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Review Article

Harmful effects of *Parthenium hysterophorus* and management through different approaches - A review

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Abstract: *Parthenium hysterophorus* is commonly known as congress grass or carrot weed in India. It belongs to Asteraceae family and native to subtropics of North and South America. It is an invasive plant species that disturbs cultivated areas, roadside vegetation, gardens etc. *P. hysterophorus* is considered as one of the worst weeds responsible for causing health problems in animals and humans viz., dermatitis, asthma and bronchitis besides loss to agriculture and ecosystem. Nowadays, it has become one of the major weeds in almost all types of agricultural lands and other areas. Many control methods ranging from preventive, physical methods by manual uprooting, burning and allelopathic management through competitive plants like *Cassia tora, Cassia uniflora* and *Cassia sericea,* have been recommended for management of *P. hysterophorus*. Likewise, insect *Zygogramma bicolorata* has proven successful in managing P. *hysterophorus*. Further, microorganisms like *Alternaria alternata, Scerotiia sclerotiorum*, *Fusarium Pallidoroseum*, *Ralstonia solanacearum*, and *Xanthomanas campestris* are reported to infest *P. hysterophorus.* Use of chemical herbicides mainly glyphosate @ 2.5 kg a.i. ha^{-1}, atrazine @ 2.6 kg a.i.ha^{-1}, 2,4-D amine @ 3 l/ ha^{-1}, Paraquat 0.5 l/ ha^{-1} were proved effective in managing *P. hysterophorus*. No single option is suitable to control this invasive weed. Successful control of this weed can only be achieved by an integrated weed management approaches.

Key words: *Parthenium hysterophorus*; Biological control; Integrated approach; Preventive measures; Allelopathic control.

Introduction

Weeds are plants that are unwanted in a given situation and may be harmful, dangerous or economically detrimental. Weeds are a serious threat to primary production and biodiversity. They reduce farm and forest productivity, *P. hysterophorus* dominate over the native species and adversely affect the biodiversity. Therefore, weed management in agricultural ecosystems is one of the most key operations (Yadollahi *et al.,* 2014). *P. hysterophorus* is a flowering plant which belongs to Asteraceae family. It is an aggressive, ubiquitous, annual, herbaceous weed with no economic importance unravelled till now. It is an erect and much branched annual or ephemeral herb, known for its notorious role as environmental, medical, and agricultural hazards (Kaur *et al.,* 2014). It is native to the American tropics, common name includes Congress grass, Congress weed, Santa Maria, Bitter weed, Carrot grass, False ragweed, Fever few, White top, the "Scourge of India". This flower head (capitulum) is surrounded by bracts (modified leaves) that form an involucre beneath or around a flower cluster (Warshaw and Zug, 1996). It is profusely branched, leafy herb resembling a bush or shrub because of its height (1-2.5m). The stem becomes tough and woody as the plant matures into a hardy bush. It can produce ~624 million pollen grains per plant and carried to spread to other areas by wind**.** It is an extremely prolific seed producer with upto 25,000 seeds (achenes) per plant. The plant is photo-thermo insensitive hence, it grows round the year except in severe winters. It grows in almost all types of soil except near the seashore as the saline soil is not conducive to *P. hysterophorus* flowering (Chembolli and Srinivas, 2007).

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It is an annual herb that was accidentally introduced into India in the year 1956 through contaminated wheat shipments from the USA (Lonkar *et al.,* 1974). It is the leading cause of plant induced airborne contact dermatitis in India. This plant has infested most of rural and urban areas and causing epidemics of dermatitis. It also showed serious impact on human health, animal husbandry, crop production and biodiversity (Chembolli and Srinivas, 2007; Mitchell and Calnan, 1978). It contains allergenic sesquiterpene lactones (SQLs). The SQLs are found in the leaves, stems, flowers, and some pollen. The highest concentrations are found in trichomes which are present on stems, the underside of leaves and in the flowering heads. Several thousands of cases of allergic contact dermatitis and also some fatalities have been reported (Lonkar *et al.,* 1974; Mitchell and Calnan, 1978). After 10 years of exposure to the weed, 10-20% of the population will develop severe allergic reactions. There may be hay fever, asthma; dermatitis caused by dust, debris as well as pollen from the plant. The severity of dermatitis in India is greater because the plant grows more vigorously in India and contains large amounts of the sesquiterpene lactone and parthenin, which is absent in *P. hysterophorus* that grows in South America (Chembolli and Srinivas, 2007; Mcfadyen, 1995). The current review emphasizes the problem associated with *P. hysterophorus* as a weed and the effective control measures.

Harmful effects of *Parthenium hysterophorus* on Agriculture and Ecosystem

The *P. hysterophorus* weed has infested about 35 million hectares of land in India (Sushilkumar, 2009). *P. hysterophorus* plant contains chemicals, like parthenin,

hysterin, hymenin, and ambrosin, and due to the presence of these chemicals, the weed exerts strong allelopathic effects on different crops (Gunaseelan, 1998). The weed affects nodulation in legumes due to inhibition of activity of nitrogen fixing and nitrifying bacteria, namely, Rhizobium, Actinomycetes, Azotobacter, and Azospirillum. *P. hysterophorus* produces enormous numbers of pollens (on an average 624 million/plant), which are carried away at least to short distance in clusters of 600-800 grains, and settles on the vegetative and floral parts, including stigmatic surface, inhibiting fruit setting in crops like tomato, brinjal, beans, capsicum, and maize. In India, *P. hysterophorus* causes a yield decline of up to 40% in agricultural crops (Khosla and Sobti, 1981).

P. hysterophorus has the potential to disrupt the natural ecosystems. It causes a total habitat change in native Australian grasslands, river banks, open woodlands and flood plains (Chembolli and Srinivas, 2007). This weed can rapidly invade into new surroundings often it can replace the native indigenous species and pose a serious threat to biodiversity (Seema Patel, 2011). It is an aggressive colonizer of roadsides, wasteland, railway sides, water courses, and cultivated fields. It is reported that *P. hysterophorus* occupied 14.25 million hectares of farm land during 2001-2007, when compared to 2 million hectares in 1991-2000 (Javaid and Adrees, 2009). A broad survey conducted in Bangladesh on invasive alien species and their presence indicate that *P. hysterophorus* can establish on different land types viz., road side, homestead, low land, fallow land and railway track. They reported that *P. hysterophorus* have ability to adapt to new habitats and thereby reducing the number of indigenous species (Akter and Zuberi, 2009). In Ethiopia, *P. hysterophorus* is reported to cause sorghum grain yield losses between 40-97% if it is left uncontrolled throughout the season (Tamado *et al.,* 2002; Aneja 1999). *P. hysterophorus* infests about 170000 km² of prime grazing country in Queensland, causing loss of around 16.8 million dollar per year to the pasture industry in Australia (Chippendale and Panetta, 1994). Also, it was reported that *P. hysterophorus* was estimated to reduce the carrying capacity of affected farms on cracking clay soil with an annual rainfall of 600 and 800 mm (Fessehaie *et al.,* 2005; Mcconnachie *et al.,* 2011).

P. hysterophorus known to cause severe detrimental effect on mankind by causing many skin and respiratory disorders. The main classical dermatitis also known as air borne contact dermatitis (ABCD) which affects the face, eyelids, neck, chest and popliteal fossae (Warshaw and Zug, 1996). The second major is chronic actinic dermatitis (CAD) which involves the exposed areas mainly forehead, cheeks, nape of neck, rim of ears, forearm and hands and under surface of chin and depth of the skin folds (Tamado *et al.,* 2002). The other skin problems include is mixed pattern combining of ABCD and CAD which shows as scattered infiltrated scaly papules over the exposed parts and dermatitis over eyelids, flexures of extremities on neck. The fourth one is photosensitive lichenoid eruption pattern which presents with violaceous papules, and plaques over sun exposed parts such as cheek, forehead, ears, upperchest and back, dorsae of hands (Kaur *et al.,* 2014). The prurigo nodularis like pattern present as multiple hyperkeratotic papules and nodules with characteristic histopathologic features similar to prurigo nodularis [Kaur *et al.,* 2014; Sharma *et al.,* 2013; Aneja, 1991). Akthar *et al.* Showed *P. hysterophorus* extracts responded with positive skin reaction to mAb2 and also involvement of TH type cytokines in *P. hysterophorus* dermatitis (Akhtar *et al.,* 2010), shown in figure 1.

The *P. hysterophorus* also acts as a collateral host for many diseases caused by viruses in crop plants. It has showed harmful effects to animals causing dermatitis with pronounced skin lesions on various animals including horses and cattles. If eaten, it is responsible for mouth ulcers with excessive salivation. Significant amount (10-50%) of this weed in the diet can kill cattle (Narasimhan *et al.,* 1977). In addition, it causes anorexia, pruritus, alopecia, diarrhea, and eye irritation in dogs besides causing acute illness. When grazing animals fed on grass mixed with *P. hysterophorus* yield bitter milk and tainted meat from buffaloes, cows and goats (Aneja, 1991). The *P. hysterophorus* extract when fed to rat results in significant reduction of rat WBC count which suggests it can weaken immune system.

Management of *Parthenium hysterophorus*

Various methods, viz., preventive, physical, cultural, chemical, bio herbicidal, and integrated approaches are being practiced to manage this weed around the globe. Singh et al. 2004 considered that use of bio prospecting tools like using insects, microorganisms and competitive plants are the most economic way of managing *P. hysterophorus* (Singh *et al.,* 2004). The new concept emerging in the use of botanical extracts which can affect germination and growth of *P. hysterophorus*. Studies are also attempted to extract the active ingredient responsible for weed controlling property of botanicals (Sushilkumar and Saraswat, 2001).

Preventive measures for management of *Parthenium hysterophorus*

It encompasses all measures taken to prevent the introduction and/or establishment and spread of weeds in local, regional or national level. No weed control programme is successful if adequate preventive measures are not taken to reduce weed infestation. Preventive control measures viz., clean cultivation, use of *P. hysterophorus* weed free clean and certified seeds, keeping seed beds free from weed, avoid feeding the material containing *P. hysterophorus* seeds to the farm animals, avoid adding the *P. hysterophorus* which has already set seeds to the manure pits, clean the farm machinery thoroughly before use, keep irrigation channels free from *P. hysterophorus*, fence-lines, and un-cropped areas clean, use vigilance and prevention by weed Laws play a pivotal role in avoiding the entry of *P. hysterophorus*.

Physical and cultural Management

Physical management involves intercultural operations coupled with hand weeding, a time consuming and unpleasant job, made worse by the health hazards involved with handling *P. hysterophorus* weed. Burning, another strategy employed to manage weed, is not a useful control strategy for *P. hysterophorus*. Burning destroys all other economically important plants growing in its vicinity. Manual uprooting of *P. hysterophorus* before flowering is the most effective method. Uprooting the weed after seed setting will increase the area of infestation. Several cultural practices like thorough land preparation, use of crops and varieties which have smothering effect, maintaining optimum plant population, crop rotation, mulching, soil solarisation, stale seed bed technique and proper fertilizer and water

management are important in controlling this weed [Ray and Gour, 2012; Javaid, 2007).

Figure 1. Common symptoms of commonly known *P. hysterophorus* dermatitis, (a, b) Airborne contact dermatitis (ABCD); (c) Chronic actinic dermatitis in a female; (d) Prurigo like lesions over dorsa of hands.

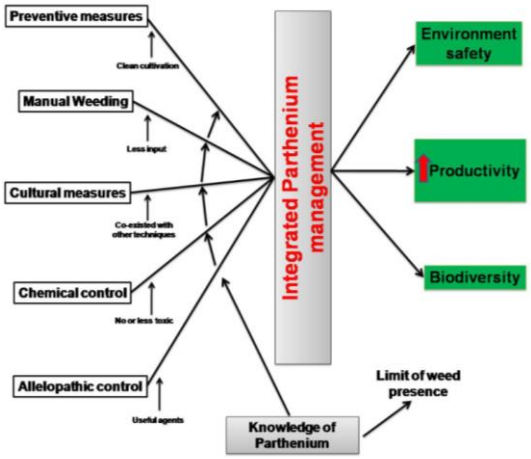

Figure 2. Schematic representation of integrated parthenium management

Biological control of Parthenium hysterophorus

Biological control is an effective and environmentally sound method of mitigating the pests and their effects through the use of natural enemies. This method does not involve in the complete eradication of the unwanted organism. But it maintains its population lower than its average that would occur in the absence of bio control agents. In the last three to four decades a great interest has been given to manage *P. hysterophorus* by many bio-control ages [Ray and Gour, 2012; Watson and Wymore, 1990). Many biocontrol agents like insects, fungi, nematodes, slugs, botanicals and microorganisms are used for controlling *P. hysterophorus* (Sushilkumar, 2009). Of the various biocontrol agents, control of weeds by using plant pathogens has gained acceptance as a safe, practical and environmentally beneficial method (Aneja, 2009).

Several insects have been tried to manage *P. hysterophorus* in different countries. In India, several insects have been reported on *P. hysterophorus* weed control but none of the insect has been found to be host specific yet. The classical approach was started by Jayanth in 1987 from Mexico with the introduction of host specific leaf feeding *Zygogramma bicolorata pallister* (Coleoptera: Chrysomelidae) and the stem galling moth *Epiblema strenuana.* These two insects have showed good potential to manage this weed (Jayanth, 1987). Both adult and larvae of *Zygogramma bicolorata* feed on leaves. In early stage, larvae feed on the auxillary and on the terminal buds and move on to the leaf blades as they grow and the fully-grown larvae enter the soil and pupate. The density of insect's one adult per plant caused skeletonization of leaves within 4-8 weeks. But, little successful was made due to very high germination of weed and moreover the insect is not a host specific and found that this insect can attack to other crops like sunflower in India (Dhileepan, 2001). The other insects such as stem borer, *Scolytid beetle* and *Hypothenamus erudisus* caused damage to the *P. hysterophorus*. Also, *cerembycid borer Oberea sp.* was able to significantly kill this weed (Kumar, 1979). *Earias sp.* also uses *P. hysterophorus* as an alternate host (Thontadarya and Hiremath, 1978). Also, Common tailed mealy bug *Ferrisia virgate* (Char *et al.,* 1975) and mite *Tetranychus cucurbitae* and *Tetranychus* sp. and insects *Aphis fabae* and *Pseudococcus* sp. were reported to feed on Parthenium (Rajulu *et al.,* 1976; Puttaswamy *et al.,* 1976). Kumar et al. (1979) conducted survey and it indicates that Bug *Leptocentrus taurus* and scale insect *Orthezia insignis* feeds on Parthenium [Kumar *et al.,* 1979; Thangavelu, 1980; Srikanth *et al.,* 1988). Several other insects such as mealy bugs, *Aphidoidea*, *Heliothis, helicoverpa, Clania cramari, Dicrasia obliqua* and grass-hoppers have been reported feeding on *P. hysterophorus* (Sushilkumar, 2009). Many indigenous insects also play an important role in exotic weed suppression. Several other insects like *Ferrisia virgata, Heliothis helicoverpa, Aphidoidea, Clania cramari, Dicrasia oblique* and *Caelifera* reported on feeding *P. hysterophorus*. *A cerembycid borer Nupserha* sp. has been found infesting *P. hysterophorus* at Jabalpur and Vindhyanagar (M.P) (Sushilkumar, 1998). Insects like *Zygograma bicolorata, Bucculatrix parthenica, Stobaera concinna, Epiblema strenuana, Carmentia ithacae, Conotrachelus albocinereus, Listronotus setosipennis, Smicronyx lutulentus, Platphalonidia mystica,* are known to act as biocontrol agents on different parts of *P. hysterophorus* [Griffiths and Mcfadyen, 1993).

Microorganisms like fungus, bacteria and viruses are used as biological agents (Sushilkumar, 2009). The biological agents produce toxins which may kill or control the weeds are known as bioherbicides. The toxins produced by the fungi are called mycoherbicides. The fungi is obligate parasites on *P. hysterophorus* which causes rust are the first option because they exhibit narrow host ranges, higher reproducible capacities and efficient aerial dispersal (Evans and Ellison, 1990). The results of the study show that about 26 species of fungi were effective in controlling *P. hysterophorus*. Among them the main promising fungi are *Puccinia abrupt var. partheniicola (Jackson) Parmelee, Puccinia xanthii var parthenii-hysterophorae* (previously known as *P. melampodii Diet.* and *Holw) (Uredinales), Entyloma compositarum De Bary (Ustilaginales)* and *Plasmopara halstedii (Farlow) Berl.* and *De Toni (Peronosporales).* Of these *Puccinia abrupta var. partheniicola* and *Puccinia xanthii var. Partheni hysterophorae* from Mexico are the most potential classical bio control pathogen of *P. hysterophorus* (Kaur *et al.,* 2014).

Many fungi have been reported to attack *P. hysterophorus*. Leaf spot disease on *P. hysterophorus* was caused by *Colletotrichum gleosporioides* (Kumar and Rao, 1977). The

herbicide prepared from *Alternaria alternate* was found to be effective against seedling of *P. hysterophorus* [Rao and Rao, 1987; Deshpande *et al.,* 1982). Pandey et al. 1996 showed that *Sclerotium rolfsii* capable of controlling the weed and increased the mortality rate of *P. hysterophorus* seedlings upto 90-95% and 35-40% in greenhouse and field trials respectively [Pandey *et al.,* 1996; 1998). The root rot fungus *Rhizoctonia solani* are capable of infecting few *P. hysterophorus* plants in North Arcot district (Kumar *et al.,* 1979). A survey conducted in Coimbatore reveals that 21-pathogenic species of *Lasidiplodia theobromee* cause blight and damage *P. hysterophorus* when it is 15-30 days' stage. Also, another *Oidium partheni* cause severe damage to *P. hysterophorus* at flowering stage (Jeyalakshmi *et al.,* 2005). About 25 species of fungi were isolated from different places of Jabalpur, Madhya Pradesh and these include species of *Alternaria alternate, Cladosporium, Acremonium, Colletotrichum, Drechslera, Phoma, Myrothecium, Curvularia, which cause* leaf spot disease and species of *Rhizopus, Chaetomium, Aspergillus* (Rajak *et al.,* 1990). Nineteen species of fungi are able to cause severe damage to the *P. hysterophorus* under laboratory trials which include *A. alternate, A. dianthi, C. gleosporioides, A. macrosporus, Fusarium oxysporum, Phoma herbamm and Bipolaris, F. nioniliforme, Myrothecium roridum,* sp. (Pandey *et al.,* 1991). Two more fungi namely *Fusarium oxysporum* and *Rhizoctonia solani* were found to be highly potential causing severe damage to the weed in lab trial (Pandey *et al.,* 1991). The sprays of *Scerotiia sclerotiorum* (200 g mycelium/litre water) showed reduction in the vigour of *P. hysterophorus*. Spore suspension of 10^7spores/ml in water reduced the number of branches, height, flowers and plant growth in of *P. hysterophorus* when sprayed for a period of 30 days (Sushilkumar, 2009). *F. Pallidoroseum* and *Alternaria alternate* are capable of reducing seed germination, height, branches, leaves, and flowers considered to be an effective biocontrol agent against *P. hysterophorus* [Kauraw *et al.,* 1997; Bhan *et al.,* 1998). Out of 16 species of fungus that belongs to root zone of *P. hysterophorus Alternaria alternate* occurred most frequently and caused leaf spot disease (Dhawan and Gupta, 1997). The above references infer that there are no weed specific fungi which can infect and control *P. hysterophorus*.

Ralstonia solanacearum and *Xanthomanas campestris* bacteria are being used as biological agent to manage *P. hysterophorus* (Kishun and Chad, 1988). Mainly tobacco streak virus was found to infest *P. hysterophorus* and the insects mainly thrip species have been found to be transmitting the diseases from *P. hysterophorus* to sunflower, tobacco, soyabean, groundnut, black gram, cotton etc (Sushilkumar, 2009). Another virus namely tomato leaf curl virus has been found to be capable of infesting *P. hysterophorus* naturally. This virus can be transmitted by sucking insects of tobacco whitefly *Bemisia tabaci* (Devaraja *et al.,* 2005). Phytoplasma type organism cause disease like phyllody, pear decline, aster yellow, potato witch broom, *P. hysterophorus* phyllody. These are obligatory pathogen which need host for their survival (Singh and Singh, 1998). Aster yellow disease caused by phytoplasma in *P. hysterophorus* and this was confirmed by direct and nested PCR using 16srRNA specific gene of phytoplasma (Raj *et al.,* 2002).

Management of Parthenium hysterophorus through plants and allelopathy

Biological control of *P. hysterophorus* can be achieved by conserving naturally occurring plant species or purposeful use of known competitive plant species to manage or control *P. hysterophorus*. The allelochemicals like aresenoides, flavonoids, pentanoids and terpenoids can be used as herbicides, insecticides, nematicides, fungicides and growth regulators. These allelochemicals can be used as defence mechanism against herbivorous predators (Datta and Saxena, 2001). Number of plants has been reported to have allelopathic potential and efforts have been made to use them in controlling weed (Knox, 2008). Economical replacement of *P. hysterophorus* weed can be achieved by planting many plants like *C. tora, C. sericea, C. uniflora, C. auriculata, Mirabilis jalapa, Sida spinosa, Amaranthus spinosus, Croton bonplandianum, Tephrosia purpurea, Hyptis suaveolens* etc. which are able to suppress the *P. hysterophorus* in natural habitats (Wahab, 2005). Swati Vitonde et al. (2014) reported that extracts of *C. uniflora* and *C. tora* have an allelopathic potential which can act as herbicide to another weed such as *P. hysterophorus* (Vitonde *et al.,* 2014). One more study showed that extracts of *Imperata cylindrical, Otcantium annulatum, Desmostachya bipinnata* and *Sorghum halepense* significantly suppressed the seedling and germination growth of *P. hysterophorus* (Javaid *et al.,* 2005). Kandasamy and sankaran from India showed that *Cassia sericea* able to reduce the accumulation of Parthenium population by 70% (Kandasamy and Sankaran, 1997). Plant parts like root and shoot extracts of *Dicanthium annulatum*, *Sorghum halepense* showed reduction in germination and early seedling growth of parthenium. Extracts of *Azadirachta indica, Aegle marmelos* and *Eucalyptus tereticomis* have inhibited the germination of *P. hysterophorus* weed (Kaur *et al.,* 2014).

In India for the first time in 1966 reported that wastelands weed *Xanthium strumarium* capable to compete with *P. hysterophorus* (Maheshwari, 1966). *C. sericea* have potential to suppress *P. hysterophorus*. The *P. hysterophorus* when it was grown along with *C. sericea* having a weak growth and low dry weight when compared to *P. hysterophorus* when grown alone [Singh, 1983; Sushilkumar, 2009). The aqueous shoot extracts of *C. occidentalis* have significant effect against *P. hysterophorus* and proved promising alternative tool to manage (Jai *et al.,* 2010). Survey conducted in Maharashtra found that Plant like *C. tora, Hyptis suavelones, Xanthium strumarium, Tephrosia purpurea* were found to compete with *P. hysterophorus* weed (Sarkate and Pawar, 2005; Gaikwad *et al.,* 2008). Khan *et al.* (2010) reported that selected pasture species mainly buffel grass, purple pigeon grass, butterfly pea, kangaroo grass and bull Mitchell grass are found to replace *P. hysterophorus* weed in the infested region. The foliar spray of aqueous and methanol extracts of leaf *W. Somnifera* at different concentrations and found that it can inhibit the growth of noxious weed *P. hysterophorus* [Khan *et al.,* 2010; Javaid *et al.,* 2011).

The leaf leachets of *Amaranthus viridis* found to have potential to inhibit the growth of *P. hysterophorus* (Thapar and Singh, 2003), and the aqueous extracts obtained from leaf, stem and root of *A. Spinosus* found to have strong inhibitory effects on germination and growth of *P. hysterophorus* confirmed by bioassay and biochemical techniques (Swain *et al.,* 2004). The *C. uniflora* is the strong growth inhibitor of *P. hysterophorus*. The study involving introduction of *C. uniflora* to a heavily infested *P. hysterophorus* area for 5 years reduced *P. hysterophorus* to 84% (Joshi and Mahadevappa, 1986; Masum *et al.,* 2013). In Australia O'Donnell and Adkins (2005) reported plant

species mainly *Bothriochloa inschupta* (blue grass), *Cenchrus ciliaris* (bafel grass), *Decanthim aristatum* (floren blue grass), and *Clitorea ternatea* (butterfly pea grass) found to be effective in inhibiting the growth of *P. hysterophorus*. Plant species like *Imperata cylindrica*, *Sorghum halepense* and *Cenchrus pennisetiformis* from Pakistan (Javaid *et al.,* 2005; Shabbir and Bajwa, 2005), and E*ragrostis curvula, Digitaria eriantha* and *Panicum maximum* from South Africa have been reported to compete with the *P. hysterophorus* (Van Der Laan *et al.,* 2008).

Chemical Management

Chemical management is widely practiced to control *P. hysterophorus* in the areas where its natural enemies are not present. Use of many chemical herbicides, such as glyphosate @ 2.5 kg a.i.ha^{-1}, atrazine @ 2.6 kg a.i.ha^{-1}, bromoxynil @ 0.56 kg a.i.ha^{-1}, common salt @ 20%, 2,4-D amine @ 3 l/ ha^{-1}, 2,4-D ester @ 4 l/ ha^{-1}, Floumeturon @ 2.24 kg a.i.ha^{-1}**,** Hexazinone @ 3.5 kg a.i.ha^{-1}, Metribuzin @ 0.7 kg a.i.ha^{-1}, Norflurazon @ 2.24 kg a.i.ha^{-1} and Paraquat 0.5 l/ ha^{-1} were known to be very effective in controlling this weed [Kathiresan *et al.,* 2005; Ramamoorthy *et al.,* 2004; Anonymous, 2011; Reddy *et al.,* 2007; Singh *et al.,* 2003; Mishra and Bhan, 1994). The application of 2,4-D EE (0.2%) and metribuzin (0.25 and 0.50%) were found to be more effective for controlling *P. hysterophorus,* causing complete elimination of parthenium species, and did not allow any emergence of weed. The stage and time of the rosette stage is the right time to apply post emergent herbicides in wasteland, non-cropped areas, along railway tracks, water channels, and roadsides (Khan *et al.,* 2012). Very effective treatments for *P. hysterophorus* weed control were glyphosate and metribuzin, having higher mortality at 4 weeks after treatment at both rosette and bolted stages than 2, 4-D, triasulfuron + terbutryn, bromoxynil + MCPA and atrazine + s-metolachlor, atrazine, s-metolachlor. One of the easiest ways to manage *P. hysterophorus* is spraying a solution of common salt at 15-20% in non- cropped areas, open wasteland, railway tracks and road sides (CRC, 2003). Herbicide use in cropping areas is risky and found to have adverse effect on agriculture crops. Controlling *P. hysterophorus* in cropping areas can be done by selective herbicide use and by crop rotation. There are many herbicides available in the market to control *P. hysterophorus*.

Integrated management of *Parthenium hysterophorus*

Any single method for weed management mayn't be effective in controlling *P. hysterophorus*. Integration of different methods like preventive measures, mechanical, cultural, biological and chemical means keep the weeds under check at an economic threshold level. Integrated parthenium management uses a variety of technologies in a single weed management with the objective to increase the productivity of crop at a minimum cost taking in to consideration ecological and socio-economic constraints under a given agro-ecosystem (Fig 2).

Conclusion and future prospects

The management or control strategies are not successful because of its high regeneration capacity, high seed production ability and high germination ability throughout the year and more resistance to many chemical herbicides and also high adaptability in wide range of ecosystem. This noxious weed can be managed by public awareness and participatory integrated approaches. There is a need to encourage the research on utilization of this weed for insecticidal properties and try to evaluate the potential on pests of different crops. So far only fewer efforts have been made to control *P. hysterophorus* by using bio herbicides. More intense research in this direction is vital in the development of bioherbicides. Also, more efforts need to be done by agriculturists, scientists and government to work together for managing this troublesome weed through integrated and eco-friendly approaches.

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