it has spread throughout India and occupies over 200,000 ha of water surface. Water hyacinth has also become a serious menace in flooded rice fields, considerably reducing the yield. It has even encroached into major river systems- Brahmaputra, Ganges, Godavari, Satluj and Beas. It interferes with the production of hydro-electricity, blocks water flow in irrigation projects (40 to 95% reduction), prevents the free movement of navigation vessels, interferes with fishing and fish culture.

Management:-
The biological control of water hyacinth began in the 1960s and produced the classical control strategy that involves the importation of natural enemies from the point of origin of the weed. Several biological control agents have been released
1. *Neochetina eichhorniae* (1972) **2.** *Neochetina bruchi* (1974) **3**. *Niphograpta albiguttalis* (1977) **4.** *Orthogalumna terebrantis*

1) **Mottled water hyacinth weevil (*Neochetina eichhorniae*):** It was first released in 1972 and adults feed on the leaves and petioles of water hyacinth. Larvae made tunnel in the petioles and crown of the plant. Stress plants, reduce flowers and seeds, and reduce plant vigor.
2) **Chevroned water hyacinth weevil (*Neochetina bruchi*):** It was first released in 1974 and reduce plant vigor and seed production and damage young water hyacinth stands.
3) **Water hyacinth moth (*Niphograpta albiguttalis*):** It was first released in 1977 and larvae feed by tunneling into the petioles of the younger, bulbous form of water hyacinth.
4) **Water hyacinth mite (*Orthogalumna terebrantis*):** It is an arachnid native to the U.S. and in high numbers, these mites can desiccate water hyacinth foliage and cause leaves to turn brown.

Commercially Registered Bioherbicides for weed management

Pathogen	Weed host	Trade name	Reference
Colletotrichum gloeosporioides f. sp. *aeschynomene*	Northern jointvetch	Collego®	Bowers, 1986; Smith, 1982, 1991
Colletotrichum gloeosporiodes f. sp. *malvae*	Round-leaved mallow	BioMal®	Boyetchko, 1999; Mortensen, 1998; Mortensen and Makowski, 1997
Phytophthora Palmivora	Stranglervine	DeVine®	Ridings, 1986
Colletotrichum gloeosporioides	Dodder	LuBao	Templeton, 1992
Cercospora rodmanii	Water hyacinth	ABG-5003	Charudattan, 1991,2001
Alternaria cassiae	Sicklepod, coffee senna, and showy crotalaria	CASST™	Charudattan et al., 1986
Puccinia canaliculata	Yellow nutsedge	Dr. BioSedge®	Bruckart and Dowler, 1986; Phatak, 1992
Chondrostereum purpureum	Black cherry	Biochon™ Stumpout®	Dumas et al., 1997 Shamoun and Hintz,1998
XanthomonasCampestris	Annual bluegrass	Camperico®	Imaizum et al., 1997

1) **DeVine:** *Phytophthora palmivora* - USA in 1981**.** It is a facultative parasite that produces lethal root and collar rot in host. Used as a liquid suspension formulation.

2) **Collego:** *Colletotrichum gloeosporioides f. sp. Aeschynomene* - USA in 1983. This used as dry powder formulations. Fungus forms special penetration structures (appressoria) that can punch the plant cuticule which is essential for plant infection. It causes lethal stem and foilage blight in host. Newly registered under the trade name of Lockdown™ and Lockdown Retro™.
3) **Biomal:** *Colletotrichum gloeosporiodes f. sp. Malvae* --- Canada in 1992. This is hydrophilic fungus and delivered as a wettable silica gel powder.
4) **LuBao:** *Colletotrichum gloeosporioides f.sp. cucsutae*--- China in 1963**.** Used as a liquid formulation.
5) **Dodder:** It is a leafless, parasitic plant that removes nutrients, reduces yield and even kills its host plant. Dodder has been recorded on a wide range of field crops, pasture legumes, vegetables and horticultural crops.
6) **ABG-5003:** *Cercospora rodmanii* - Abbott labs, USA**.** ABG consists mycelial fragments and spores applied as wettable powder.
7) **CASST™:** *Alternaria cassiae* - USA 1983**.** It causes seedling blight in sicklepod. Spores are used in water with an oil based adjuvant.

Advantages and disadvantages:-

Advantages:-

- Selective, so little danger of damage to non-target plant species
- Effective in inaccessible areas
- Negligible environmental impact
- No problems associated with herbicide residues, contaminated groundwater and weed resistance to herbicides
- A small number of biocontrol agents can, once established, grow to very high densities and provide continuous control of a weed over a large area
- When the cost of development is considered, classical biocontrol is generally less expensive than chemical control.

Disadvantages:-

- Populations require time to become established, so signs of weed suppression are rarely evident in the first year
- Screening work (determining the selectivity and effectiveness of a biocontrol agent) is also very time consuming and is subject to limited funding

Is biocontrol a suitable solution for weed problem?

Biocontrol agents do not eliminate weeds because they can never find or utilise every plant. A successful biocontrol attack may reduce the vigour and abundance of a weed so that it stops spreading and it may reduce existing infestations to a level that we can live with or eliminate effectively and economically by other means. If biocontrol is successful, plants become increasingly rare and the agent population reduces accordingly so a new equilibrium forms between the abundance of agents and their host plants. Biocontrol is an option when we do not need to control the weed immediately because it takes time for the agents to build up damaging populations. Weeds are removed gradually so large areas of soil are not exposed to erosion and invasion. Biocontrol is an option when it is important that we harm only the target weed, a result that is difficult to achieve by mechanical or chemical means. Biocontrol agents rarely pose health risks to handlers. Biocontrol may be the only option when other methods are not physically or economically possible.

Conclusions:-

Biological control is an effective management tool for the control of weeds. Finding host specific agents is sometimes difficult, but necessary for reducing risk to non-target organisms. Technology transfer has advantages because the probability of success is greater and the research time (and cost) is reduced. There are many challenges and constraints inherent in the development of biological herbicides, the increasing prevalence of both herbicide-resistant weeds. There is significant potential for the development of new weed control strategies that can be employed to delay herbicide resistance, produce food in accordance with consumer concerns, and reduce the environmental impact of modern agriculture and ecosystem management**.** Bio-herbicides and natural predators offer the potential for one more means to achieve sustainable, high yield production systems.

References:-

1. **Bailey, K.L., Boyetchko, S.M. and Langle, T. (2010).** Social and economic drivers shaping the future of biological control: a Canadian perspective on the factors affecting the development and use of microbial biopesticides. *BioControl* 52: 221-229.
2. **Bhagwat, S.A., Breman, E., Thekaekara, T., Thornton, T.F. and Willis, K.J. (2012).** A battle lost? Report on two centuries of invasion and management of *Lantana camara* L. In Australia, India and South Africa. *PLoS ONE* 7(3): e32407. doi:10.1371/journal.pone.0032407.
3. **Bowers, R.C. (1986).** Commercialization of Collego: An industrialist's view. *Weed Sci.* 34 (Suppl. 1): 24–25.
4. **Boyetchko, S.M. (1999).** Innovative application of microbial agents for biological weed control. In: Mukerji, K. G., Chamola, B. P., Upadhyay, R. K., eds. *biotechnological approaches in biocontrol of plant pathogens*. New York: Plenum Publishers, pp. 73–98.
5. **Bruckart,W.L., Dowler, W.M. (1986).** Evaluation of exotic rust fungi for classical biological control of weeds. *Weed Sci.* 34 (Suppl. 1): 11–14.
6. **Charudattan, R. (1991).** The mycoherbicide approach with plant pathogens. In: TeBeest, D. O., ed. *microbial control of weeds*. New York: Chapman & Hall, pp. 24–57.
7. **Charudattan, R. (2001).** Biological control of weeds by means of plant pathogens: significance for integrated weed management in modern agro-ecology. *BioControl* 46: 229-260.
8. **Charudattan, R. (2001).** Biological control of weeds by means of plant pathogens: Significance for integrated weed management in modern agroecology. *BioControl* 46:229–260.
9. **Charudattan, R., Walker, H.L., Boyette, C.D., Ridings, W.H., TeBeest, D.O., Van Dyke, C.G. and Worsham, A.D. (1986).** Evaluation of *Alternaria cassiae* as a mycoherbicide for sicklepod (*Cassia obtusifolia*) in regional field tests. S*outhern cooperative service bulletin*. alabama: alabama agricultural experiment station, Auburn University, pp. 1–19.
10. **Chippendale, J.F. and Panetta, F.D. (1994).** The cost of parthenium weed to the Queensland cattle industry. *Plant Prot. Q.* 9: 73–76.
11. **Combellack, J.H. (1992).** The importance of weeds and ways of reducing concerns about methods for their control. In**:** proceedings of the first international weed control congress, Melbourne pp 43-63.
12. **Dumas, M.T., Wood, J.E., Mitchell, E.G. and Boyonoski, N.W. (1997).** Control of stump sprouting o1f *Populus tremuloides* and *P. grandidentata* by inoculation with *Chondrostereum purpureum*. *BioControl* 10: 37–41.
13. **Ellison, C.A., Puzari, K.C., Kumar, P.S., Dev, U., Sankaran, K.V., Rabindra, R.J. and Murphy, S.T. (2006).** Sustainable control of *Mikania micrantha*-implementing a classical biological control strategy in India using the rust fungus *Puccinia spegazzinii*. In: Program and Abstracts, Seventh International Workshop on Biological Control and Management of *Chromolaena odorata* and *Mikania micrantha*, 12-15 September 2006. National pingtung university of science and technology, Pingtung, Taiwan, Republic of China, pp 3-4.
14. **Holm, L., Doll, J., Holm, E., Pancho, J. and Herberger, J. (1997).** *World Weeds: Natural Histories and Distribution*. John Wiley & Sons, Inc, New York, p1129.
15. **Imaizumi, S., Nishino, T., Miyabe, K., Fujimori, T. and Yamada, M. (1997).** Biological control of annual bluegrass (*Poa annua* L.) with a Japanese isolate of *Xanthomonas campestris* pv. *poae* (JT-P482). *BioControl* 8:7–14.
16. **Joy, PJ., Sathesam N.V., Lyela, K.R. and Joseph, D. (1985).** Successful biological control of floating weed *Salvinia molesta*, using the weevil, *Cyrtobagous salvinae* in Kerala (India),. In: *proceedings of 10th Asian pacific weed science society conference*, Bengaluru, pp 622-629.
17. **Julien, M.H. and Griffith, M.W. (1999).** Biological control of weeds: A world catalogue of agents and their target weeds (fourth edition). CAB International, Wallingford, Oxon, UK, p 223.
18. **Julien, M.H., Scott, J.K., Orapa, W. and Paynter, Q. (2007).** History, opportunities and challenges for biological control in Australia, New Zealand and the Pacific Islands. *Crop Prot.* 26: 255–265.
19. **Klingman, G.C. and Ashton, F.M. (1975).** Weed Science: Principles and Practices. 2nd ed. John Wiley & Sons, New York, pp 112-115.
20. **Kumar, P.S., Rabindra, R.J., Dev, U., Puzari, K., Sankaran, K.V., Khetarpal, R.K., Ellison, C.A. and Murphy, S.T. (2005).** India to release the first fungal pathogen for the classical biological control of a weed. *BioCont. News Info.* 26: 71–72.
21. **Kumar, S. (1993).** Biological control of forests and waste land weeds in India. *Ann. Entomol.* 11(2): 131-153.
22. **Kumar, S. (2005).** Biological control of Parthenium through *Zygogramma bicolorata*. National research centre for weed science, Jabalpur, India, p. 88.

23. **Kumar, S. (2009).** Biological control of *Parthenium*in India: status and prospects. *Indian J. Weed Sci*. 41(1&2): 1-18.
24. **Kumar, S. (2012).** Current spread, impact and management of *Parthenium* weed in India. *International Parthenium News* 5: 1-6.
25. **Kumar, S. (2015).** History, progress and prospects of classical biological control in India. *Indian J. Weed Sci*. 47: 306–320.
26. **Kumar, S. and Saraswat, V.N. (2001).** Integrated management: The only solution to suppress *Parthenium hysterophorus*, pp.150-168. In: *Alien Weeds in Moist Tropical Zones: Banes and Benefit*s, (Eds. KV Sankaran, ST Murphy and HC Evans) Workshop Proceedings, 2-4 November, 1999, Kerala Forest Research Institute, India and CABI Bioscience, UK Centre (Ascot), UK.
27. **Kumar, S. and Varshney, J.G. (2010).** *Parthenium* infestation and its estimated cost management in India. *Indian J. Weed Sci*. 42**(**1&2): 73-77.
28. **Mortensen, K. and Makowski, R.M.D. (1997).** Effects of *Colletotrichum gloeosporioides* f. sp. *malvae* on plant development and biomass of non-target crops under field conditions. *Weed Res.* 37:51–360.
29. **Mortenson, K. (1998).** Biological control of weeds using microorganisms. In: Boland, G. J., Kuykendal, L. D., eds. *Plant-Microbe Interaction and Biological Control*. New York: Marcel Dekker, pp. 223–248.
30. **Phatak, S.C. (1992).** Development and commercialization of rust (*Puccinia canaliculata*) for biological control of yellow nutsedge (*Cyperus esculentus* L.). *proceedings of the first international weed control congress*. Melbourne: Weed Society of Victoria.
31. **Pimental, D., Mcnair, S., Janecka, J., Wightman, J., Simmonds, C., Connell, C.O., Wong, E., Russel, L., Zern, J., Aquino, T. and Tsomondo, T. (2001).** Economic and environmental threats of alien plant, animal, and microbe invasions. *Agric. Ecosyst. Environ.* 84: 1-20.
32. **Ridings, W.H. (1986).** Biological control of stranglervine in citrus: A researcher's view. *Weed Sci.* 34(Suppl. 1): 31–32.
33. **Shamoun, S.F. and Hintz, W.E. (1998).** Development and registration of *Chondrostereum purpureum* as a mycoherbicide for hardwood weeds in conifer reforestation sites and utility rights-of-way. *International bioherbicide workshop: Programme and Abstracts,* Aug 6–7. Glasgow: University of Strathclyde, p14.
34. **Singh, S.P. (1989).** Biological suppression of weeds. NCIPM, Faridabad: *Technical bulletin no.1*. 15-16.
35. **Singh, S.P. (2004).** Some success stories in classical biological control in India. Asian and Pacific Coconut Community, pp 7-12.
36. **Smith, R.J. Jr. (1982).** Integration of microbial herbicides with existing pest management programs. In: Charudattan, R., Walker, H. L., eds. *biological control of weeds with plant pathogens*. New York: John Wiley & Sons, pp. 189–203.
37. **Smith, R.J. Jr. (1991).** Integration of biological control agents with chemical pesticides. In: TeBeest, D. O., ed. *Microbial control of weeds*. New York: Chapman and Hall, pp. 189–208.
38. **Sreerama, P.K., Rabindra, R.J. and Ellison, C.A. (2007**). Expanding classical biological control of weeds with pathogens in India: the way forward. XII international symposium on biological control of weeds, p 165-172.
39. **Templeton, G.E. (1992).** Use of colletotrichum strains as mycoherbicides. In: Bailey, J. A., Jeger, M. J., eds. *colletotrichum: Biology, Pathology and Control*. Wallingford, UK: CAB International, pp 358–380.
40. **TNAU (2014).** http://agritech.tnau.ac.in/agriculture/agri_weedmgt_aboutweed.html.
41. **Viraktamath, C.A. (2002).** Alien invasive insect and mite pests and weeds in India and their management. Micronesica Suppl., 6: 67-83.