Invasive weeds and their management in India

Syed Khalida Izhar[1], Shareen Fatima Rizvi[1], Saba Siddiqui[2] and Uzma Afaq[1]*

[1] Department of Biosciences, Integral University, Lucknow, UP-226026, India
[2] Integral Institute of Agricultural Science & Technology Integral University, Lucknow,India.
*Corresponding author: Assistant Professor, Department of Biosciences, Integral University, Lucknow, UP-226026, India.
Email: uzmaafaq89@gmail.com

Abstract

Weeds are an ever-present pest that causes severe casualties in crop yields and quality. One-third of global crop losses occur as a consequence of invasive weeds. An aggressive weed is a problem in Asian countries, particularly in India. These invasive weeds can be found in a large variety of environments. Native fauna is depleted and hydrology and bionetwork function are improved as a result of invasive species. The annual cost of dealing with invasive species is expected to be in billions of dollars, including management expenditures, poor health consequences, lost agricultural productivity and damage to ecosystem resources. Approximately 20-30% of all introduced species in the globe generate some sort of issue. The list of invasive alien weed species in India is well-documented and accessible to the general public. In India, 173 alien invasive species from 117 species of the genus and 44 families have been described, responsible for 1% of the available flora. In both cultivated and non-cropped conditions, different plant management methods are used to combat these weeds. None of the present solutions are sufficient to fully eradicate these weeds. As a result, all of these weed control methods must be integrated. Considering the magnifying of yield fatalities instigated by these noxious weeds, an inclusive, reliable and widely adopted technology is urgently needed to address these issues. This article attempts to summarize the current scenario of weeds in India, in particular, major types of weeds found in the region agricultural, ecological losses associated to it and popular physical, biological and chemical methods of their management. Potential opportunities and future prospective of effective as well as sustainable management is also briefly discussed.

Keywords: Weed, Ecosystem, Human health, Biological control, Yield loss

Introduction

A weed can be described as "an undesirable plant" from a human perspective, which usually means that a weed in one location might not be a weed in another. According to the European Weed Research Society, any herb or grass, except fungi,competing with people's priorities or requirements. Weeds are usually described by two characteristics: invasive or noninvasive, and noxious or not noxious. The species of animals, plants or microbes which poses threat to native biodiversity are known as Invasive species. Invasive species are defined by IUCN as "an alien species that has established itself in a new natural or semi-natural habitat as an agent of change, threatening the survival of local biological diversity". Invasive weeds have been discovered by a number of internationally known invasion research organisations. According to the GISP definition of invasive species, invasive alien species are non-native creatures that cause or have the potential to cause harm to the ecology, economy, or human health (GISD, 2010). Ignorance, mismanagement, or mistake are the most common causes of invasive weeds entering an ecosystem. Weeds are seen as a major challenge in the ongoing struggle to provide enough food for the world's population. Weeds have a negative impact on every agricultural enterprise and every aspect of our ecosystem. They have always gotten in the way of human endeavours. One of the main biotic constraints in achieving optimal crop production has been weeds. Untimely and insufficient weed control results in the loss of a significant number of crop harvests per year. Weeds reduce crop production and efficiency, creating a danger to food Protection and environmental health. Crop yields are being reduced caused by many different types of weeds exist in severity dependent on the crop and the agro-ecological effects that are linked with it. Even with current crop conservation measures in place, weeds account for one-third of all agricultural product losses globally. It is estimated that the entire grain output lost due to just weeds is about 200 million metric tonnes, if we estimate a 10% yield loss from the work done at the FAO (Food and Agriculture Organization of the United Nations).Weeds cost India's agricultural industry more than around $11 billion each year (Gharde et al., 2018). In India, its presence decreases crop yield by 31.5 percent (22.7 percent in the winter and 36.5 percent in the summer), ensuing in an annual loss of Rs. 2799 crores (Das et al., 2008).Some of India's most common invasive weeds. *Parthenium hysterophorus Linnaeus* (Carrot grass), *Cyperus rotundus* (Nut grass), *Saccharum spontaneum* (Wild sugarcane), *Pluchea lanceolata* (Roshna), *Solanum elaegnifolium* (Silverleaf nightshade), *Avena fatua* (Wild oat), *Chromolaena odorata* (Big sage).(Narayan et al.,2022).

A weed is one that is unwanted, problematic, and hard to manage. The term "invasive" refers to a weed's unattractiveness as well as its difficulty in regulation. Weeds have a high rate of reproduction and spreading capability, and they use devious tactics to evade human control (Das, 2008). ‘‘Pernicious weeds" or ‘‘special problem weeds" are terms used to define invasive weeds. A invasive weed is a plant that has been declared by the government of a country as harmful to human health, agriculture, recreational, wildlife or land. A invasive weed is a crop that's cultivated an in appropriate region and is "competitive, recurrent and pernicious" (Das et al., 2008). Weeds that are cause important reduction in yield. Some weeds, such as *P. hysterophorus* used to flourish in uninhabited wilds are as rather than crop fields in the early years (Raj et al., 2018). .(Narayan et al.,2022).

Losses due to weeds

Thrashing of biodiversity from natural ecosystems, habitat modification, reduction in productivity and richness of fauna and flora, alteration of population structure, and many other losses are produced by invasive weeds (Dogra & colleagues, 2009). The threat is not restricted to loss of biodiversity; it also affects the climate, economic activities, and human health. Globalization has increased the possibility of foreign invasive weeds being introduced (trade, vacation industry and travel). The overall charge of invasive non-native species to the worldwide economy has been calculated at 5 percent of yearly output (Pimentel et al., 2001).

The cost of dealing with invasive species is expected to be in the hundreds of billions of dollars per year, including management expenditures, severe health consequences, and decreases in agricultural output and natural systems (Sastroutomo et al., 2007).The majority of calculations only consider yield losses. However, when weed control costs, decreased input usage efficiencies, quality losses, pests and disease occurrences (weeds are alternate hosts for many pest and diseases) are factored in, the figures may be very high (Baki, 2004). Invasive weed species were well-known and made publicly accessible in Australia (DiTomaso, 2012), India (Reddy, 2008), Malaysia (Baki, 2004), Indonesia (Tjitrosoedirdjo, 2005), China (Xu et al., 2012), the Tropics (Yaduraju&Kathiresan 2003), the Pacific (Sherley, 2000) and South and South East Asia (Pallewatta et al., 2003). Several current studies have been undertaken to quantify the economic impact of INS (Invasive Non Native Species) in a number of nations, and the findings reveal that the cost of INS to a country's economy can be very high, albeit estimates vary greatly (Yaduraju&Rao, 2013),.(Narayan et al, 2022), .(Narayan et al. 2021).

Management of Weed

Weed management can be describe as a process of weed population and growth reduction below the economic injury level with minimum pollution. Various techniques have been used for weed control including preventative, cultural, mechanical, chemical and biological weed control. .(Narayan et al., 2020).

Preventive Weed control-

Crop rotation, cover crops (as green manures or dead mulches), tillage methods, seed bed preparation, drainage and irrigation system management and crop residue management are all examples of preventative methods. .(Narayan et al., 2021).

Crop rotation- Integrated weed management necessitates crop rotation. Weeds grow in monoculture and might share the same life cycle as the crop. By putting in different-maturing and seed-maturing plants, you can cause annual weeds to lose their lifespan. Rotating crops has many advantages, one of which is removing the weed seed bank in the soil. *P. minor* is one of several problematic weeds that grows near wheat. Crop rotation, though it may be a difficult habit to adopt, can help break this relationship by preventing the growth of *P. minor* near wheat in the first place. By alternating wheat fields with sunflowers, sugarcane, or clover, you can help prevent the spread of *P. minor* (Cauwer et al., 2014). .(Narayan et al.,2020).

Seeding rate-Greater plant competitiveness with weeds can be achieved by increasing the number of plants (raising seed rate or reducing space between plants) or making more room for plants by spreading them out (decreasing the distance between plants).Weeds are smothered by the higher density and closer spacing, which provides superior early canopy coverage. Weed control benefits from short rows and greater crop density when moisture is not a concern (Rao et al., 2017). .(Narayan et al, 2022).

Tillage- Tillage affects the bulk soil density, penetration resistance, average weight diameter and ruggedness of the surface. So, changes in seedbed mechanical properties brought about by tillage can alter crop and weed growth. Weeds can be especially dangerous in orchards and vineyards because, as a vine or tree grows, the shade inhibits weed growth. The only way to minimize weed numbers in these important cropping systems is to apply a carefully controlled herbicide application that targets the seed bank below the soil surface. Organic matter, for example, is a soil parameter. Microbial populations, evaporation, temperature, and pH are influenced by tillage, and those properties can influence herbicide activity (Chhokar et al., 2012), (Choudhary et al., 2022).

Cultural weed control-

Using a cultural methodology in weed management will allow skillful control of the weed species and will additionally save money while preserving the environment (Westerman, et al., 2005).Cultivation choices like crop rotation, tillage, planting timing, cover cropping, and row spacing all impact weed populations. Many studies have demonstrated that a mix of different cultural practises, such as crop rotation, tillage, and cover crop residues, effectively control weed growth and population. Applying these strategies will yield many protective measures against weed establishment before planting, which will reduce emergence. This will allow for the in-season application of herbicides and other cultural control techniques, which will help reduce the amount of herbicide that must be applied (White, et al., 2007), (Awasthi et al., 2019).

Mechanical /Physical Weed Control-

Mechanical control refers to procedures that kill or remove weeds by physically disturbing them. Excavation, discovery, tugging, ploughing and mowing are some of the tactics used. Primary and secondary tools, such as row growers and rotary horses, are used in the mechanical management of weeds, which begins with seed boing. Simplified breeding strategies for several vegetable crops were eventually established. Mechanical control has a number of limitations to consider when designing and developing weed management systems. A rainy spell can decimate mechanical management alternatives and lead to weed competition because dry weather has such huge impact on mechanical management (Riaz et al., 2015), (Narayan et al., 2017).

Hand pulling and digging- Musk thistle, kochia and diffuse knapweed are among the biannual and annual weeds that respond well to this treatment. Annual weeds that grow upright and erect are efficiently controlled by hand digging, however straight, prostrate, rosette and straight weeds are pulled up by hand, they are frequently broken off at the base or at the soil surface, and they can regrow from tap roots left in the soil,(Mall et al., 2023).

Mulching - Mulching is an effective way to control weeds. Mulches are divided into two types: synthetic (plastic) and organic (wood) (leaves, straw, compost and paper).Natural mulches are best for small and specialised regions because they are difficult to spread across large areas. Natural mulches should be evenly strewn over the soil, at least 112 inches dense and thick, to limit light protection. Natural mulch substance should be free of weed seeds and other nuisance organisms, as well as heavy enough to resist being carried away by wind or water. Natural mulches improve the soil by providing organic matter. Synthetic mulches keep weeds at bay, save moisture, raise soil temperature, and are easy to use (Marshall et al., 2003).

Shallow tillage – For instance, it is a good technique to use for annual species such as cheatgrass or kochia, but it might backfire on perennials like field bindweed, Canada thistle, leafy spurge, or Russian knapweed. Weed management is substantially facilitated by before-sowing light and frequent surface tilling followed by watering (Das and Yaduraju, 2001).

Mowing- This is a seed head suppression technique that can prevent or reduce seed head formation. Weeds that have been mowed will re-grow and produce seed at a lower height, necessitating the use of a combination control approach (Mauchline et al., 2005).

Chemical Weed Control

All pesticides have the highest consumption, manufacturing, and market share. Herbicides are less expensive than manual and mechanical approaches, which are typically more expensive to use. Chemical farming may be less cost-effective for small dispersed farmer holdings (Jabran et al., 2018).

- Dichlorophenoxyacetic acid (2,4-dichlorophenoxyacetic acid)
- Atrazine
- Glyphospate SL
- Metribuzin WP
- Naphathelene acetic acid

Biological weed control-

Biological control described as 'management for a population below that which naturally happens when there is no introduced/employed organism employing a different live creature (Gupta, 1998). Special bacteria and other types of microorganisms are typically used for this kind of thing, but they may be, if they suit, parasites, insect and mite predators, pathogens (such as fungi, bacteria and viruses), detectable rhizobacteria, herbivorous fish and more conventional animals (such as ducks, geese and snails) (Shaw et al., 2018).Horses Grazing gives mowing-like outcomes and bacteria and fungi are rare in the use of harmful weeds. The most common term for biological control is 'insect biocontrol'(Sharma et al., 2014).

Biological control does not harm the environment because it leaves no pollution behind. Except for bioherbicide, it is self-sustaining and self-perpetuating. The introduction of bio-agents and bugs every year isn't necessary to conduct classical biological control, making it more durable and long-lasting. Although the initial financial expenditure is considerable, it is cost-effective in the long term. Weed control via biological means/agents is not 100 percent successful, but it is still better than nothing because it helps preserve biodiversity. It works in locations that are inaccessible to humans. That weed is expected to be controlled by insect bio-agents wherever it is found, including deep forests and high mountains (Heimpel et al., 2017). Mycoherbicides are native pathogens, primarily fungi that are used as bio-herbicides. A number of inoculums, such as bacteria, fungi, parasitic, nematodes and viruses,that have been shown to control weed species can be used as herbicides. Every season, bioherbicides are sprayed on the selected weed in the crop field. The bio-agent is usually only extremely active on weed populations that are present at the same time. Then, unlike in traditional bio-control, they wither away without any cyclic perpetuation. The pathogen may, however, continue to be active for 3–4 years in some circumstances, such as the soil-borne disease *Phytophthora citrophthora* (Sharma et al., 2014).

Some Invasive Weeds of India and their management

Cyperus rotandus

Cyperus is a genus of sedges that includes a huge amount of annual and persistent species and is part of the *Cyperaceae* botanical family. *C. srotundus* (purple nut sedge, nut grass, coco grass) is a weed that grows in the tropics and sub - tropics and is difficult to manage (Das, 2008). It spreads fast compared to a wide network of interconnected tubers with a apical dominance is really powerful. (Nelson & Renner 2002; Webster et al., 2008). It is regarded as the worst herb on the planet (Holm et al., 1991). *Cyperus* has tubers, seeds, rhizomes, corms and cormlets as well as rhizomes, corms and cormlets. When deeply buried, the tuber or bulbs may remain dormant or inactive for a long time, typically at least three years. A single tuber of *C. rotundus*, on the other hand, grows on average 150 tubers vegetatively in 3-5 months. *C. esculantus L.* (yellow nut sedge) and *C. rotundus L.* (purple nut sedge) are the two most common nut sedge species (purple nut sedge). A prominent basal bulb can be originated just below the ground level on a purple nut sedge. This basal bulb develops a ramification chain of tubers that can reach a depth of 60 cm in the soil. Fresh shoots emerge from the tubers in purple nut sedge, on the other hand. The seeds of the purple nut sedge have a low viability rate (2-10%), but the tubers are noticeable and grow quickly. A mother tuber can develop four daughter tubers during the first month of growth of purple nut sedge, and the tuber population can reach nearly 100 in three months. Purple nut sedge is much more dangerous than yellow nut sedge (Nelson & Renner 2002; Webster et al., 2008).*C. rotundus L.* (*Cyperaceae*) is a pharmaceutical herb used to treat for various clinical situations at home such as diarrhoea, diabetes, pyrosis, asthma, malaria, gastrointestinal and bowel disorders. It is currently one of the most common, troublesome and economically destructive agronomic weeds in the world, spreading rapidly through tropical and subtropical regions (Peerzada et al., 2015).

Fig-.*Cyprus rotundus*

1. Biological control of *Cyprus*-

a. Control by Insect-*Bactra verutanazeller*, a native moth that is ineffective in suppressing purple nut sedge, *C.rotundus* L. has been studied (Frick et al., 1975). *Bactra* is a weed sedge biocontrol agents (Vargas et al., 2019). Ghorai et al., (2005) isolated a pathogen from contaminated *C. rotundus* plants in a farmers' field at Kairapur farm. *Fusarium oxysporum* (Schlect) Snyder & Hansen was identified as the pathogen. The infection began approximate two weeks later the isolated fungus solution was applied to *Cyperus*. The sedges' central leaf whorls began to yellow, followed by wilting, and they eventually died. On young seedlings emerging from tubers the pathogen was found to be more infectious than on older seedlings. Almost the entire population died within 40 days of being inoculated. *Bactra verutanazeller* (Moth borer) was found to control *C. rotundus* in India, Pakistan, and the United States, according to (Das, 2008). *Crocidosema lantana Busck* (Tortricid moth), *Agromyza lantanae* (Seed fly), and *Thecla echion* and *Thecla bazochi* (Lycaenid butterfly) were all effective at controlling lantana. Lantana has been successfully managed by insects in India, Australia, and Fiji (Sharma et al., 2014).

Fig- *Bactra verutana zeller*

b. Control by fungal pathogen-

The effectiveness of *Puccinia romagnoliana* as a purple nut biocontrol agent for purple nut sedge was also investigated.. Although a variety of illnesses have been proposed as potential biocontrol agents for the control of nut sedge, using fungal pathogens as biological control agents is a viable option (Charudattan et al., 2000).In other situations, even the potential for purple nut sedge management of these biological agents appear to be confined to certain nut sedge biotypes or specific agro climate circumstances. *Puccinia romagnoliana*, the tropics' thriving mulberry groves candidate for biological control, was found to have the ability to induce leaf rust in purple nut sedge, which will damage the plant. Purple nut sedge, abundant in regions including place like India, is subject to a severe outbreak of rust that can do considerable damage. However, only preliminary studies have been done to see if *P. romagnoliana* can be used for purple nut sedge control. The introduction of a pathogen in the target weed and the succession of it are prerequisites among the different parameters required for the success of the weed biocontroller. The biocontrol agent should not infect the principal of commercial crop at the same time .*Poccinia chondrillina* was introduced to western USA in order to manage the weeds *Puccinia carduorum* (Gupta et al., 2002).

2. Physical control

During the summer months, deep tillage without planking is beneficial for controlling *Cyperus* by revealing the perennating structures, such as tubers, bulbs, rhizomes, corms, and cormlets, to the hot sun. Using herbicides like glyphosate, paraquat and diquat on *Cyperus* plants before cultivation helps to breakdown the buds' dormancy and improve their sprouting. *Cyperus* control performance is greatly improved as a result of this. Tillage breaks up tubers, bulbs, rhizomes and other plant parts into smaller pieces, which can sprout due to apical dominance breaking or become dried up/desiccated (Das et al., 2008).

3. Chemical control

Various herbicides can control *C. rotundus* with varying degrees of efficacy in both crop and non-crop circumstances. In maize, a post-emergence treatment of 2, 4-D di-methyl amine at 0.73 kg/ha was found to be more genuine than other formulations in regulating *C. rotundus* (Singh et al., 2010).These herbicides are used in particular crops for post-emergence treatments. Glyphosate is much more powerful in this regard since it is translocated to the tuber's regenerate (Thakur et al., 1992).

Table - Chemical control of *Cyperus rotundu s*under crops and non-crop situations

Herbicides/ combinations	**Rate (kg a.i./ha)**	**Time of application (Pre/Post)**	***C. rotundus*control efficiency (%)**	**Crops/ non-crops situation**	**References**
Brown manuring* + 2,4-D	0.750	Post	84.5	Maize	Sushaet al., (2014)
2,4-D-dimethylamine	0.730	Post	-	Maize	Singh et al., (2010)
Cyhalofop-butyl + (chlorimuron + metsulfuron)	0.090 + 0.020	Post	-	DSR	Pratapetal., (2016)
Ethoxysulfuron	0.018	Post	80.4	PTR	Raj etal., (2016)
Ethoxysulfuron	0.060	Post	92.9	Sugarcane	Shyamand Singh (2015)

Lantana camara

Linnaeus described the genus *Lantana Verbenaceae* in 1753, and it included seven species, six species belongs to South America and one belong to Ethiopia. One species of *L. camara*is believed to have arisen in Africa while another originated in India (Lowe et al., 2003 &Heshula, 2009).The prickly multi-stemmed, deciduous shrub *Lantana camara*, often known as wild sage, reaches a height of 2 metres (6ft). The plant is classified as belong to the *magnoliopsida* class, order *lamiales*, family *verbenaceae*, and genus *Lantana* in taxonomic terms. Stems are square in shape, bristly haired while green, and often armed or sprinkled with various size of prickles. The root system *of Lantana camara* is quite strong. Even if the roots are cut repeatedly, they grow new branches. Leaves are opposite, rather short and roughly hairy with rounded petioles. Blades are short, oblong, blunt-toothed and hairy (Hussain et al., 2015*)*.The leaves of have a strong odour. It has small, multicoloured blooms that are stalked and densely packed in flat-topped clusters with a thin tube and four short spreading lobes on the corolla. The colour of the blossoms varies after anthesis. This flower is available in white-pink-lavender or yellow-orange-red colours . The yellow colouring of the bloom serves as a visual cue to pollinators, and the shift in colour occurs after pollination occurs. *Lantana camara* berries are round, fleshy, 2-seeded drupes that start out green, turn purple, and finally turn blue-black. The berries, on the other hand, are extremely deadly in nature, despite their attractiveness to insects and birds. In *Lantana camara*, seed germination is simple and quick .*L. camara*, the most widespread species, is also known as wild or red sage. *L. camara* is a fast-spreading perennial evergreen alien invasive shrub with a lot of seeds and shallow crown buds (Priyanka et al., 2013).It's a straggling woody plant with red, pink, white, purple, and violet flowers in a diversity of colours. Prickly prickles or spines can be found on the stems and branches (Ghisalberti et al., 2000). *L. camara* is both a weed and a common ornamental garden plant in many places of the globe and it has a wide range of folk medicine applications. It's from South and Central America's tropical and subtropical regions (Stirton, 1977). It can be found in the tropics, subtropics, and warm temperate zones all over the world as a common decorative plant (Broughton, 2000). Lantana has been naturalised in over 50 countries since its introduction and is regarded as one of the worst weeds on the planet (Baars et al., 1999). Only two species in South Africa and Australia are present in all *lantana* regions, indicating that climate can play a role in agent distribution (Day et al., 2000). Lantana is a resilient plant that thrives in tropical, subtropical, and temperate climates at heights of up to 2000 metres (Holm et al., 1977). Lantana is a common and troublesome invasive plant that has caused problems in more than 60 countries around the world. It is indigenous to tropical America and was widely spread as an ornate and living fence to other nations across the world primarily by British colonialists (Kannan et al., 2013). Invasive in various areas of Africa, Asia, and Oceania, it currently resides throughout sections of the globe (Bhagwat et al., 2012). Even in places where lantana has been around for years, it's getting more abundant. Estimates state that Lantana has occupied a total of 10 million hectares in Australia, 16 million hectares in India, and 4 million hectares in South Africa, and continues to grow in those locations (Shackleton et al., 2017). With multicoloured flowers. However, it then fled to open meadows, river *L. camara* is an ivasive alien shrub that spreads quickly its abundant seeds and shallow crown buds. This tropical American hybrid species, which is known as *L. camara*, has caused problems in more than 70 countries and island groups around the world (Zalucki et al., 2007).The herb is a Mexican native. It was introduced to India from Sri Lanka in 1809 as a hardy, ornamental hedge beds, wastelands, cultivable fields and forests, where it quickly displaced native vegetation, causing grazing grounds and some other land utilities to suffer (Rajashekar, 2013). After cuttings, trampling, or burning, the seeds of *L. camara* regenerate rapidly from the crown buds, founding dense, impenetrable thickets. Lantana leaves contain lantad-C, a toxic compound that induces lesions and changes in blood plasma in animals forced to graze on them (Thomas et al., 2000).

Fig-*Lantanacamara*

Biological control of *Lantana* –

1. Control by insect-345 phytophagous bug species have been researched on Lantana in Brazil (Mukhtar et al., 1983). Lantana-specific insects include *Teleonemia, Alagoasa, Uroplata, Salbia, Neogales, Calycomyza, and Ophiomyia* (Sharma et al., 1988). Leaf miners, woody stem borers, and leaf gallformers are some of the insects that attack the Lantana plant's vegetative portions by gnawing or sucking sap from the leaves or stems. The *Lantana* plant's flowers and fruits are attacked by an uncommon insect species (Winder et al,. 1983). The current status of *L. camara* biological control in India. They discovered that existing insects were largely ineffective, and recommended that new insects such as *Calcomyza lantanae* and *Salbia haemorrhoidalis* be introduced to India to monitor *Lantana* (Cilliers et al., 1991; Muniappan et al., 1986).

Fig-*Lantana leafminer* (*Uroplatagirardi*)

2. Physical control of Lantana- In India, the most popular physical methods for controlling *Lantana* in forests are:

(i) Hand pulling

(ii) Slashing/chopping of the stems

(iii) Burning

(iv) Grubbing by hand with a large portion of the root system removed. (Love et al.,2009; Sharma et al., 2005& Syed et al., 2004).

3. Chemical control of Lantana-As a foliar spray, glyphosate is only marginally efficient, and regrowth is normal. Fluroxypyr, when used as a preventative measure, is reliably reliable (Priyanka & Joshi, 2013). The most effective treatment for large Lantana infestations is foliar spraying with a glyphosate-based herbicide (Dohnet et al., 2013). Two applications of fluroxypyr+aminopyralid were successful in controlling lantana (Ferrell et al., 2011).

Parthenium hysterophorus

One of the most invasive weeds is parthenium.On the planet affecting natural habitats and agro ecosystems in more than 30 countries. In many countries around the world, parthenium weed is causing crop and pasture losses, degrading biological diversity of natural plant ecosystems, posing health of humans and animals risks and causing significant financial losses to individuals and their interests. Its invasiveness is aided by a number of biological and ecological characteristics (Lonkar et al., 1974). To reduce losses produced by this weed, various management techniques have been utilised, including cultural, mechanical, chemical, and biological control. But the majority of these methods are in efficient, uneconomic and/or have restrictions (Kohli et al., 1994). While herbicides and exotic insects and pathogens have been used to help manage the weed, despite this the weed is still a major issue (Timsina et al., 2011)

Fig-*Parthenium hysterophorus*

Biological Control of Parthenium

1. Control by insect- Australia's successful insect introduction scheme began in 1975 and continues today. Six insect species have been introduced, and only one of them, the moth *Epiblema strenuana*, is actually useful in controlling weeds (Dhileepan et al., 2018). The Partheniums' seed growth is stunted and seed production is reduced due to the moth larvae which produce galls on the stems and shoots of the Partheniums (McFadyen et al., 1992). Australia has introduced nine insect species and two kinds of rust fungi to fight the weed Parthenium (Dhileepan.K et al., 2007). To minimise seed production and growth, the biological control agent collaborated with the two competing plants (Shabbir et al., 2020). Just three of the species that have been let loose in the region appear to be damaging weeds: the stem-galling moth *Epiblema strenuana Walker*, the leaf-feeding beetle *Zygogramma bicolorata pallister*, and the stem-boring weevil *Listronotus setosipennis Hustache* (Adkins et al., 2014). Early plant growth saw the plant *E. strenuana* almost eliminate weeds (90% reduction in density and 78% reduction in biomass). When the *Z. bicolorata* defoliates at 85-100%, Parthenium weed density is reduced by 96%. (Jayanth& Bali, 1994; Jayanth&Visalakshi,1996). In several Indian states, the beetle *Zygogramma bicolorata* has been successful in suppressing Parthenium, but due to the weed's immense reproductive and survival capability, complete control isimpossible (Kumar et al., 2015).

Fig- *Epiblema strenuana walker*

Fig- *Zygogramma bicolorata pallister*

2. Physical Control- The most successful method for uprooting Parthenium before flowering and seed set is by hand. If we try to pull out the weed after it has already started to sow seeds, the resulting larger infestation area will make future removal more difficult (Kaur et al., 2014). Landowners can eradicate Parthenium weed (in the form of a rosette) by ploughing it; however, this has to be done in tandem with seeding or directly planting the next year's pasture crop (Ray et al., 2012). Physical control, such as burning, which is used to handle weeds, is not an effective control mechanism for Parthenium (Kushwaha et al., 2012).

Chemical control- Parthenium control requires significant chemical controls in the absence of Parthenium's natural enemies. Certain organic herbicides, including Chlorimuron ethyl, glyphosate, atrazine, ametryn, bromoxynil, and metsulfuron, have all been shown to successfully manage this weed. (Javaid et al., 2007; J. S. Mishra et al.,1994). The study results showed that spraying with 2,4-D EE (0.2 percent) and metribuzin (0.25 and 0.50 percent) is more successful at treating Parthenium 15 days after application and delivers complete Parthenium eradication (Wahab et al., 2005).

Datura innoxia

Datura is an annual herb that grows to be 2-5 feet tall and bushy. It grows on clayey-loamy soils in fallow fields, croplands, old feedlots, waste areas, around building sites, abandoned unoccupied locales, and even waste areas, emitting a horrible odour. On the vine, purplish-green empty stems alternate with delicate erect oval-shaped leaves. Flowers occur in three colours: purple, red, violet, and greenish-white, and have a pleasant aroma. They are bisexual and both agender, preferring to be referred to with feminine pronouns. They are, on average, huge. In the *solanaceae* family, *D. innoxia* is noted for its importance in medicine and pharmacology as a source of medicines. A big part is played by medicinal plants. In the case of persons living in rural areas, and is used by the vast majority of underprivileged groups worldwide (Ayuba et al., 2011, Latif et al., 2003; Shinwari et al., 2006).Plants contain a plethora of biochemical and medicinal molecules. Biotechnology can generate some of them, such as secondary metabolites. (Dechaux & colleagues,2005). AAL-toxin, a strong natural herbicide generated from the fungus *Alternaria alternata*, has been proven to control *D. stramonium* in maize, wheat, and several dioecious crops, such as tomato, at low concentrations (Abbas et al., 1995; Stewart-Wade et al., 1998). Despite the fact that a range of fungal infections have been shown to have mycoherbicidal capability(Boyette&Abbas,1994).

Fig-*Datura innexin*

Biological Control of *Datura innoxia*

1. Control by insect-Botanical insecticides, as opposed to synthetic insecticides are usually less costly, easier to handle and used by farmers and small businesses (Belmain et al., 2001). These insecticides could lead to the creation of new classes of safer insect control agents because they are only active against a small number of species, are typically biodegradable to non-toxic things, and are appropriate materials for use in integrated pest management (Kim et al., 2003).

2. Physical control- To get rid of weeds, the hand-pull method is recommended for confined crops, while the cultivation of weed seedlings is best for bigger infestations. Plants become woodier with age, and as a result, their roots often aren't removed completely, leading to less successful cultivation. To treat infestations, more plantings may be needed, as plants grow very slowly (Parsons & Cuthbertson, 1992). Tillage also has a positive effect on seed longevity, since seeds on the surface are susceptible to rapid decay, whereas buried seeds will decay more slowly, and the long-term effects of no-tillage systems are worse than those of traditional ones, as seeds are more likely to be consumed by vermin.

3. Chemical control- *D. innoxia* can be handled with 2, 4-D during the seedling and early growth stages, but as they mature, they become resistant to it (Parsons &Cuthbertson, 2001). Non-selective herbicides include atrazine, diquat, paraquat and glyphosate. In soybeans and peanuts, herbicides such acifluorfen and bentazone are utilised; 2, 4-DB is used in some peanut kinds; dicamba is used in grain sorghum and maize; metolachlor is used in maize; and picloram + 2,4-D is used in summer cereals (Parsons &Cuthbertson, 2001).

Eichhornia crassipes

The common water hyacinth is an aqueous plant native to the Amazon basin, it is an extremely troubling invasive species in areas outside of its natural habitat. It is a member of the *Pontederiaceae* family of plants. It is an annual aquatic plant that is endemic to tropical and subtropical South America, where it is known as the water hyacinth (hydrophyte) (Brundu et al., 2013).Water hyacinth can reach a height of 1 metre (3 feet) above the water's surface thanks to its long, dense, shiny, ovate leaves. Water hyacinth is a fast-growing perennial broad-leaved grass weed that thrives in bodies of water. It has firmly developed itself everywhere it has invaded and naturalised over time and space, such as in India. The rhizomatous and stoloniferous water hyacinth has long, pendant and adventitious roots. The leaves emerge from the nodes of the rhizome and float above the water (Das et al., 2008).This weed poses several risks, including ecological, economic and social ones. It also threatens biodiversity, induces eutrophication, shelters pests, clogs fresh water ways and has an impact on agriculture and aquaculture as well as transport and recreational activities (Patel, 2012).Water hyacinth has long been regulated with herbicides (Terry, 1991). In China, glyphosate, 2, 4-D, and paraquat have been used for the past decade to control water hyacinth, which was a rampant problem (Chu et al., 2006). Weed infestation is still a problem, even with herbicides that can diminish it; while herbicides may help, they do not give long-term sustainable control, and they can pollute water (Harley et al., 1990).Furthermore, herbicide-killed weeds can reduce oxygen levels in water, resulting in secondary population that is toxic to fish (Chu et al., 2004).

Fig-*Eichhornia crassipes*

Biological Control of *Eichhornia crassipes*

1. Control by insect- To supplement biological control efforts by *Neochetina weevils*, the moth *Niphograpta albiguttalis*, the mite *Orthogalumna terebrantis*, and the hemipteran bug *Eccritotarsus catarinensis* are advised. Rearing pools are suggested to be established near the lake since they are easier to operate and have a higher capacity (Jimenez et al., 2007). Floating mat releases help with redistribution and diffusion to non-release places. The proliferation of weevils on floating mats of water hyacinth is caused by wind and water currents (Julienet al., 2001). In South Africa, the *Niphograpta albiguttalis Warren* (*Lepidoptera: Crambidae*) was utilised to control water hyacinth infestations in eutrophic water bodies. In the year 1968, *Niphograpta albiguttalis* was discovered in South America (Julien et al., 2001). After testing, it was discovered to be a suitable biological control agent because it can disperse over long distances (up to 4 km per day), is climate tolerant, has a short generation time (about 35 days from egg to egg), high fecundity (up to 300 eggs per female) and most importantly, is wil-specific. Adult female water hyacinths oviposit on the leaves, primarily where the epidermis has been damaged (Hill and Cilliers 1999). Larvae go through five instars and eat under the skin of the leaves, generating windows that are more harmful. Older larvae eat toward the centre of the plant, causing the ichthyosis in the leaves and sinking of the plant (Canavan et al., 2014).

Fig-*Niphograpta albiguttalis*

2. Physical method-*Eichhornia* can be removed by netting from the water surface or can be manually picked up and collected on a boat and removed from the water bodies. This could be best method of its control, which is less costly, economical and not degradable to water bodies and the environment. The collected biomass of *Eichhornia* could be utilized alternatively (Mangaset al., 2004; Tellez et al.,2008).

3. Chemical method-The population and infestation level of water hyacinth, as well as the season of application, determine the effectiveness of water hyacinth control. 2, 4-D has been commonly used at rates ranging from 1.0 to 8.0 kg/ha (Yadav et al., 2010). Five compounds, namely acetic acid, citric acid, formic acid, and propionic acid, were sprayed in three concentrations (10, 15, and 20%) and compared against the herbicide glyphosate (1.8 kg ha–1). The water hyacinth was successfully controlled by all five chemicals. As expected, as the concentration was increased from 10% to 20%, the efficacy rose. When formic and propionic acids were used instead of other acids or the pesticide glyphosate, the plants died faster. Acetic acid followed formic and propionic acids in terms of efficacy. Citric acid was ranked last. When compared to formic acid/acetic acid mixtures, formic acid/propionic acid mixtures were more efficient in preventing water hyacinth development, especially at the rate of (8:2) at various doses (3, 5, and 10 percent). Using a formic acid/propionic acid mixture (8:2; at 3%) in the open field provided good control and confirmed the feasibility of these chemicals in the successful treatment of water hyacinth. These chemical treatments could be used on water in the future to combat water hyacinth. These compounds may be able to take the place of routinely used herbicides in the future. Because of their quick decomposition into carbon dioxide and water, these compounds are thought to be environmentally friendly. For best efficacy, especially in harsh sunshine, complete coverage is required (El-Shahawy et al., 2015).

Conclusion

There are many chances to design weed management strategies that are both sustainable and effective, despite the fact that weeds present a difficulty in the farming systems that are now in use in India. There is a need for additional research on the ecology and biology of weeds, particularly with the process of understanding the seed bank dynamics in various locales and cropping systems. For efficient weed management, a deeper comprehension of the germination process of weed seeds is required. As a result, the evaluation of the impact of different agronomic approaches has to be the primary focus of study in the future (i.e. cultural weed control methods, such as narrow rows, high seeding rates, weed-competitive cultivars etc.) on weed management and crop yield in various places, particularly those with restricted access to herbicides or ones with lower levels of effectiveness. In addition to the development of weed-competitive cultivars, the identification and evaluation of allelopathic agricultural cultivars is also possible. Rotations are an essential component of the toolbox for weed management. It's possible that these are techniques of rotating establishments (e.g., direct-seeding and transplanted rice), tillage systems (e.g., notill, reduced-till and conventional tillage), crops (having different management practices) or herbicides. When crops and herbicides are alternated, there is a possibility of achieving greater herbicide efficacy. However, very little is known about how the use of various crop rotations can affect the effectiveness of various cropping systems in preventing the growth of weed populations. Research on these kinds of subjects will lead to improvements in weed management. There is a pressing need to create transgenic and non-transgenic HT crops and conduct research on them. Such crops have the potential to be utilised in the eradication of weeds such as *Cyperus rotundus*, *Eichhornia crassipes* and *Datura innoxia*. There is a significant window of opportunity for weed scientists in India to carry out research with the participation of farmers in order to build integrated weed management (IWM) programmes for various crops that are cultivated in a variety of geographical and climatic zones.

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