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Parthenium hysterophorus L: Ecological and Socio-economic Impacts and Its Management Practices in Ethiopia: Review

Fitsum Temesgen[1] Feleke Woldeyes[2] Alemayhu Hailemicael[2]
1.Semera University, Department of Horticulture, Afar, Ethiopia
2.Arbaminch University, Department of Biology, Arbaminch, Ethiopia

Abstract
Biological invasive alien species (IAS) are non native species of plant and animal origin, and widely recognized among the greatest threats to ecosystem biodiversity and productivity. Parthenium (Parthenium hysterophorus L., Asteraceae) is one of the invasive alien species. It is originated in sub tropical area of south and North America but currently distributed in most other tropical and sub tropical countries like Australia, India, China, Kenya, West Indies, Israel, Taiwan, Nepal and Ethiopia. Parthenium is becoming a major challenge for developing countries like Ethiopia striving for food security. In Ethiopia the weed is spreading almost throughout the country. But the degree of infestation varies from region to region and dominantly was observed in road sides, vacant sites and partially in agriculture. The negative effect of parthenium weed was reported in crop production and pasture land, human health, animal production and health, biodiversity and soil property. The impact of the weed causes substational yield loss of cereals, horticultural crops & pastures. Parthenium weed affects natural habitat of native plants, and the allelopathic potential of P. hysterophorus is believed to play an important role in the ability of the plant to displace natural vegetation and interrupt natural succession in the natural environments. The soil chemistry and nutrient availability of parthenium infested area is changing as the time is longer. Manual and Mechanical, Prevention, cultural, chemical and biological control strategies have been proved futile individually to curb proliferation of P. hysterophorus. So, integrated approaches are warranted to restrict the invasion of this weed. Currently, even though P. hysterophorus is considered a weed, its beneficial attributes are coming to the forefront. Traditional medicine, Nano-medicine, bio-pesticide, green manure potential, agent for bioremediation of toxic metals and dyes, herbicide, cheap substrate for enzyme production, as source of protein for livestock and source of biogas are some of the recently discovered future implication of P. hysterophorus. So, utilization of parthenium for different purpose is one of the controlling mechanisms.
Keywords: Management; distribution; impact, Allelopathy; *Parthenium hysterophorus* L.

1. Introduction

Biological invasions by non-native species constitute one of the leading threats to natural ecosystems and biodiversity (CBD, 2005; MA, 2006). The above authors also describe that the impacts of invasive alien species (IAS) on agriculture, forestry, fisheries, and other human enterprises and on human health. In agricultural system, invasive weeds affect the productive capacity of the land and increase agricultural labour time, affecting human well being by threatening the availability of food. Moreover, these non-native plant and animal species harm or endanger native plants and animals or other aspects of biodiversity. They have invaded almost every type of native ecosystem and caused hundreds of biological extinctions throughout the world (Joshi, 2001; Baillie *et al.*, 2004). One of such an invasive weed species introduced to Ethiopia in a recent past is *Parthenium hysterophorus* (Tamado Tana, 2001; Taye Tessema, 2002; GISP, 2004).

Parthenium hysterophorus is a herbaceous invasive weed that is believed to be originated in tropical America, now occurs widely in Australia and East and South Africa. Its annual procumbent, diffused leafy herb, 0.5-2 m tall, bearing alternate, pinnatified leaves, belongs to the family Asteraceae (Compositae) tribe Helintheae, sub-tribe Ambrosiinae (Navie *et al*., 1996; Hedberg *et al*., 2004). IAS like parthenium weed are species that are introduced to new geographic areas as a consequence of human activities, where they become established and then proliferate and spread, to harm many of human welfare activities and natural system services (Joshi, 2001).

The recent growth and development of world trade system has strengthened a long-standing trend in the redistribution of IAS in general and parthenium weed in particular (The opening of new markets or trade routes has also resulted in the introduction of new species either as the object of trade or as the unintended consequence of trade (McNeely *et al.*, 2001).

IAS affect native species both directly and indirectly for example, competing with them for resources such as food and breeding sites as well as indirectly by altering habitat and modifying hydrology, fire regimes, nutrient cycling and other ecosystem processes (IUCN/SSG/ISSG, 2000; CBD, 2005MA, 2006;). Together, these impacts are resulting in the loss of biodiversity and dramatic changes to ecosystems, which is confirmed by a recent global assessment that showed invasive alien species to have affected 30% of threatened birds (but as much as 67% on islands), 11% of threatened amphibians, and 8% of threatened mammals (Baillie *et al.,* 2004). They also observed that invasion of alien species across the planet is rated as being the second biggest threat to biodiversity behind habitat loss.

Apart from their threat to biodiversity and ecosystem services, invasive species have significant socio-economic impacts. The weed can affect crop production, animal husbandry, human health and biodiversity (Evans, 1997a). IAS in general and *P. hysterophorus* in particular, reduces the effectiveness of development investments, for example, by choking irrigation canals, fouling industrial pipelines and threatening hydroelectric schemes. Indeed, invasive species such as parthenium weed contribute to social instability and economic hardship, placing constraints on sustainable development, economic growth, poverty alleviation and food security (GISP, 2004).

Parthenium weed is thought to have been introduced to Ethiopia probably between 1974 and 1980, and it was also thought to have been introduced during 1980s when drought induced famine triggered a massive multinational relief effort (Hedberg *et al*., 2004; GISP, 2004). The weed was first seen growing near food-aid distribution centers, so it is likely that imported wheat grain was contaminated with its seeds. The weed spread rapidly, and soon came to dominate pastures and crop fields because it has allelopathic properties, releasing chemicals that suppress the growth and germination of neighboring plants (Tadelle Tefera, 2002). Its invasion of Ethiopia has not only had a devastating effect on crop production, but also results in grazing shortages, since the weed is unpalatable to livestock; if it is mixed with fodder, it taints the meat and milk (GISP, 2004). Parthenium weed *(P. hysterophorus)* invades disturbed land, including overgrazed weak pastures and recently cleared or ploughed lands. Moreover, it will readily colonize disturbed, bare areas along roadsides and heavily stocked areas around yards and watering points (GISP, 2004; Shabbir and Bajwa, 2006).

The ability of Parthenium to grow in a wide range of habitats, strong reproductive and regenerative capacity, persistent seed bank, and its allelopathic potential make its management difficult (Kohli *et al*., 1998; Dhileepan, 2007).However, Integrated methods are needed to prevent epidemic spread of Parthenium. Management options for Parthenium include chemical, physical, legislative, fire, mycoherbicides, agronomic practices, competitive displacement and classical biological control (Evans, 1997; Dhileepan, 2007).Even though parhenium is a noxious weed, recently many innovative uses of this hitherto notorious plant have been discovered. Parthenium hysterophorus confers many health benefits, viz remedy for skin inflammation, rheumatic pain, diarrhoea, urinary tract infections, dysentery, malaria and neuralgia and in industry, agriculture etc (Patel, 2011).
Therefore, the aim of this paper is to review socio-economic and ecological impacts (the problem of *P.hysterophorus* as a weed and latent beneficial prospects of the weed) and its effective management practices which can be implemented.

2. Distribution and Status of parthenium weed

2.1 Global Distribution of parthenium

Parthenium hysterophorus L. is native to subtropical areas in South and North America, but currently widely distributed in other tropical and subtropical countries such as Australia, India, China, Kenya, West Indies, Australia, Ethiopia, Israel, Taiwan, Nepal and also reported in South Africa, Madagascar, Mozambique, Bangladish, Mauritius, Rodriquez, the Seychelles,Vietnam, Many south pacific Islands may be having the greatest impact (McFadyen,1992; Navie *et al*.,1996; Evans 1997; Shabbir and Bajwa 2006; Bhowmik *et al.,* 2007; Sankaran,2008;IUCN SSC Invasive Species Specialist Group,2010). The weed has achieved major status in India and Australia within the last few decades (Navie *et al.,* 1996).

Parthenium hysterophorus was introduced into Asia, Africa and Oceania with cereal and grass seed shipment from America during the 1950s (Bhowmik and Sarkar, 2005). It was first introduced in the south-east Queensland of Australia in 1955 by aircrafts and machinery parts during the Second World War. The weed was introduced a second time in central Queensland in 1958 by contaminated pasture seeds (Navie *et al.,* 1996). Parthenium weed has recently reached in Africa, being recorded in Kenya in 1975 in Nairobi herbarium records and it is now a weed in coffee plantations (Njoroge, 1991). In South Africa, *Parthenium* was reported during the 1880s, but it become troublesome only since 1980s (Henderson, 2001). And in Ethiopia was recorded since 1974-77 (Fasil Reda, 1994; Frew Mekbib *et al.,* 1996; Hedberg *et al*., 2004). Parthenium weed was imported to Ethiopia from North America during the 1988 famine in Ethiopia as contaminants of grain food aid and distributed with grain. In Alamata of Ethiopia alone, about 10,000 hectares of land has been invaded with *Parthenium* (Bezabih and Araya, 2002).

Parthenium was thought to be initially introduced in India before 1950s (Bhowmik and Sarkar, 2005) with food grains imported from the USA, but heavily introduced after 1956 through the transport of Milo (red wheat) from Mexico. After 1956, the weed spread throughout India in all kinds of disturbed habitats including roadsides, pasture lands, cultivated areas. This indicates that parthenium weed has a potential of spreading and may become more prominent in other part of the world in the near future unless measures are taken (Wise *et al.,* 2007).

2.2 Parthenium weed distribution, means of introduction and status in Ethiopia

In Ethiopia, it is believed to have been introduced in 1976/77 with army vehicles from Somalia and has become a serious weed both in arable and grazing lands (Tamado Tana *et al*., 2002). Similarly according to Seifu (1990) Parthenium weed was introduced accidentally into Ethiopia in the mid-1970s and it was first reported from Ethiopia in 1988 at Dire-Dawa and Harerge, eastern Ethiopia. But in contrast to this, Hedberg *et al*., (2004) reported that it was introduced into Ethiopia in 1974. Others also believed that *P. hysterophorus* may have also been spread through the provision of humanitarian emergency food aid. For example, this weed was introduced to Africa through grain shipments for famine relief to Ethiopia (McNeely *et al*., 2001). The presence of parthenium in Kenya and Somalia and the capacity of the seed to travel long distance through wind, water, and other means also suggested the possible entry into Ethiopia from these neighboring countries (Njoroge, 1991).

The weed was first seen in 1980s near food-aid distribution centers in Ethiopia (GISP, 2004). However, currently, it is widely distributed throughout the country. In eastern Ethiopia, Tamado Tana and Milberg (2000), and Tamado Tana (2001) reported that parthenium weed is the second most frequent weed (54%) after *Digitaria abyssinica* (63%). Tamado (2001) found out that 90% of the interviewed farmers rank parthenium weed as the most serious problem both in rangeland and crop lands. Furthermore, a soil seed bank study in Jijiga rangeland indicated that 28% of the entire seed bank is dominated by parthenium (Belaynesh, 2006). It seems that its fast and robust growth helps the weed to colonize both productive to marginal lands. Today, the weed is found in range lands, along road ways, rail ways, around home yards, footpaths, and at periphery of the crop fields (Frew Mekbib *et al.,* 1996).

In the Amhara region, it is estimated that about 37,105 hectares of land is infested with parthenium (Berhe, 2002). It is abundantly found in Gojjam, in south and north Gonder with the potential to spread to agricultural districts of Metama and Setit Humera (Fessehaie, 2004). In much of the low lands of Wello, parthenium has become the most dominant weed. In these areas, the weed has been reported in 42 Woredas. Furthermore, the weed is well established in many districts of South, north, and central Tigray. In one district alone, Alamata, about 10,000 hectares of the land has been infested with parthenium. The weed is also a serious problem in the Regional State of Oromia although there is no actual survey data on the total area of land infested in the region. Currently, parthenium is spreading at an alarming rate in Eastern Ethiopia; the central rift valley, and neighboring localities of Afar Region, East Shewa, Arsi, and Bale and in Southern Ethiopia (Bezabieh and Araya, 2002).

In the central farmlands of East Shewa: Dukem, Bishoftu, Modjo, and Koka areas heavy and widespread infestation occurs mostly on roadsides, wastelands, towns, villages and gardens. One can also see parthenium weed infestation on field borders and in some fields; parthenium weed grew in crop field during fallow period. In Ziway, Awassa and Wolkite, parthenium weed was observed only in the town along the road and near dwelling sites indicating its recent introduction into the area (Taye Tessema, 2002).

High infestation of parthenium weed was observed in sorghum fields around Kobo and in sorghum, maize and Teff fields around Robit, Gobie, Woldiya, and Kombolcha both during the growing period and after harvesting time. Similarly, in East Shewa (Wolenchitti, Wonji, Methara), Afar region (Awash, Anano, and Miesso), and West and East Hararghe, heavy infestation of parthenium weed was observed both during fallow and cropping seasons. Similarly in Hataye, Shewa Robit, Ambo, and Nazareth area, parthenium weed has entered crop fields (Berhanu G/Medhin, 1992; Fasil Reda, 1994; Taye Tessema, 2002). In highly infested areas from Woldiya to Alamata, the original grass and shrub vegetation had been very open and the disturbance allowed a dense stand of parthenium weed to cover thousands of hectares of grazing and cultivated lands. From Sirinka to Mersa and then to Dessie, parthenium weed was present on the narrow strip along the main road for several kilometers. And also reported that in many Woredas of West Shewa: Shoboka, Tibe, Guder, and Wolliso, only localized infestation of parthenium weed was observed on roadsides and rarely in crop fields (Taye Tessema, 2002).

Taye Tessema *et al.*, (1998) also observed that the plant occurred in the towns, usually on roadsides, and vacant sites and grew only at irregular intervals. The introduction in this area is very recent, probably since 1997 for there had been no parthenium weed observed in West Shewa region from 1995 – 1996 during which intensive qualitative and quantitative determination of weeds occurring in these areas took place.

3. Determinant impacts of parthenium weed

3.1 Impact on crop production and pasture land

The presence of parthenium in cropped lands can almost double cultivation costs and restricts the sale and movement of contaminated produce (Chippendale and Panetta 1994). Parthenium weed has been observed to cause substantial yield loss in crop production like sun flower (helianthus annus L.), and Sorghum (Sorghum bicolor) in Queensland, Australia (Parsons and Cuthbertosn, 1992). Yield of grain sorghum was reduced by 69% when the parthenium density was only three plants per square meter; reductions as high as 97% occurred at higher weed densities (Tamado and Milberg, 2002) and Eragostis teff (Tadelle, 2002) in Ethiopia, and also reported one of the most important weed in coffee Arabica in Kenya (Njorage, 1991).In South Africa P.hysterophorus is a ‘major nuisance in Saccharum species, Musa species and orchards (Bromilow,2001). In

India, reported by Khosla and Sobti (1981), about 40% sorghum (*Sorghum bicolor L.*) yield reduction, due to parthenium weed was recorded. The above authors also explained that the forage production of Indian croplands and grasslands was reduced by 40% and 90% respectively due to the invasion of this weed. According to Channappagoudar *et al.,* (1990) also reported that the presence of parthenium weed in irrigated sorghum in India reduced grain yields from 6.47 to 4.25 tons/ha (34.3%) and decreased grain weight by 30%.The weed was also found to invade the agriculture lands of sugarcane, vegetable crops field and even rice fields in India (Singh *et al.,* 2004). *P.hysterophorus* has been reported negatively affect crop production in the Caribbean, and most likely other countries which it has invaded. However, its overall impact on the production system is multifaceted, both direct and indirect, thus making it difficult to quantify losses (Evans, 1997a).

Other than direct competition for nutrients, water and sunlight, allelopathic effects of parthenium weed on other plant is another important biological characteristic for the success and its aggressiveness as a weed to affect agricultural important plants. In many studies water soluble phenolics (caffeic acid, ferulic acid, vanicillic acid, anisic acid, and fumaric acid) and sesquiterpene lactones, mainly parthenin, have been reported from the roots, stems, leaves, inflorescence, achenes fruit and pollen of parthenium weed (Pandy *et al.,* 1993).

These chemicals have been observed to exhibit an inhibitory effect both on the germination and growth of a wide variety of crops including pasture grasses, cereals, vegetables, other weeds and even tree species (Evans, 1997a; Navie *et al.,* 1996; Tadelle Tefera, 2002). *Parthenium* has strong negative allelopathic effects on germination and growth of cultivated plant species like *Brassica campestris, B. oleracea and B. rapa*, *Glycine max*, *Lolium multiflorum*, *Oryza sativa*, *Phaseolus vulgaris*, *Raphanus sativus*, *Cicer arietinum, Triticum aestivum*, *Vigna* 26 *radiata* and *Zea mays*) have been well documented (Batish *et al.,*2005; Singh *et al.,* 2003 ; Maharjan *et al.,* 2007).

Kanchan and Jayachandra (1981) reported that the growth and nodulation of legumes were inhibited by parthenium weed because of the inhibitory effect of allelochemicals on nitrogen fixing and nitrifying bacteria. Further, parthenium weed pollen was found to reduce the chlorophyll content of leaves to which it comes in contact with and can interfere with the pollen germination and fruit set of the nearby species. Towers *et al*., (1977) also reported that heavy accumulation of parthenium weed pollen on the stigmatic surface caused 40% reduction in the grain filling of maize and predicted that the weed may still exhibit an inhibitory influence on crops even when grown at a considerable distance.

Furthermore, Singh *et al*., (2003) explored the allelopathic properties of unburnt (UR) and burnt (BR) residues of *P. hysterophorus* on the growth of winter crops, radish and chickpeas. The extract prepared from both UR and BR was toxic to the seedling length and dry weight of the test crops. BR extract was more toxic due to its highly alkaline nature. Growth studies conducted in soil amended with UR and BR extracts revealed phytotoxic effects towards test crops, UR being more active than BR unlike crude extracts. These effects were attributed to the presence of phenolics. According to (Gunaseelan, 1987) Parthenin has been also reported as germination and radicle growth inhibitor in a variety of dicot and monocot plants and it enters the soil through the decomposing leaf litter. Burning of *P. hysterophorus* in fields reduced germination, biomass growth, plumule and radical length of Phaseolus mungo (Kumar and Kumar, 2010). Poor fruiting of leguminous crops and reduction in chlorophyll content of crop plants were observed in P. hysterophorus-infested fields *and* played role as alternate host for crop pests functioning as an inoculum source. This weed has been reported to serve as a reservoir plant of scarab beetle, a pest of sunflower (Lakshmi and Srinivas, 2007).

3.2 Impact on animal production and health

According to Evans (1997a) the impact of parthenium weed on livestock production is both direct and indirect by affecting grazing land, animal health, milk and meat quality, and marketing of pasture seeds and grain. The occurrence of parthenium weed in grasslands was observed to reduce the forage production in addition to making the land less fertile.

Parthenium hysterophorus invasion causes changes in above-ground vegetation and below-ground soil nutrient contents, disturbing the entire grassland ecosystem in Nepal as reported by (Timsina *et al*., 2010). *Parthenium hysterophorus* is a serious invasive weed of pasture systems, reducing pasture productivity 90% (Evans, 1997). It has become a major weed of grazing lands in central Queensland and New South Wales in Australia. It squeezes grasslands and pastures, reducing the fodder supply (Dhileepan, 2007). He observed dwindling effect of *P. hysterophorus* on grass biomass of grazing fields in Queensland, Australia. According to Chippendale& Pannet (1994) identified that parthenium weed could completely dominate grazing land, resulting in a weed monoculture and reduced stocking rate of up to 80%, with a net annual loss of AU$ 16.5 million in Australia.

Studies in India on toxicity of the weed to cattle and buffaloes have shown that a significant amount (10 – 50%) of the weed in the diet can kill these animals within 30 days (Narasimhan *et al*., 1980). Animals fed parthenium weed developed dermatitis with pronounced skin lesions, became highly emaciated, and eventually died due to the rupture of tissues and haemorrhages in their internal organs (Nisar Ahmed *et al*., 1988). Taints of meat have been detected from sheep given a diet of 30% parthenium weed (Tudor *et al.*, 1982) and tainting of milk has also been reported from cows (Towers and Subba Rao, 1992).

The hepatoxic allelochemical parthenin adversely affects animal health, and the quality of milk (taste bitter) and meat (Shashie Ayele, 2007; Wegari, 2008). The toxic signs such as erythematous eruptions on body, alopecia and de-pigmentation of neck and shoulders, and oedema around eyelids and facial muscles on buffalo calves and crossbred calves were recorded while feeding on Parthenium in India (Ahmed *et al.,* 1988). Tudor *et al.* (1982) reported the taints in meat from sheep grazing in Parthenium invaded Australian grasslands.

Exposure to *P. hysterophorus* also causes systemic toxicity in livestock (Gunaseelan, 1987). Alopecia, loss of skin pigmentation, dermatitis and diarrhoea has been reported in animals feeding on *P. hysterophorus*. Degenerative changes in both the liver and kidneys and inhibition of liver dehydrogenases have been reported in buffalo and sheep (Rajkumar *et al*., 1988). The milk and meat quality of cattle, buffalo and sheep deteriorate on consumption of this weed (Lakshmi and Srinivas, 2007). Significant reduction in rat WBC count after oral treatment of Parthenium extract signifies its immune system weakening ability (Yadav *et al*., 2010).

3.3 Impact on human health

Literature is rapidly increasing on hazardous effects of *Parthenium* on human health. Bhowmik *et al., (*2007) reported that the weed is toxic to humans and that regular contact with the plant or its pollen could cause dermatitis, hay fever, bronchitis and even asthma in humans. Agriculturists are always concerned about *P. hysterophorus* affecting food and fodder crops, since the pollen and dust of this weed elicit allergic contact dermatitis in humans (Gunaseelan, 1987). Studies have shown also that those who came into contact or continued contact with parthenium weed can develop allergic eczematous contact dermatitis (AECD) and also causes mental depression (Oudhia and Tripathi, 1988). Dermatitis is a T cell-mediated immune injury and the disease manifests as itchy erythematous papules and papulovesicular lesions on exposed areas of the body (Akhtar *et al*., 2010). The clinical progression of parthenium dermatitis indicated that the severity of a reaction might worsen over time and thus may lead to chronic actinic dermatitis (Sharma *et al.,* 2005). The mild dermatitis can be treated with topical corticosteroids. However, moderate to severe dermatitis particularly airborne contact dermatitis require systematic corticosteroids and other immunosuppressive drugs (Verma *et al*., 2001).

Another widespread allergic reaction of parthenium is allergic rhinitis, or hay fever. This is caused by the presence of its pollen grains in the air (Patel, 2011). For instance, Mangla *et al.,* (1981) have reported that in areas that were infested with the weed, almost 44 % of the pollen load in the atmosphere during the months of June to September was derived from parthenium. The inhalation of the pollen of the weed can cause allergic trinities and speeds up the development of bronchitis or asthma if the pollen enters the respiratory tracts during mouth breathing (Evans, 1997). *P. hysterophorus* is known to be the causative agent of this reaction, and is one of the very reactive toxic classes of compounds known as sesquiterpene lactones (Towers, 1981).

The toxic parthenin and other phenolic acids are lethal to human beings and animals (Mahadevappa, 1997). McFadeyen (1992) reported that 10% to 20% human population developed severe allergic reaction after they were exposed to the weed for a period of 1 to 10 year based on research conducted in Australia. Furthermore*, Parthenium* has high sensitizing potential. As much as 56% of occupationally exposed persons were found sensitive to this weed, although not manifesting apparent dermatitis (Mahajan *et al.,* 2007). Direct or indirect contact sensitization is also possible in view of the widespread growth of the weed. Sensitization occurs more frequently during the weed's growing season, when there is little dust and detritus of plants left (Guin, 1989). Mahajan *et al.,* (2007) reported that a *Parthenium* patch-test-positive patient showing widespread dermatitis of non-airborne contact dermatitis improved when moved to a *Parthenium*-free area. His condition rapidly worsened (8-10 hr) when returning to an invaded area. Shabbir and Bajwa (2006), based on a study conducted in Islamabad, suggested that *P.hysterophorus* may cause pollen allergy and high fever. The ever-increasing infestation of this weed in urban areas poses a serious threat to the health of the inhabitants. Further, the survey undertaken in Central Queensland demonstrated that individuals sensitized to parthenium were found to have a greater economic outlay to treat the effects of allergy symptoms than none sensitized residents in the same area. Seventy seven percent of individuals sensitive to parthenium weed spent up to $40 per month for medication to help treat their allergy symptoms considerably more than those who are non-sensitized in the study (Goldsworthy, 2005).

There has been an epidemic of hundreds of cases of parthenium weed dermatitis in India and several cases have been reported from USA (Towers, 1981). It is also reported that there is an increasing incidence of respiratory allergies in India, with 7% of sample of Bangalore residents were affected by allergenic rhinitis due to parthenium weed pollen, and 42% of patients suffer from nasobronchial allergy. In Australia about 15% of individuals regularly exposed to parthenium weed developed dermatitis, with another 7-15% developing respiratory problems (McFadyen, 1992). In Ethiopia, it was reported that individuals who remove parthenium with hands in infested crops suffer from dermal allergy, fever, and asthma (Taye, 2002).

Ramos *et al*., (2001) assessed the mutagenic potential of a crude extract of P. hysterophorus in the Salmonella/microsome (Ames) assay and the mouse bone marrow micronucleus test. However, it did not show genotoxic potential. Sharma *et al*., (2005) observed that the clinical pattern of Parthenium dermatitis progresses from airborne contact dermatitis to mixed pattern or chronic actinic dermatitis pattern. Eczema herpeticum is reported to complicate parthenium dermatitis. Sriramarao *et al*., (1993) worked on the use of murine polyclonal anti-idiotypic antibodies as surrogate allergens in the diagnosis of P. hysterophorus hypersensitivity. Parthenium-sensitive patients with rhinitis who had positive results on skin prick tests to P. hysterophorus pollen extracts responded with a positive skin reaction to mAb-2. Akhtar *et al*., (2010) studied the involvement of TH type cytokines in Parthenium dermatitis.

3.4 Impact on biodiversity

McNeely (2001) has defined biodiversity as an umbrella term for the degree of nature's variety, including both the number and frequency of ecosystem, species, and genes in a given assemblage. Weeds can compete with indigenous plant species for resources (including, sunlight, moisture, nutrients and even for spaces) (IUCN/SSC/ISSG, 2000). Besides, the impacts of invasive alien species are immense, insidious, and usually irreversible and they may be as damaging to native species and ecosystems on a global scale as the loss and degradation of habitats (IUCN/SSC/ISSG, 2000; Shabbir and Bajwa, 2006). Furthermore, invasions may alter hydrology, nutrient accumulation and cycling, and carbon sequestration on grasslands (Polley *et al*., 1997). The global extent and rapid increase in invasive species is homogenising the world's flora and fauna (Mooney & Hobbs, 2000) and recognized as a primary cause of global biodiversity loss.

These weeds rapidly invade new surroundings often replace the indigenous species and pose a serious threat to biodiversity in India (Patel, 2011). Akter and Zuberi (2009) conducted an extensive survey on invasive alien species (IAS) and their impact on different land use types viz. road side, low land, fallow land, homestead and railway track in Bangladesh. Among others, P. hysterophorus exhibited the ability to invade and adapt to new habitats, thereby reducing the number of indigenous plants. The more vigorous mode of reproduction and the possession of an array of secondary metabolites give the weed the status of invasive alien species (Akter and Zuberi, 2009).

Parthenium hysterophorus, because of its invasive capacity and allelopathic properties, it causes a lot of damage to natural ecosystems. Very sparse or sometimes no other vegetation can be seen in *P. hysterophorus*-dominated areas. It has been reported to be causing a total habitat change in native Australian grasslands, open woodlands, riverbanks, and flood plains (McFadyen, 1992; Chippendale and Panetta, 1994; Lakshmi and Srinivas 2007). It releases allelopathic chemicals that inhibit the germination and growth of pasture grasses, legumes, cereals, vegetables, other weeds species and even trees in the field (Tadelle Tefera, 2000;Tamado Tana, 2001).

The allelopathic potential of *P. hysterophorus* is believed to play an important role in the ability of the plant to displace natural vegetation and interrupt natural succession in the natural environments. *P. hysterophorus* displaces the native as well as exotic species and also medicinal plants (Shabbir and Bajwa, 2006). They further explain that, the domination of parthenium weed affects the biodiversity. The population of many common medicinal plants growing in the wastelands of Islamabad might be rapidly declining because of the aggressive colonization by *P. hysterophorus*.

3.4.1 Effect on species diversity and composition

Parthenium have allelopathic effect on neighbouring flora by which it is capable to replace most of the associated herbaceous species (Bhowmik *et al.,* 2007). Pandey *et al.,* (1993) reported that *Parthenium* suppress the associated species through the release of allelochemicals from decomposing biomass and root exudates. *Parthenium* competes directly with pasture species, reducing pasture vigour and seed set leading to habitat and ecosystem change (Evans 1997; Shabbir and Bajwa, 2006). In similar ways, studies in Australia and India have also demonstrated that *Parthenium* adversely affects the composition and diversity of species thereby resulting displacement and imbalance in natural and agricultural system effect on biodiversity (Grice, 2006).

Based on a study conducted in the rangelands of Northern Himalayas (India), Kohli *et al.,* (2004) found that invasion by *Parthenium*, *Ageratum conyzoides* and *Lantana camara* significantly decreased species richness in the invaded areas. The presence of *Parthenium* was reduced pasture production by excluding beneficial forage plants, resulting in a monoculture (Annonymous, 2004). Timsina (2007) reported that *Trifolium repens, Imperata* sp.*, Chrysopogan aciculatus, Sporobolus* sp. and *DactylocteniumEuphorbia hirta* was reported in good proportion in high *Parthenium* invaded site than the other sites by (Ayele ,2007). The survey conducted in India by Wahab (2005) has shown that species like *Cassia sericea*, *Cassia tora, Cassia auriculata, Croton bonplandianum, Amaranthus spinosus, Tephrosia purpurea, Hyptis suaveolens, Sida spinosa* and *Mirabilis jalapa* could suppresses *Parthenium* in natural habitats*.* Wegari (2008) declared that *Chrysopogon aucheri* and *Cynodon dactylon* could out-compete the growth of *Parthenium*. Similarly, Seed germination of *Parthenium* was inhibited by leaf leachates of *Azadirachta indica* and latex of *Calotropis procera* (Goyal and Singh, 2003).

According to Karki (2009) Species richness declined with increasing *Parthenium* density within the invaded area in Nepal. From his result *Parthenium* density (402 plant/m2) at Hetauda site was the highest record and might be highest in the world indicating that the habitat was most favorable for this weed. Plant species such as *Borreria articularis, Centella asiatica, Elephantopus scaber, Oxalis corniculata* and *Phyllanthus urinaria* were found more sensitive to *Parthenium* invasion, while *Euphorbia hitra, Imperata cylindrica* and *Trifolium repens* were resistant to invasion in the study area.

3.5 Impact on soil physico-chemical property

In Australia, *Parthenium* was dominant in alkaline clay loam soil, but it is capable of growing in most soil types. *Parthenium* changes the habitat that it invades by replacing neighboring flora, and changing soil characteristics (Anonymous, 2006). Timsina (2012) and Karki (2009) found that soil pH changed from acidic towards neutral due to invasion of *Parthenium* in grasslands. Bhowmik *et al.,* (2007) concluded that soil might become slightly acidic or neutral in *Parthenium* invaded plots due to allelochemicals from root exudates. In the same fashion Joshi (2005) found high density of *Parthenium* in both acidic and neutral soil in Kathmandu valley. Similarly, Batish *et al.,* (2002) reported a reduction in soil pH due to addition of *Parthenium* residues to soil.

Partenium weed also changes soil chemistry and nutrient availability. Carbon content and nitrogen availability was greater in areas invaded by invasive weeds, and the weeds had greater nitrate reductase activity than native species (Timsina *et al*., 2011). Karki (2009) found no significant changes on soil N and organic carbon by *Parthenium* invasion in grasslands of central Nepal. But, Batish *et al.,* (2002) reported an increase in organic carbon and decrease in soil N due to addition of *Parthenium* residues in soil. Soil pH, phosphorus and potassium were highest in the invaded, and lowest in the non-invaded. Due to changes in above-ground vegetation and below-ground soil nutrient contents, *P. hysterophorus* invasion is likely to have an overall negative effect on the functioning of the entire ecosystem (Timisna *et al*., 2011: Dogra and Sood, 2012).

Similar study by Batish *et al.,*(2002) examined on the modified(parthenium infested) soils and unmodified (control) soil under laboratory condition . The pH of all the modified soils decreased whereas the conductivity, organic carbon and organic matter increased. Further, the amount of sodium and potassium increased, whereas that of zinc decreased. In the soil infested with 4 g of *Parthenium* residue, the amount of available nitrogen decreased. The presence of significantly high amounts of phenolics in all modified soils indicated their possible interactions with soil chemical properties. The growth studies carried out in the modified soils indicated their phototoxic nature, as seedling growth of both chickpea and radish was significantly decreased compared with seedlings grown in unmodified soils. The extracts prepared from *Parthenium* residues were also found to be phototoxic to both the test crops and were also rich in phenolics. The presence of phenolics in *Parthenium* residues and their interference with soil chemistry upon release may be responsible for a decrease in the growth of radish and chickpea.

According to Dogra and Sood, (2012) laboratory result the amount of phenolics in the P.hysterophorus invaded soil was 29.4+0.57mg/100g and in control soil was 14.82+,42mg/100g,respectively.The percent increase in the amount of phenolics contents in the invaded soil was 49.59% as compared to the control. The pH of the control soil was 7.62 and of parthenium amended soil 7.8 respectively. The electric conductivity of the ions was increased by 18.21% in the invaded soil as compared to control ones. The amount of available N, P and K in the invaded soil was increased by 47.7, 51.31 and 39.89% respectively. The amount of available calcium in the control soil was 5.83+.58 and 17.57+.6g/100g in the invaded soil. It was increased by only 16.51% in the parthenium invaded soil. Further, the available Mg and chloride increased by 12.99 and 26.57% in the parthenium invaded soil.

Collins (2005) and Karki (2009) concluded that no significant changes occurred in soil nutrient pools by *Parthenium* invasion within short period, it requires longer periods of time to show difference to native patches.

4. Beneficial attributes of parthenium weed

4.1 Uses of parthenium in traditional and modern medicine

Health aspect: *Parthenium* has been traditionally used by indigenous people in the Caribbean and Central America because of its medicinal properties (Navie *et al.,* 1996). The decoction of P. hysterophorus has been used in traditional medicine to treat fever, diarrhoea, neurologic disorders, urinary tract infections, dysentery, and malaria as emmenagogue. Ethno botanically, it is used by some tribes as remedy for inflammation, eczema, skin rashes, herpes, rheumatic pain, cold, heart trouble and gynaecological ailments. Parthenium hysterophorus has been found to be pharmacologically active as analgesic in muscular rheumatism, therapeutic for neuralgia and as vermifuge (Maishi *et al*., 1998). This weed is also reported as promising remedy against hepatic amoebiasis. Parthenin is the major constituent of the plant, exhibits significant medicinal attributes including anticancer property (Venkataiah *et al*., 2003). The methanol extract of the flowers showed significant antitumour activity and parthenin exhibited cytotoxic properties against T cell leukaemia, HL-60 and Hela cancer cell lines (Das *et al*., 2007). Previously, Ramos *et al*., (2002) had established the antitumour potential *of P. hysterophorus* extracts in vitro and in vivo with positive results in terms of tumour size reduction and overall survival of cell lines. Aqueous extract of P. hysterophorus has hypoglycaemic activity against alloxan-induced diabetic rats (Patel *et al*., 2008). So, flower extract of this weed can be used for developing drug for diabetes mellitus.

Parashar *et al*., (2009) reported the synthesis of silver nano-particles by reducing silver ions present in the aqueous solution of silver nitrate complex using the extract of *P. hysterophorus*. This discovery can promote this noxious plant into a valuable weed for nanotechnology-based industries in future. Applications of such eco-friendly nano-particles in bactericidal, wound healing and other medical and electronic applications makes this method potentially exciting for the large-scale synthesis of other nano-materials.

4.2 Agricultural uses of parthenium

Enhancement of crop productivity**:** Allelopathy of P.hysterophorus can be used to increase crop production at minimal expenses and to diminish the current reliance on synthetic agrochemicals that degrade the environmental quality (Patel, 2011). Huge amount of locally available Parthenium India can be utilized as a source of organic matter to prepare its compost. The decomposition of Parthenium plant is done by composting and the composted product becomes enriched with mineralizable plant nutrients. The *Parthenium hysterophorus* compost contains two times more nitrogen, phosphorus and potassium than Farm Yard Manure (FYM) (Channappagoudar *et al*., 2007). Numerous studies revealed that the integrated use of Parthenium in soil modifies the physico-chemical, biological and nutritional quality of the soil. The high concentration of elements (N, P, K, Fe, Mn, Cu and Zn) in composted Parthenium increases the yield of many agricultural crops (Kishor *et al*., 2010). Incorporation of organic wastes of parthenium enhanced the moisture content of the soil to the tune of 45.5 to 77.4% as compared to application of NPK alone to maize crop. This enhancement could be attributed to the higher water holding capacity of the soil due to the influence of organic waste application. The moisture in soil due to application of Parthenium compost was 14.5 and 16.5% at 0-15 and 15-30 cm depths as compared to 10.7 and 11.6% at 0-15 and 15-30 cm depths of soil due to application of NPK alone (Son, 1995).

Javaid (2008) used *P. hysterophorus* weed as green manure for maize and mung bean production. The highest root and shoot biomass in maize was obtained in 3% green manure treatment, which was significantly greater than that obtained in the control and equivalent to that obtained in the NPK fertilizer treatments.

The effect of *P. hysterophorus* green manure and EM (effective microorganisms), a biofertilizer, on wheat (Triticum aestivum L.) cultivation was studied. Highest root biomass was recorded in 3% green manure-amended treatment. Spike length, number of grains per spike and grain yield gradually increased by increasing the quantity of green manure. There was 43–253% increase in grain yield over control due to various green manure treatments as compared with 96% increase due to NPK fertilizers over control (Javaid and Shah, 2010). *P. hysterophorus* being rich in N, P, K, Ca, Mg and chlorophyll content is ideally suited for composting. Ordinary *P. hysterophorus* compost cannot sufficiently reduce the allelopathic effects of high levels of parthenin and phenolics, which impede the early growth, development and dry matter yield of both monocot and dicot plants. For maximum exploitation of the nutrient contents of *P. hysterophorus,* without incurring the ill effects of phenolics, millipede Harphaphe haydenianamediated novel composting procedure was tried. This milli-compost (MC) was more effective than ordinary parthenium compost (OPC) (Apurva *et al*., 2010).In Ethiopia by Wakjira *et al*.,(2009) reported that composting parthenium before flowering is a means to minimize its allelopathic inhibition potential and one way of management by utilization. So, if tapped properly, this weed can contribute to agronomic processes.

Use as bio-pesticides**:** The allelochemicals of p.hystrophorus can be exploited as herbicides, insecticides, nematicides, fungicides and growth regulator. Pesticidal potential has been established in terms of ovicidal and anti-fleedant effects (Datta and Saxena, 2001). The allelochemicals also provide defence against herbivorous predators**.** Pandey (1994) studied the effect of dry *P. hysterophorus* L. leaf powder on aquatic weeds like Salvinia (Salvinia molesta Mitchell), water lettuce (Pistiastratiotes) and water hyacinth (Eichhornia crassipes) choke off water bodies suffocating aquatic creatures. The treatment caused wilting and desiccation of above-water parts of these floating plants. With the increasing concentration of P. hysterophorus extracts, the seed germination and growth of lovegrass (Eragrostis) decreased significantly (Tadelle Tefera, 2002).

The weed population in rice field was found to be influenced by the incorporation of composted organic wastes. The application of organic waste composts reduced the weed count from 30.5 to 39.8% over NPK at 60 DAT. This could be attributed to the role of allelopathic compounds such as phenol present in these two plant debris even after composting (Son, 1995). Similar reduction in weed population due to Parthenium as green leaf manure for rice was reported earlier by Sudhakar (1984). Among the different composts, coir pith and Parthenium compost recorded lower weed population in maize. The beneficial effect of organic wastes in reducing the incidence of pests such as stem borer and leaf roller was observed due to the application of organic waste composts. Generally under incorporation of organic wastes, the reduction in pest incidence was to the extent of 43.4 to 50% at 60 DAT as compared to NPK alone (Son, 1995). Incidence of leaf roller in rice crop was the highest with urea application, whereas it was the lowest with Parthenium as green leaf manure application

(Sudhakar, 1984).

Livestock feed**:** Decoction of *P. hysterophorus* can be used as a flea-repellent for dogs and other animals (Maishi *et al*., 1998). This weed is a valuable source of potash, oxalic acids and high-quality protein (HQP) which can be used in animal feed (Mane *et al*., 1986).

4.3 Industrial uses of parthenium

As additive in cattle manure for biogas production**:** In the wake of oil crisis, energy generation from biowastes by anaerobic digestion has attracted immense attention. Energy crops are likely to be future sources of digester feed stocks for methane generation. P. hysterophorus was mixed with cattle manure at a 10% level and allowed to digest anaerobically at room temperature in 3-l batch digesters. The chemical changes during the course of digestion and the effect of digested slurry (inoculum) on biogas production were investigated and significant increase in methane content was achieved. The methane content of the gas varied between 60 and 70% (Gunaseelan, 1998). P. hysterophorus should be seriously considered as a substrate for the production of biogas in India via anaerobic digestion, considering the abundance of this weed and large quantity of livestock (Patel, 2011).

Use as substrate for commercial enzyme production**:** *P. hysterophorus* as substrate for enzyme production Xylanases are hydrolytic enzymes that cleave xylans. The end products of xylan degradation have industrial applications for biofuel, artificial sweetener, animal feed production, baking and textile industry, clarification of fruit juices and coffee extraction. Besides, there has been an increasing interest in using xylanases for ecofriendly bleaching of pulp in paper industries. The potential of P. hysterophorus as low-cost raw material for xylanase production was studied by Dwivedi *et al*., (2009). They investigated xylanase production from a mutant of Penicillium oxalicum in submerged fermentation. Considerably higher level of the enzyme production in medium containing P. hysterophorus confirms the feasibility of using this cheap resource as an alternative carbon source to save costs of the enzyme production process.

Removal of heavy metals and dyes**:** Environmental pollution with heavy metals has become a global phenomenon. Nickel (II) is present in the effluents of silver refineries, electroplating, zinc base casting and storage battery industries. At higher concentrations, nickel causes cancer of lungs, nose and bone. Cost effective alternative technologies or absorbents are needed for the treatment of metal-contaminted wastewaters especially in developing countries like India (Patel, 2011). Lata *et al*., (2008) studied the adsorption capacity of *P. hysterophorus* for the removal of nickel from aqueous solution by varying parameters such as agitation time, Ni (II) concentration, adsorbent dose and pH. The dried biomass of *P. hysterophorus* is used for carbon preparation by mixing it with concentrated sulphuric acid (1:1.5 w/v ratios) and keeping it at 120_C for 24 h, followed by washing and drying. This sulphuric acid-treated carbonized Parthenium (SWC) could be an effective, easily available and low-cost adsorbent for the removal of Ni (II) from dilute aqueous solution.

Cadmium (Cd) is widely used in electroplating, plastic manufacturing, metallurgical processes and industries of pigments and Cd/Ni batteries. However, it is extremely toxic even in low dosages and responsible for causing renal disorder, high blood pressure, bone deformity and destruction of RBCs. Because of bioaccumulation, Cd (II) is considered as a priority pollutant by the US Environmental Protection Agency (Patel, 2011). Ajmal *et al*., (2006) studied the efficiency of dried powder of P. hysterophorus as an adsorbent for removing Cd (II) from waste water. Batch process was employed for adsorption of Cd(II) ions by dried and crushed mass of P. hysterophorus. Atomic absorption spectrophotometry (AAS) of the filtrate showed that P. hysterophorus is an effective adsorbent over a wide range of initial Cd(II) concentration. The maximum adsorption of Cd(II) ions in the pH range 3–4 was 99.7%. The desorption studies showed 82% recovery of Cd(II) from the adsorbent, when 0.1 M HCl solution was used as effluent.

Cresol, a phenol derivative, is found in effluents of petrochemical, oil and metal refineries, chemical and glass fibre manufacturing, ceramic and steel plants, phenolic resin manufacturing industries, etc. This toxic effluent is known to cause stomach tumours, corrode the eyes, skinand respiratory tracts and affect the central nervous system, cardiovascular system, lungs, kidney and liver, even leading to unconsciousness and death. Activated carbon prepared from *P. hysterophorous* by chemical activation using concentrated H_2SO_4 is an effective adsorbent material. In order to test the adsorbent efficacy of parthenium-based activated carbon (PAC), it is compared with commercial grade activated carbon (AC). PAC is found to be as good as AC for removal of p-cresol up to a concentration of 500 mg/l in aqueous solution. AC is an expensive activated carbon and so regeneration is essential. In contrast to this, PAC is inexpensive, easily available and does not need regeneration and thus promises sustainable utilization in p-cresol removal from industrial wastewater (Singh *et al*., 2008).

The discharge of coloured waste into streams affects their aesthetic nature, reduces photosynthesis and renders aquatic bodies toxic due to the metals and chlorides in it. Adsorbents prepared from *P. hysterophorus* are tested to remove methylene blue from an aqueous solution in a batch reactor. Dye adsorption capacity of sulphuric acid-treated parthenium (SWC) and phosphoric acid-treated parthenium (PWC) is compared with that of commercially available activated carbon (AC). Maximum dye is sequestered by AC; however, PWC and

SWC also showed significant results and can be considered as potential adsorbents for methylene blue removal from dilute aqueous solutions (Lata *et al*., 2008). Going by these promising findings, this weed can be exploited for industrial pollution control.

5. Management of Parthenium weed

5.1 Prevention

The easiest way to avoid parthenium weed is to prevent it from establishing in the first place (PAG, 2000). Prevention is much cheaper and easier than cure. Parthenium seeds can spread via water, vehicles, machinery, and stock, feral and native animals and in feed and seed. Drought conditions aid the spread of seed with increased movements of stock fodder and transports (Anonymous, 2011).

Simple precautions, such as sowing of uncontaminated crop and pasture seeds, cleaning of cultivating and harvesting vehicles before moving them into non-infested areas, and short term quarantine of stock that have been in parthenium weed infested areas will reduce the spread of parthenium weed (Navie *et al*., 1996; PAG, 2000; Anonymous, 2011). Maintenance of grass crown cover in problem areas (heavily grazed areas, watering points, roadsides, and holding paddocks, etc.) and spot spraying of isolated outbreaks with a residual herbicide were recommended as they reduce the occurrence and distribution of parthenium weed (PAG, 2000). Further this group suggested that maintaining good hygiene on the field and property can also prevent the spread of parthenium weed. Seed-check vehicles and controlling the movement of animals can also help to control in the field.

5.2 Manual and Mechanical control

Hand weeding of parthenium is not advisable as the weed causes contact dermatitis, asthma and fever to human beings a danger that mature seeds will drop off and increase the area of infestation. In addition, hand weeding is laborious as it requires frequent work following the emergence pattern of the weed (Anonymous, 2011). Despite the serious risks of health hazards, hand pulling is still practiced in India and Ethiopia, because it was found to be cost-effective (Dhileepan 2007; Wegari 2008). Hoeing can also be used to get rid of parthenium, but repeated operation is needed as long as there is the seed of the weed in the soil. In eastern Ethiopia, repeated hand hoeing before flowering was found to be more effective method (Tamado and Milberg 2004). They described also manually removing parthenium is the most ideal method. However, it is effective as a method only in limited areas such as residential colonies and agricultural fields. It is not a suitable or economical method to deal with the weed that has infested pasture and wastelands of wider areas. These manual and mechanical control methods of this weed, however, suffer from several limitations. Navie *et al*., (1996) pointed out that hand

pulling is not effective without proper disposal. Tamado and Milberg (2004) indicated that hand hoeing before flowering is time consuming and labor intensive.

According to Gupta and Sharma (1977), cutting parthenium from base using metal blades or swards is seldom effective because it usually facilitates rapid regeneration of plants from crown buds. The authors suggested that the weed should be uprooted to prevent its regeneration from the remaining lateral shoots and that the uprooting should be done before its flowering period and when the soil is moist enough to facilitate easy removal. Who should do the removal of the weed should also need careful decision. For example, Mahadevappa (1997) and Bahn *et al*., (1997) recommended that only a person insensitive to parthenium allergy should be engaged; Gupta and Sharma (1977) also suggested that protective clothing should be worn and subsequently washed to prevent the possibility of allergic reaction.

Manual and mechanical control methods are reported to be very expensive and cannot be employed everywhere, and the relief from these methods is temporary and needs to be repeated (Bhan *et al*., 1997). Mowing or slashing of parthenium weed is not recommended for it results in rapid regeneration of plants from lateral shoots (Gupta and Sharma, 1977; Haseler, 1976). However, deep ploughing greater than 7 cm soil depth to bury seeds or repeated harrowing to destroy the seedlings before sowing is recommended (Bhan *et al*., 1977; Tamado Tana, 2001). Bhan *et al*., (1997) also suggested that the plants should be uprooted to prevent regeneration from the remaining lateral shoots and that such operation should be done before flowering and when the soil is moist enough to facilitate easy removal. The latter author also noted that hand pulling is recommended only in small areas like in gardens, flower beds, intensively cultivated fields or high value crops since manual removal is not cost effective.

Burning can also kill parthenium weed seed near the soil surface, but buried seeds may survive (Vogler *et al*., 2002). Fire can temporarily increase parthenium weed densities, but repeated burnings can reduce the weed populations, especially if post-fire management maintains competitiveness of desirable pasture plants (Vogler *et al.,* 2002) However, smoke has been shown to stimulate parthenium weed seed germination and, in some cases, seedling emergence (Adkins *et al*., 2003). Mulching (“Cultural – smother crops") Rice straw mulch was effective during rose production in controlling an array of weeds that included parthenium weed. This suggests that mulching, common in landscaping, may help control parthenium weed. The use of inorganic mulches, like woven polypropylene groundcovers, can be effective in controlling weeds in nurseries, especially if they are kept free of organic debris (Singh, 2005).

5.3 Cultural control (growing competitive field crops)

Growing of competitive crops or displacement with beneficial plants to suppress parthenium weed was also suggested as alternative but, since parthenium weed grows in different ecology, the scope of this practice is limited to only certain situation (Bhan *et al.,* 1997). Kandasamy and Sankaran (1997) conducted two field experiments at Tamil Nadu, India, to evaluate the competitive ability of major field crops (cereals, millets, oilseeds, and pulses) and other plants competitive with parthenium weed. They reported that growing of maize, sorghum and sunflower significantly reduced the parthenium weed population by reducing its branching, growth and flower head production as compared to other crops. In these crops, dry matter accumulation of parthenium weed was reduced by more than 80% and the yield reduction due to parthenium weed in maize, sorghum and sunflower was only 12.3, 14.7 and 14.1%, respectively, indicating the competitive ability of these crops with parthenium weed.

Some researchers have advocated growing competitive crops such as *Cenchrus ciliaris, Clitorea terneata* and *Digitaria milanjiana,* to suppress *Parthenium.* However, as the *Parthenium* is mainly a wasteland weed, the scope of this practice is limited to only certain situations (O,Donnell & Adkins, 2005).. Parthenium weed can be also suppressed using crops such as cowpeas in Ethiopia (Tamado and Milberg, 2004).

5.4 Chemical control

Using herbicides to control parthenium weed is not environmentally sound and economical feasible for small holder farmers and pastoralists in developing countries. However, under special situations spraying pasture with herbicides can be a useful way of eliminating the weed. However, parthenium should be sprayed early before it has set seed. Again, small and isolated infestation should be treated immediately. Usually, herbicide control will involve a knockdown herbicide to kill plants that are present. Residual herbicide, on the other hand, is applied to control future germination. Repeated spraying may be required even within one growing season to prevent future seed productions. However, to overcome excessive infestation one should carry out herbicide treatment in conjunction with pasture management (Mountmorgan, 2006).

Herbicides can be applied as pre emergence or post emergence. Pre emergence herbicides are herbicides must be applied repeatedly in areas where the seed bank contains parthenium seeds since they may remain viable for 2–6 year. The herbicide barriers need to be in place during all times of the year when the seeds are likely to germinate (Tamado, Schutz and Milberg, 2002).but Post emergence herbicides – Some of these herbicides are not selective, and the ones that are selective can still damage many crop plants, so care in selection and application is very important. Some of these herbicides should only be used in non crop areas. Additionally, some of these products are listed as both effective and ineffective, depending on the parthenium weed biotype being treated (Stamps, 2011).

Herbicides like Bromacil, diuron and terbacil, at 1.5 kg/ha by Kanchan and Jaychandra (1977), diquat at 0.5 kg/ha Dhanraj and Mitra (1976) were reported to effectively control parthenium weed. Spraying 2 kg/ha of 2, 4-D sodium salt or 2 l/ha of MCPA in 400 L. of water was found effective to control parthenium weed at the seedling stage (Bhan *et al*., 1997). Balayan *et al*., (1997) also reported 1-2% solution of glyphosate with or without surfactant and Metribuzin at 1-2 kg/ha gave 90-98% visual toxicity on parthenium weed and advocated the supremacy of chemical control over other control measures on the bases of quick relief, time saving and cost effectiveness.

A field trial undertaken in Assam, India, indicated that metribuzin 0.2% solution effectively controlled parthenium. The experiment revealed also that the native grass species were not affected and re-growth of parthenium was not observed up to three months (Rajkhawa *et al.,* 2005). One should not, however, that when the amount of metribuzin exceeds 0.2%, it destroys all plants (Sharma *et al*.,2005). Glyphosate 1.5kg/ha, paraquat 0.5kg/ha and 2, 4-D 1.0kg/ha were also able to control parthenium. Their side effect was that they killed the other vegetation. This suggested that they are effective and less harmful only when they are sprayed on road side, rail way tracts, industrial sites and dwelling habitats. However, re-growth of parthenium was noticed after 30 days of spray of these herbicides (Singh *et al.,* 2003; Rajkhawa *et al*., 2005). In none crop areas (i.e. along rail ways, road sides and waste land); spraying common salt solution at 15-20% during the active growth stage of the weed will effectively control it (Ramamoorthy *et al.,* 2003). High concentration of common salt brings about plasmolysis which in turn leads to desiccation of the treated parthenium plants. After this, the weed is burned to prevent its regeneration.

Similar experiment carried out in New Delhi on a fallow land that was heavily and uniformly infested with natural population of parthenium revealed that metribuzin at 1 and 1.5kg/ha resulted in 100% control of flowered as well as non-flowered parthenium plants, followed by 50-60% of glyphosate at 1.0 and 1.5 kg/ha. The experiment suggested again that the vegetativly active growing plants were comparatively more sensitive to these herbicides than the flowered plants. For example, 2, 4-D Ethyl Eatier at 1.0kg/ha resulted in 40% more mortality of non flowered parthenium plant than 2, 4 D Na salts. It also suggested that chlorimuron ethyl was inferior to other herbicide treatments in reducing the growth of parthenium (Sharma *et al.,* 2005). On its part, an experiment conducted in Werer Agricultural Research Center in Ethiopia on sorghum fields that were infested naturally by parthenium revealed that both Gesaprium Combi (5.5 L/ha and Primextra TZ 500 FW (5.5 L/ha) were found to be most effective in controlling parthenium for a prolonged period of time after application (Kassahun *et al.,*1999).

Chemical pollution of the environment, enormous cost, danger of toxicity to non-target plants, necessity of the chemical application in non-agricultural areas, rapidity of re-invasion of treated areas soon after the effect is diminished are the draw backs of chemical control (Singh, 1997). Similarly, Bhan *et al*., (1997) reported that chemical control alone is not justifiable as the effect of herbicide will always be of temporary nature and repeated operations are required which will not remain cost effective. As parthenium weed is a weed of wasteland and road side, a common man will never invest his money in this venture. Moreover, plants suppressed by chemicals have been observed to regenerate after remaining dormant for a few days. Chemical treatment can only kill existing population at the given sites but cannot prevent the entry of the seeds from neighboring places.

5.5 Biological control

Biological control is basically practiced either host-parthenium weed interaction or through the use of competitive plants (releasing allelopathic against the weed).

5.5.1 By utilizing organisms (host-weed plant interaction)

According to Julien (1997), biological control is defined as the “utilization of organisms for the regulation of host plant densities.” It is also defined as ‘the action of predators, pathogens, and/or parasites in maintaining another organism's population density at a lower average level than would occur in their absence.' It may be achieved via direct or indirect action of the biotic agent that can bore into the weed and weaken its structure, consume or destroy vital plant parts, reduce weed vigor and reproduction, or enhance conditions that favor pathogen attack.

There are two techniques or approaches used in biological control: Classical biological control and non-classical biological control. The classical biological control involves introduction of natural enemies from their native range into an exotic range where their host plant has become a weed. It is the most commonly used technique. Managing weeds using classical biological means is less expensive, permanent and pollution free. Whereas the non-classical biological control concentrates on use of native natural enemies like inundative (release of large numbers of the agent to control the target weed. e.g. Mycoherbicides or augmentative (i.e. Mass rearing and release of large numbers of a control agent that cannot be utilized as a mycoherbicides) (Adkins, 1997& Auld, 1997).

The idea of using plant pathogens to reduce the weed population is not new and has previously occurred to scientists as well as laymen. Biological control of parthenium weed was first proposed in India in 1970 and a brief survey of insects attacking it was made in West Indies. Further, considerable work on mycoherbicides for control of Parthenium weed has been carried out in India (Bennet and Cruttwell, 1971). Deshpande (1982) appears to have been the first to explore the possibility of exploiting local pathogens, although no specific potential agents were identified. Rajak *et al*., (1990) undertook a survey around Jabalpur (Madhya Pradesh), collecting diseased specimens of *P. hysterophorus* and isolating suspected pathogens.

Biotic factors suppress the plant within its native range as compared to its increased fitness or vigour in their absence (Evans, 1997a). Hence, the fact of parthenium weed undoubted vigour in Australia and India compared with its limited importance in the countries of origin suggests that biotic factors contribute to its suppression there. If the natural enemies were introduced, the ability of the plant to compete with pastures and crops could conceivably be reduced to the point where it was no longer of economic importance (Haseler, 1976). Therefore, biological control appeared to offer the best, long-term solution for the management of parthenium weed and which is environmentally benign. The use of bio-control agents including insects, pathogens and strong interfering smoother crops and plants are recommended as element of integrated parthenium weed management (PAG 2000).

Surveys for natural enemies were carried out in Mexico by the Commonwealth Institute of Biological Control (now CABI Bioscience, Ascot, UK). Eight insect species and two rust fungi were introduced and released in Australia after preliminary screening in Mexico and final evaluation in quarantine in Australia (Evans, 1997). However, adverse climatic factors have prevented the released natural enemies from achieving their full potential. Microorganisms associated with parthenium were also studied in India and such efforts are still in progress towards the development of indigenous pathogens as bio-herbicides. Native natural enemies may be more effective than introduced because of more adaptability and no necessity of quarantine measures. Since no attempt has been done so far in Ethiopia but recently a new approach can be explored to manage parthenium.

Hence, the search for pathogens causing diseases to parthenium at various levels is an essential step for future implementation of biological control in an integrated parthenium management system in Ethiopia (Taye Tessema, 2002)

Abundant literature exists on the various natural enemies of P.hysterophorus that have been screened and /or introduced with varying degree of success. biological control would be most likely offer the best and most effective solution to the p.hysterophorus weed problem (Haseler,1976).But to date biological control of parthenium hysterophorus has only achieved limited control in Australia, and India (McFadyen,1992) and elsewhere in the world. Species that have successfully been introduced in Queensland, Australia, Include: Zygogramma bicolorata aleaf defoliating beetle; Listronotus setosipennis a seed feeding weevil; Puccinia abrupt var of Partheniicola,a winter rust;Epiblema strenuana,astem gulling moth;Conotrachelus spp., astem-gulling weevil; Platphaloniadia mystica, a stem-boring moth; Carmenta nrithacae,a root boring moth and Puccinia melampodii,a summer rust(PAG,2000)

Recently researchers found that larvae of a beetle *Zygogramma bicolorata* Pallister feeding on leaves and causing defoliation of *Parthenium.* Studies have shown that *Z. bicolorata* can be used as a potential biological agent to control *Parthenium.* The beetle was first introduced to Australia from Mexico in 1980 (McFadyen, 1992) and subsequently was introduced to India in 1984 . Probably the beetle came from India to Pakistan. Dhileepan (2007) studied the effectiveness of leaffeeding beetle Zygogramma bicolorata stemgalling moth Epiblema strenuana and stem-boring weevil Listronotus setosipennis introduced against P. hysterophorus in Australia.The moth Carmenta ithacae and leafrust Puccinia melampodi were released to eliminate this weed, but little success has been attained in this regard as the weed has great regenerative potential and moreover the insect consumes only the foliage of the weed which stimulates further leafy proliferation (Dhileepan and Strathie, 2009). The flowers and seeds, which are the main source of its dissemination, remain unaffected.

There are many other arthropods like a seed feeding weevil *Smicronyx lutulentus* Dietz (Curculionidae), a stem-galling moth *Epiblema strenuana* Walker (Tortricidae), a leaf mining moth *Bucculatrix parthenica* Bradley (Lyonetiidae), a sap-feeding plant hopper *Stobaera concinna* Stal (Delphacidae), a stemboring curculionid weevil *Listronotus setosipennis* Hustache (Evans, 1997) that can be introduced in Pakistan as potential biological control agents of *Parthenium.* Furthermore, a rust fungus *Puccinia abrupta* Diet. & Holw. Var. *partheniicola* (Jackson) Parmelee from Mexico is also known to severely damage the *Parthenium* (Evans, 1987). Recently Javaid *et al.,* (2007) have reported the attack of a mealy bug species and causing severe damage to *Parthenium* plants of all ages. The attacked plants first showed symptoms of die-back and ultimately dried to death**.**

According to TayeTessema and Monika Gossmann (2007) field survey showed that on the potential effect of rust and a phyllody disease on Parthenium suggests that it may be possible to develop bio-control agents to useful for agricultural application. The association of phyllody disease to parthenium in Ethiopia, India (Mathur and Muniyappa, 1993) and Australia Navie *et al*., (1996) suggests that parthenium is susceptible to and naturally affected by phyllody disease in different areas of the world. The susceptibility of parthenium to phyllody disease can, therefore, be utilised as classical biological control of parthenium by inducting phyllody using vectors of the pathogen responsible for the disease in order to check its growth and reduce its competitiveness. Healthy parthenium plants in vacant lands, roadsides and grasslands might be controlled by releasing the leaf hopper vector(s). However, host range of phyllody disease to the related economic plants to determine the potential risk of specificity and further confirmation of insect vectors that transmit phyllody for utilisation in areas where the disease is not present in Ethiopia is imperative (Taye Tessema,2002). In addition survey conducted at various habitats of Central India for weed pathogens yielded an isolate of *Colletotrichum dematium* FGCC#20, CFCF of this strain showed promising herbicidal potential against *Parthenium hysterophorus. Colletotrichum* spp and other spore suspensions of fungal are bio-control agents. On the basis of results obtained, the secondary metabolites of *C. dematium* FGCC#20 possess high herbicidal potential and can be developed as potential herbicides for the management of the deadly weed, *Parthenium hysterophorus (*Sadaf *et al*., 2009*).*

5.5.2 Use of competitive plants (allelopathic effect)

Competition is one of the several types of interference among species or population. Interference refers to any type of positive and negative interactions between species. Interference may involve physical factors like space, light, moisture, nutrients, and atmosphere. It may also be a type of chemical interaction (Monaco *et al*., 2001). Competition between weeds and crops are generally associated with negative interference. Such a competition involves physical factors that decrease growth in both type of plant due to the absence of an insufficient supply of a necessary growth factor. Competition can be either within the same species (intra), that is when two or more plants of the same species co-exist in time and space or between different species (inter), that is when two or more different species co-exist. For example, allelopathy is a negative type of interference between plants that occurs in the form of chemical influence (Monaco *et al*., 2001).

Under the biological methods, use of plants with allelopathic effect is an important component of biological control of parthenium. Generally, two approaches are followed to control parthenium through bio agents. One is through maintaining naturally occurring biodiversity and the other is through planting selected plant species in target areas (Wahab, 2005). A recent botanical survey across India has shown that species such as *Cassia sericea, Cassia tora, Cassia auriculata, Croton bonplandianum, Amaranthus spinosus, Tephrosia purpurea, Hyptis suaveolens, Sida spinosa, and Mirabilis jalapa* are capable of effectively suppressing parthenium in natural habitats (Wahab, 2005). Only *Cassia sericea* reduces the accumulation of parthenium by 70% and parthenium population by 52. 5% (Kandasamy and Sankaran, 1997).

A study on Eucalyptus, a native of Australia, is a known allelopathic tree that exerts its toxicity through leachates and volatile terpenes on adjoining vegetation/agricultural crops. The volatile terpenes present in leaves of eucalyptus emanate in the form of vapours into the surroundings. The vapours get adsorbed to soil, curbing the seed germination and reducing the chlorophyll content as well as cellular respiration. The oil vapours increase water loss leading to wilting. Eucalyptus oils may be used as natural herbicides for the biocontrol of P. hysterophorus owing to its allelochemicals (Kohli *et al*., 1998). Also marigold (Tagetes erecta) is reported to suppress P. hysterophorus growth in field trials (Lakshmi and Srinivas, 2007).

In USA, there are a large number of plants that compete with parthenuim for resource and space. Studies confirmed that parthenium could be a weak competitor in the face of other native and non native plants such as Johnson grass (*Sorghu*m *halepense*), aqueous extracts from Congongrass(*Imperata cylindrica*), barnyardgrass (*Echinochloa crus*galli), *Senna obtusifolia*, *etc* markedly suppressed seedling growth and germination of parthenium *(*Anjum and Bajwa, 2005; Javaid and Anjum,2006).

The occurrence of allelopathy has been widely reported in grasses like *Desmostachy*a *bipinnata* (Anjum and Bajwa, 2005; Javaid and Anjum, 2006). *Imperata cylindrica, Eragrostis poaioides, Cenchrus ciliaris, Panicum antidotale* (Bajwa *et al*., 1998). Many other grasses have also been reported to exhibit allelopathy to preclude the associated species through reducing their regeneration, growth and yield. A survey in Pakistan revealed that in parthenium infested areas there was a marked reduction in the density of parthenium, particularly at *Imperata cylindrical* and Desmostachya *bipinnata* dominated localities, when compared to the infested nearby grasses. The conclusion drawn from the study was that this low density of parthenium could be due to allelopathic nature of these grasses (Anjum and Bajwa, 2005). In similar manner, a greenhouse study in Australia indicated that grasses like Bothriochloa *insculpta*, *Dichanthium aristatum* and *Cenchrus ciliaris* out compete parthenium and that among the legumes that were tested butterfly pea (*Clitoria ternatea*) competed strongly with parthenium(O'Donnel and Adkins, 2005).

According to Javaid *et al.,* (2005) study the allelopathic grasses *Imperata cylindrica* (L). Beauv. and *Desmostachya bipinnata.* Stapf. significantly reduced the distribution of *Parthenium* and aqueous extracts of these grasses had a significantly negative impact on germination and growth of the target weed. Later on Javaid & Anjum (2006) reported similar negative impact of aqueous extracts of other allelopathic grasses viz., *Dicanthium annulatum* Stapf., *Cenchrus pennisetiformis* Hochest, *Sorghum halepense* Pers., on germination and seedling growth of *Parthenium.* Shafique *et al.,* (2005) demonstrated that aqueous leaf extracts of allelopathic trees viz., *Azadirachta indica* (L.) A. Juss*., Ficus bengalensis* L., *Melia azadarach* L*., Mangifera indica* L. and *Syzygium cumini* (L.) Skeels, have the potential to decline germination and seedling growth of Parthenium *(*Javaid *et al*., 2007).

6. Conclusion

Now a day's invasive alien plant species particularly parthenium weed threats natural ecosystem, biodiversity, agriculture, and human well being. The severity of parthenium weed is concentrated in poor or developing countries like Ethiopia which have little awareness about the weed and lack of integrated control measures. Recently the spreading of this weed has been increasing globally in an alarming rate. Similarly in Ethiopia it is distributed throughout the nation, starting from the main introduction area. The pronounced harmful effect of parthenium weed in crop production, in animal production, in human and animal health, in biodiversity and soil property has been reported from different corners of the world. But the degrees of losses or negative effects are higher in agricultural production and biodiversity. Various strategies or approaches have been developed to control parthenium weed problem on ecological and socio economic aspects. From the controlling approaches manual and mechanical, cultural and biological control measures are more effective and efficient than chemical control in terms of economic feasibility in production and environmentally sound. But chemical control is environmentally unsafe and costly. However, manual plucking, fencing, burning etc are less effective than others because of its health impacts such as allergies, asthma, and hay fever. Generally Manual and Mechanical, cultural, chemical and biological control strategies have been proved un successful individually to manage P. hysterophorus. So, integrated approaches are warranted to restrict the invasion of this weed. To address this problem successfully, public awareness has to be developed and participatory approach to control the invasive weeds should be adopted.

At present, although Parthenium hysterophorus is considered a weed, its beneficial attributes are coming to the forefront. These attributes have been successfully developed in countries which have well organized planning, strategies and equipped laboratory to control parthenium by utilization. For example, Traditional medicine, Nano-medicine, bio-pesticide, green manure potential, agent for bioremediation of toxic metals and dyes, herbicide, cheap substrate for enzyme production, as source of protein for livestock and source of biogas are some of the recently discovered implications of P. hysterophorus. So, utilization of parthenium for different beneficial aspect is one of the controlling mechanisms of the weed indirectly beside to its additional uses.

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