Journal of Agricultural Sciences and Engineering
J. Agri. Sci. Eng.

Review Article: A Review on *Parthenium hysterophorus L.* and Its Application in Agriculture

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Citation Oli Sarita, Joshi Rajeev, Bohara Bhuwan. A Review on *Parthenium hysterophorus L.* and its application in Agriculture, Journal of Agricultural Sciences and Engineering, 2024, 6(1), 16-31.

https://doi.org/10.48309/jase.2024.183986

ARTICLE INFO

Received: 2023-07-30

Accepted: 2023-11-15

Checked for Plagiarism: Yes.

Language Editor:

Fatimah Ramezani

Editor who approved publication:
Dr. Amin Baghizadeh

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Keywords:
Parthenium hysterophorus, Biopesticides, Green manure, Agricultural crops.

ABSTRACT

Parthenium hysterophorus, one of the world's most invasive weeds, is accountable for enormous losses to the biodiversity, agriculture, and even the health of human beings and animals. It is regarded as immensely prolific weed and most awful in crop production which devastated all the useful crops. However, various studies revealed that *Parthenium* can be used in agriculture in different form. In agriculture, it can be used as biopesticides, green manure, compost, soil amendment values, and vermi composting. Being a competitive weed, it consumes more and more nutrients from the soil and hence, the plant is rich in nutrients. During premature stage, i.e. before flowering, the plant is uprooted from field and burying it in the soil produces higher quality organic manure. Green manure and compost used improves the physical, chemical and biological properties of soil, increased the yield of agricultural crops. Numerous studies show that it has also insecticidal and pesticidal properties to control several insect pests in agricultural crops. This review briefly discusses the application of *Parthenium* in agriculture concluded by various researchers.

Introduction

Parthenium hysterophorus L. is an invasive weed plant belonging to the family Asteraceae [1]. It is native plant of North-East Mexico and was predominant to America, but nowadays, it is extensively scattered in all over the world [2]. including Africa, Australia, United States, Central and South America, West Indies, India, Nepal, China, and Vietnam, and established magnificently [3]. It is acknowledged with diverse names in different countries such as carrot weed, star weed, congress grass, wild feverfew, ragweed, bitter weed, white top, and the "Scourge of India" [4]. Thus, it is now considered as one of the "100 most invasive species in the world by "International Union for Conservation of Nature (IUCN)" [5].

It is an annual short-lived (4 to 6 weeks), highly branched, continuous and profuse flowering until senescence [6], high seed productivity (up to 15,000 to 100,000 per plant) [7], light seed weight, upright (erect) herbaceous plant having height reaches up to 2 m or even more. Seeds are

disseminated across large distances by means of machinery, vehicles, livestock, contaminated crop seeds, and feedstock [8] whereas wind and water spread them to shorter distances. It shows significant adaptability over varied range of ecological conditions i.e. growing in diverse types of territories. Although seasonal variations considerably affect growth, development and seed setting in *Parthenium*. Usually, the plant favours conditions like rain, moisture, mild soil, and optimum temperature between 12 and 27 $^{\circ}C$ for proper growth and development [1] throughout the year. Generally, majority of this invasive weed inhabitants in barren lands, rock cracks, irrigation canals, along road sides, railway tracks, mine areas, and developing residential colonies around the towns.

Parthenium hysterophorus L. being rich in N, P, K, Ca, Mg and chlorophyll content is preferably appropriate for composting [9]. Well prepared compost is ready within 14 weeks. Incorporation of *Parthenium*-based compost in soil enriched its moistness level more than nitrogen, phosphorus and potassium (NPK) alone [10]. Anaerobic fermentation of *Parthenium* dried solids can be applied as green manure for maize and mung bean production. The maximum root and shoot biomass in maize was found in 3% green manure treatment [9]. Studies reported that the effect of *P. hysterophorus* green manure and EM (effective microorganisms), on wheat (*Triticum aestivum* L.) cultivation recorded maximum root biomass in 3% green manure-amended treatment. Spike length, number of grains per spike and grain yield steadily 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 [11].

Normal *P. hysterophorus*-based compost cannot satisfactorily diminish the allelopathic effects of maximum levels of parthenin and phenolics. Extreme manipulation of the nutrient contents of *P. hysterophorus*, without sustaining the ill effects of phenolics, millipede *Harphaphe haydeniana*-mediated novel composting procedure was tried. This milli-compost (MC) was more effective than normal *Parthenium*-based compost [12]. Vermicomposting of *Parthenium* consumes nutrients and restricts unwanted plant noxiousness [13]. Moreover, it also increases nutrient quality, which could be advantageous for organic farming and bioremediation [14].

Allelochemicals can be used to surge crop production at nominal expenses. The allelochemicals can be oppressed as herbicides, insecticides, nematicides, fungicides and growth regulator. These chemicals also provide defense against herbivorous predators. Chemicals extracts from *P. hysterophorus* abridged weed density and also had allelopathic effects on *Eragrostis tef* (Alessandro Trotter), *Cynodon dactylon* (Christiaan Hendrik Persoon), *Cyperus rotundus* (Cyperus rotundus), *Digitaria sanguinalis* (Giovanni Antonio Scopoli), *Portulaca oleracea* (Carl Linnaeus), *Echinochloa crus-galli* (P.Beauv.), *Euphorbia prostrata* (William Aiton), *Xanthium strumariam* (Carl Linnaeus),etc [15]. Various studies proved that *Parthenium* extract could be used as a promising herbicide, shows its effects on weed germination, density, and biomass. Thus, ecologically sound, natural herbicides based on *Parthenium* could be a substitute to synthetic herbicides [16].

Method

Rigorous desk study was conducted for the literature collection on *Parthenium hysterophorus* L. and its application in agriculture. Various research papers, review articles and reports studied thoroughly for the compilation of this review information. The database referred included research gate, science direct, google scholar, academia, and semantic scholar.

Taxonomy and Nomenclature

It belongs to the Domain Eukaryota and falls under the Kingdom Plantae, Phylum Spermatophyta, Subphylum Angiospermae, Class Dicotyledonae, Order Asterales, Family Asteraceae, Genus Parthenium, and its specific species is *hysterophorus* L.

Description

The word "Parthenium," is derived from the Latin word "*parthenice*." Similarly, the word "*hysterophorus*," which refers to the plant's prodigious seeding behavior, is derived from the Greek words "hystera" (womb) and "phoros"

(bearing). It is an annual or ephemeral herb belonging to the family Asteraceae (Tribe: Heliantheae) with fast-maturing, upright, and heavily branching plant.

Origin and Global distribution of Parthenium

The *Parthenium hysterophorus* is indigenous to Central America, Southern North America, the Gulf of Mexico, the West Indies, and Central South America (Figure 1). The plant has now colonized every continent, including islands. It has spread at an alarming rate throughout India and other Asian nations including China, Bangladesh, Nepal, Pakistan, etc. In several nations, including Australia, South Africa, Ethiopia, India, and Pakistan, it has a significant spread and infestation. With the importation of American cereal and grass seed in the 1950s, it was introduced into Asia, Africa, and Oceania [17].

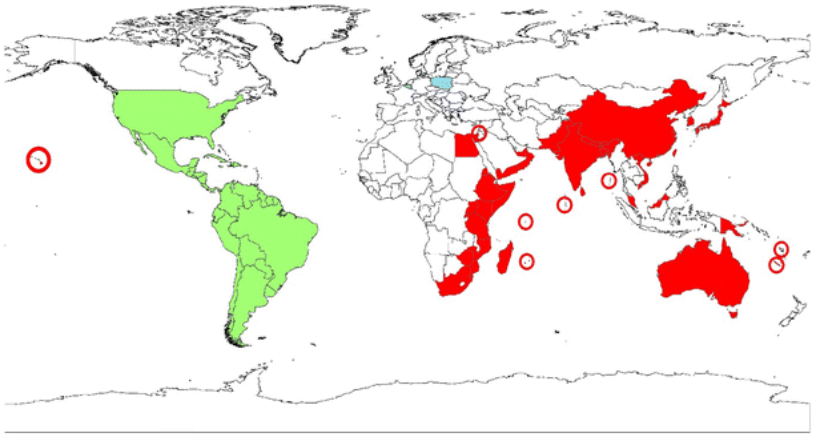

Figure 1. An international map showing the location of *Parthenium* weed. The nations shaded in red or circled in red are those where *Parthenium* weed is invasive; the nations shaded in green are those where it is thought to be native. Map source [1].

Origin and Distribution of Parthenium in Nepal

Early in 1967, a botanical expedition team collected the first specimen of *P. hysterophorus* in Nepal from the Trishuli Valley (the Hill area, central Nepal), and [18] later listed it in a checklist of flowering plants in Nepal [19]. Due to the fact that the first specimen was not discovered there until 1989 [20], the weed was not described in [21] Flora of the Kathmandu Valley. Thousands of cars travel between India and Nepal every day and do so at numerous locations thanks to an open border and numerous direct road links. Through these route connections, it is believed that *P. hysterophorus* invaded Nepal from India, where the weed was first discovered.

P. hysterophorus is a dominating species that may be found growing in grasslands, fallow fields, abandoned agricultural lands, and certain crops. It can be found growing along road edges, in and around important urban centres including Kathmandu, Hetaunda, Bharatpur, Butwal, Pokhara, Dang, Surkhet, and Nepalgunj. In addition, the weed has spread into the buffer zones surrounding the Chitwan National Park, a site of world natural heritage [22]. There hasn't been a comprehensive analysis of the weed's spread across the country. However, a preliminary map based on geographic positioning system co-ordinates for 'presence only' data has revealed that the weed is now common in Nepal, from east to west, in the Tarai, Siwalik, and Hill regions. *P. hysterophorus* dissemination is likely caused by initial infections, according to recent surveys of the disease's distribution in Nepal [23]. Generally, in the Kathmandu valley it can yield up to 3865 seeds [24]. According to a distribution study conducted in two municipalities in central Nepal, industrial estates and urban areas with a high concentration of weed were the most prevalent locations for the weed [25]. This weed predominately grows in communal grasslands and on defunct agricultural fields in the peri-urban areas. The irrigated agricultural lands, which are intensively

managed and utilized all year long, have not yet shown any signs of it. In upland cropping systems, where the land is only used for growing upland rice (*Oryza sativa* L.) and maize (*Zea mays* L.) during the wet season (June through September), *P. hysterophorus* exhibits dense growth during the winter (October to January) and summer (February to May) seasons [22]. Difficult stands are less common throughout the growing season in such places (Figure 2).

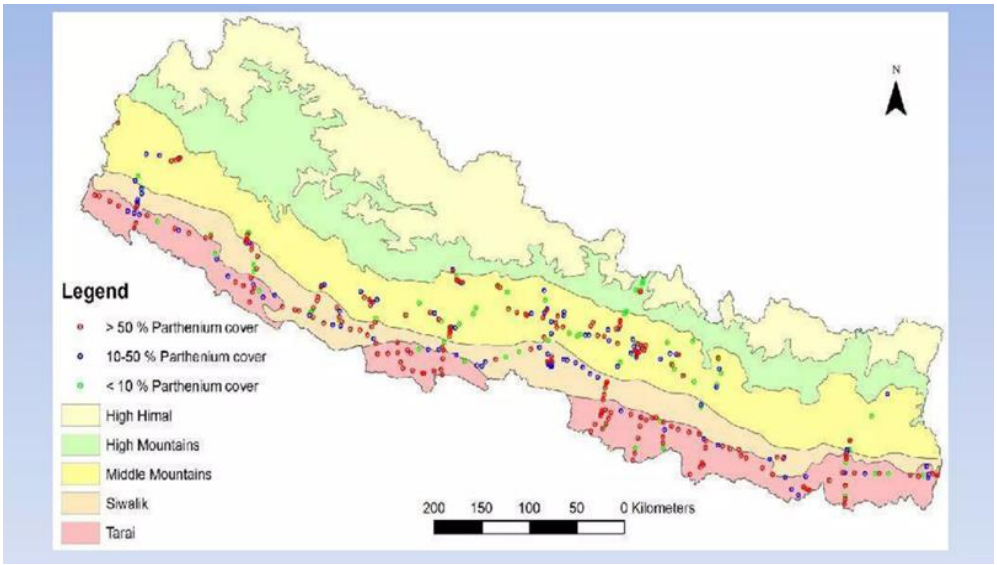

Figure 2. *Parthenium hysterophorus* L. distribution throughout Nepal's various physiographic zones [26].

Habitat

This exotic weed is typically found on bare terrain, in industrial regions, developing residential colonies, on highways, railway lines, and in ditches, among other places. In addition, this weed thrives in gardens, forests, and farmlands. It may produce about 15,000 seeds per plant because of its great luxuriance development, and these seeds have a high dispersal and germination rate [27]. It has the capacity to adapt to a range of habitat circumstances. It infests wooded areas, open spaces in urban areas, overgrazed pastures, built terrains, irrigated and exposed zones, such as roadside ditches and railroad lines, and heavily populated places, such as stockyards and watering locations like irrigation canals, water channels, and ditches [28].

A warmer climate is favorable for its growth. The growth of this harmful weed benefits from high temperatures. It can grow up to a height of 1.5 to 2.0 m in ideal climates with more than 500 mm of average rainfall and temperatures around 30 °C. Even at heights of only 10 cm, in dry conditions, the plants may mature and set seed. This weed is distinguished by its biomass and density variations depending on the kind of soil. To flourish luxuriously, it likes alkaline clay and loam soil to dense black clay [29]. The majority of the locations where Parthenium has invaded have sandy loam soil, which has a pH range of 5.4 to 7.4, a water retention capacity of 16.8 to 63%, total nitrogen of 0.055 to 0.206%, organic matter of 1.134 to 4.24%, and concentrations of phosphorus and potassium of 31.86 to 69.93 kg/ha and 74.72 to 746.5 kg/ha, respectively [30]. Parthenium may grow in a variety of moisture, pH, and temperature conditions but it requires high soil moisture for its seed germination.

Morphology

Parthenium hysterophorus is a densely branching, annual herbaceous plant with an upright (erect) habit that forms rosette habitats when young [31]. Although they rarely grow taller than 2 meters when fully grown.

Stem

According to [32], the stem is cylindrical, firm, and somewhat fluted with longitudinal lines that correspond to the extension of the midrib of the leaves. As they mature, stems grow more harder and are covered in tiny, soft hairs known as hirustles. Mature stems are greenish in color.

Figure 3. Stem of *Parthenium hysterophorus*

Leaves

According to [31], the leaves are oriented alternately and have petioles that can reach a length of 2 cm. It develops rosette habitat during the earliest phases of life. The leaves are simple, alternating, and deeply pinnatifid. Lower leaf blades are wider and more sharply split than upper leaf blades, measuring 11 to 15 cm long by 6 to 10 cm wide. In close proximity to the surface, short, stiff hairs cover the abaxial surface of leaves.

Figure 4. Leaf of *Parthenium hysterophorus*

Flowers

The tops of the branches (in terminal panicles) are clustered with numerous tiny flowerheads known as capitulum [33]. A stem called a pedicel supports each flower-head, or capitulum. A white or off-white capitulum (3-5 mm in diameter) with ray florets that are 0.3-1 mm long is present. In addition, they contain two rows of tiny green bracts (an involucre) around variety of small flowers (tubular florets) that range in size from 15 to 60. It can bloomed at any time of the year, but generally occur during rainy season.

Figure 5. Flower of *Parthenium hysterophorus*

Seeds

Each flower head produces five tiny "seeds," or achenes as they are more often known. Two or three tiny scales called pappus, which are around 0.5-1 mm tall, two straw-colored papery structures (which are actually dead tubular florets), and a flat bract make up the black, oblong seeds, which are 2 mm long and 1.5 mm wide [34].

Figure 6. Seeds of *Parthenium hysterophorus*

Seed germination and longevity

In *Parthenium*, flowering occurs 24-48 days after germination. Anytime of the year is a possibility for this. The ideal day/night temperature cycle for its weed seed development is 21-16 ° C [35]. In addition, its seeds can survive for 4-6 years in the soil as a seed bank. Additionally, studies have revealed that buried seeds have a far longer lifespan than seeds that are exposed to the soil [36].

Reasons of Rapid Extent of Parthenium

High Propagative Potential

With up to 25,000 seeds per plant [37] and a huge seed bank estimated at 2,00,000 seeds/m^2 in abandoned fields [30], *Parthenium* weed is a very prolific seed producer. Given the proper moisture levels, *Parthenium* seeds may sprout at any time of the year, remain viable for a long time, and even flourish in extremely unfavorable climatic circumstances.

Fast Growing Rate

It is an annual that matures quite quickly. Plants typically start flowering between 4 and 8 weeks after they are born, and they may continue to bloom for several months. The weed may germinate, develop, mature, and set seeds in four weeks under unfavorable circumstances, such as drought stress.

Allelopathic Potential

Through allelopathy, *Parthenium* prevents the germination and development of other plants. Aqueous extracts of leaves and inflorescence were found to prevent the germination and development of barely, wheat, and peas. Cell viability and chlorophyll content were significantly decreased when *Parthenium* extracts were sprayed directly on agricultural plants, as demonstrated by [38].

Indigestible to Animals

According to published research, goats can ingest Parthenium but cows, sheep, and buffaloes cannot [39]. Investigations conducted before in India have found significant health risks for animals in *Parthenium*-invaded regions. In artificial feeding tests, calves, bulls, and buffalo all readily absorbed the weed, either by itself or in combination with green feed. The majority of individuals experienced severe dermatitis and toxic symptoms and passed away between 8 and 30 days later.

Chemical Components in Parthenium

The chemical components of *Parthenium hysterophorus* has both its advantageous and detrimental effects. Numerous secondary metabolites, including alkaloids, flavonoids, pseudoguaianolides, oils, and phenolics, are present in all plant components, including the hair, trichomes, and pollen [40]. After inflorescence, fruit, root, stem and leaves have the largest concentration of these metabolites [41]. The plant produces these secondary metabolites to protect itself against herbivory, diseases, and competition from other plants. These substances are sometimes referred to as allelochemicals because of the allelopathic effects that some of them exhibit. The chemical makeup of the parthenium plant and the numerous functions connected to its constituent. The whole plant contains the flavonoids, parthenin, stigmasterol, and 6-hydroxykaempferol-3, 7-dimethyl ether (Table 1). The components of leaves include parthenin, acids, campesterol, stigmasterol, and essential oil. Ambrosanoli is present in flowers. Alcohol, chloroform, ether, acetone, and ethyl acetate are among the solvents that Parthenin and its derivatives can be found to be soluble in [42]. Furthermore, it has been shown that none of the components of the *Parthenium hysterophorus* extract have an azeotropic melting point, with all of them having boiling points between 165 and 220 °C, whereas methanol's is 64.7 °C. As a result, they can all be separated using straightforward distillation methods.

Table 1. Chemical component of *Parthenium*

Chemicals class	Major components	Plant parts
Phenolic acid	Anicic acid, Fumaric acid, Ferulic acid, Vanicillic acid, and Chlorogenic acid	Root, leaves, and stem
Flavonoids	Apigenin, Luteolin, Syringaresinol, Santin, Saponins, and Aglycone	Aerial parts
Pseudoguainolides	Parthenin, Anhydroparthenin, and Flavanols Hysterones A to D	Stems, leaves, flowers, and their calli
Secopseudoguananolides	Charminarone	All plant parts
Sesquiterpene lactones	Coronopilin, hystrin, Acetylated pseudoguananolides	Stem, flowers, and trichomes
Minor sesquiterpenes	Ambrosonalides, 1, 3 –hydroparthenin	Flowers
Others	Free amino acid, glucose, galactose and KCl	Whole plant

**Sources: [2]*

Control Measures of Parthenium Weed

Parthenium weed can be controlled by various methods such as cultural, physical, chemical, and biological techniques. Biological techniques has included the use of suppressive plants that can suppress the growth of P. hysterophorus [43] as well as classical biological control agents, including insects (e.g., Z. bicolorata, Epiblema strenuana Walker) and pathogens (e.g., Puccinia abrupta var. parthenicola). However, the weed has not been controlled below the threshold level and is threatening biodiversity and posing ill problems for the plants, humanity and animals. Different methods are being utilized to control this weed all over the world are summarized below:

Physical Control

The best technique for removing *Parthenium* manually is before it flowers and sets seed. When a weed is pulled out after seedset, the infection area grows. Physical control requires manual weeding, a laborious and unpleasant task which create difficult health risks associated with handling *Parthenium* weed [44]. If plants are uprooted after they have finished blooming, the seeds should not be dispersed by moving the plants too far away from the burning site. Furthermore, to get speedy results, the manual technique is also included in the integrated approach. Similarly, another commonly practiced physical method of controlling *Parthenium hysterophorus* weed is burning. Bulk vegetation of the weed can be burnt by this practice. However, it cannot be regarded as safe control strategy for the weed since there is great risk to soil, air and existing plant and animal diversity. Its ash has also allelopathic effect on crop yield but yield loss is low in comparison to the leachate and dry mass of this weed [45].

Chemical Control

Chemical method is considered as the best strategy for controlling the weed. Chemical herbicides including glyphosate, atrazine, ametryn, bromoxynil, and metasulfuron are reported to be quite successful for suppressing this weed (Table 2). After15 days of spraying, it was discovered that the application of 2,4-D EC (0.2%) and metribuzin (0.25 and 0.50%) was more successful in controlling Parthenium [46]. Spraying a solution of table salt (sodium chloride) at a concentration of 15-20% has been proven to be useful in open wastelands, uncultivated regions, along railroad tracks, and on the sides of roadways. According to [1], it is effective to apply synthetic herbicides such alachlor, paraquat, simazine, 2,4-D, 2,4,5-T, glyphosate, atrazine, and metribuzin. The ideal time to use post emergent herbicides is before flowering [43]. Glyphosate and Metribuzin were found to be very effective treatments for P. hysterophorus control, with greater effects at 28 days following herbicide application.

Table 2. Parthenium weed control at rosette and bolted stages with various herbicidal application at 4 weeks after treatment (WAT)

Serial number	Herbicides	% Mortality at rosette stage	% Mortality at bolted stage
1	Glyphosate	96	91
2	Metribuzin	87	75
3	2,4-D	71-80	43
4	Bromoxynil + MCPA	57-79	50-61
5	Atrazine	56.5	36.5
6	S-metolachor	57.5	41
7	Pendimethalin	42.5	30

**Source: [31]*

Allelopathic control

Molisch (1937) first used the term allelopathy, which generally refers to a plant species which shows negative impact on the germination, growth, and reproduction of another plant species seeds. Allelopathic potential has been observed in many plants, and efforts have been undertaken to employ these plants to manage weeds [47]. According to a study conducted in India [48], Cassia sericea reduces parthenium population by 52.5% and parthenium accumulation by 70%. According to a different study [49], aqueous extracts from the plants *Imperata cylindrica* (Christiaan Hendrik Persoon), *Desmastachya bipinnata* (Stapf), and *Sorghum halepense* (Christiaan Hendrik Persoon) significantly inhibited the growth and germination of *Parthenium* seedlings. *Dicanthium annulatum* (Otto Stapf), *Cenchrus pennisetiformis* (Hochst. & Steud), and *Sorghum halepense* (Christiaan Hendrik Persoon), three allelopathic grasses, both the root and shoot extracts of which inhibited germination and suppressed early seedling growth of Parthenium.

Biological Control

Biological control of Parthenium is the most efficient, ecologically safe as well as environmentally friendly method. Some of the biocontrol agents utilized so far includes; *Epiblema strenuana* (stem-galling moth), *Bucculatrix parthenica* (leaf-mining moth), *Platphalonidia mystica* (stem-boring moth), *Zygogramma bicolorata* (leaf feeding beetles), *Listronotus setosipennis* (stem-boring weevil), *Conotrachelus albocinereus* (stem-galling weevil), *Semicronyx lutulentus* (seed-feeding weevil), *Carmenta ithacae* (root-boring moth), *Puccinia abrupt* (winter rust fungus), and *Puccinia melampodii* (summer rust fungus) (Table 3).

Table 3. Release of insect biocontrol agents to eradicate *Parthenium* weed in various nations

Biological control agent	Feeding habits	Native country	Released country
Bucculatrix parthenica	Leaf mining moth	Mexico	Australia
Conotrachelus albocinereus	Stem galling weevil	Mexico	Australia
Epiblema strenuana	Stem galling moth	Mexico	Australia
Listronotus setosipennis	Stem boring weevil	Argentina and Brazil	Australia
Platphalonidia mystica	Stem boring moth	Argentina	Sri Lanka
Smicronyx lutulentus	Seed feeding weevil	Mexico	Pakistan, Australia
Stobaera concinna	Parthenium sap feeder plant hopper	Mexico	Australia
Zygogramma bicolorata	Leaf feeding beetle	Mexico	Australia, India

**Source: [31]*

Application of Pathenium hysterophorus L. in Agriculture

Parthenium hysterophorus L. commonly known as *Parthenium* weed or congress grass is an invasive weed species that is considered as major threat to agriculture and environment in various regions. However, it does have certain efficacy in agriculture. Here are some applications of *Parthenium* weed in agriculture which are enlisted below.

As a Green Manure

Parthenium in agriculture is manipulating as a green manure. Addition of *Parthenium* leaf manure during rice cultivation leads to increase in height of rice plants, yield of grains and straw, with no any appearance of weed during rice cultivation. Green leaf manure has shown remarkable increase in number of filled grains in ratoon rice crop. In the ratoon crop, *Parthenium* recorded the highest grain yield at 100 Kg N per ha level [9]. It also enhanced the growth and development of maize crop. It decreases the amount of chemical fertilizers needed for crop cultivation to about 25% [50]. It has also been noticed that it accelerate the seed germination and seedling growth of wheat plant when treated with Parthenium green manure [45]. The proper time to utilize this weed for manuring purposes is at before flowering stage to avoid spread of weed through diffusion of seeds after seed setting in the plant. Studies reported that green manure obtained from *Parthenium hysterophorus* revealed high absorption rate of nitrogen and phosphorus by maize crop [51]. Therefore, this naturally available weed can be applied for enriching soil with manure substituting the synthetic chemical fertilizers.

As a Bio-Pesticides

Bio-pesticides are a type of pesticide that can be used in combating insect resistance and environmental pollution. *Parthenium* have insecticidal activity due to the presence of phenolic compounds i.e. Partheniun. It is the foremost volatile compound of *Parthenium* having phytotoxic and insecticidal activity against different insects such as *Spodoptera litura, Callosobruchus aculatus* and *Meloidogyne incognita*, and their larvae [52]. Researcher reported that it can control aphids and the number of whiteflies in the field of potato and okra [53]. Pyrazoline adduct, saturated lactone, and propenyl derivatives of *parthenin* revealed remarkable phytotoxic and nematicidal activities [54]. A field experiment was carried out with extract from shade dried *Parthenium* leaves to *Brassica juncea*, for controlling mustard aphid, *Lipaphis erysimi*. Population density was noted three days after extract application. The extract of Parthenium shown a tremendous reduction (down to 29% of the initial infestation) in the number of *L. erysimi*, one of the most important pests of B. *juncea*, may be due to the effect of phenolic acids [55].

As a Biochar preparation

They [56] showed that parthenium weed biomass could be converted to biochar by burning at different temperatures (200-500 $^{\circ}C$) for varying periods. With increases temperature, biochar yield decreased but its stability was highest at 300-350 ° C and charging for 30-45 min. Incorporation of this biochar up to 20g/kg of soil increased the soil microbial biomass and several important soil enzymes. Biochar has been formulated successfully from *Parthenium hysterophorus* by its pyrolysis to sequester carbon for negative carbon dioxide emission. Addition of this biochar to the soil improved soil quality as evidenced by increased growth of *Zea mays*, increased basal respiration and microbial biomass carbon, increased catalase and dehydrogenase activities, and decreased soil stress and hydrolytic enzymes activities [57]. During charring, ambrosin chemical present in Parthenium, having phototoxic effect, was lost by degradation at high temperature. Adding large amounts of biochar did not show any negative effect on soil.

As a Vermicomposting

Vermicomposting of *P. hysterophorus* is possible for the management of this invasive weed through polyculture of the earthworm *E. foetida* and *E eugeniae* to obtain a value-added organic fertilizer i.e. vermicompost [58]. Vermicomposting is also a remarkable strategy for the management of *Parthenium*, it has also been enhancing its nutrients and overcome the

allelopathic capacity. In vermicomposting, phenolic components of *Parthenium* are remarkably decrease, it also decreases heavy metal percentage and toxic substances. There is significant increase in selected macronutrients (N, P, and K) and decrease in organic carbon in *Parthenium* compost, which is suitable for organic farming. Vermicomposting of *Parthenium* may be quite significant for its appropriate management because the weed may be recycled and again reach to the desired crop [59].

As a Compost

Parthenium hysterophorus L. is a good source of micro and macro-nutrients and thus can be used as alternative of compost (Table 4). *Parthenium* contains plenty of micronutrients such as Fe, Zn, Mn, and Cu and macronutrients including NPK making it two times richer than farmyard manure [60]. Organic acids released during composting help in liberation of insoluble K and increase the uptake of P and K [61]. Compost also contains abundant enzymes, vitamins, antibiotics, plant growth regulators, and large number of associated useful microorganisms including Azotobacter and phosphate solubilizers [9]. Moisture holding capacity of compost increases its utility value [62]. Amendment with other plant materials such as saw dust [63] and poultry manure also gives good quality compost, minimizing the required dose of chemical fertilizers. Compost formed has shown growth promotion in *Capsicum annuum*, *Sorghum bicolor*, *Vigna radiata* and *Triticum aestivum*, and *Arachis hypogaea*. Chances of weed emergence are reduced greatly if composting is done before flowering in plants as all seeds are not destroyed completely during the process. Allelochemicals present in the final compost lessen the chances of infestation by other weeds. Though significant reduction in allelochemicals occurs during composting but better compost is obtained from plants in pre inflorescence stage. Influence of compost has been strengthened by addition of useful bacterial species *Azotobacter chrococcum* proved by increased productivity in wheat [9]. Similarly, researcher reported, production of improved compost (millicompost), with more nutrients and less allelochemicals, upon introduction of millipede *Harpaphe haydeniana* during composting [12].

Table 4. Chemical and biological characteristics of composted *Parthenium*

Characteristics	Value
Macronutrients (%)	
Total N	1.58
Total P	0.33
Total K	1.64
Total S	0.29
Micronutrients (ppm)	
Fe	7829
Mn	304
Zn	116
Cu	66
Electrochemical	
Ph	7.8
EC (ds/m)	1
Biological (g/compost)	
Total Bacteria	13.66×10^{6}
Fungi	9.67×10^{4}
Azotobacter	2.33×10^{6}
Actinomycetes	7.67×10^{3}
Phosphate solubilizing Bacteria (PSB)	2.67×10^{6}

**Source: [9]*

As a Phyto-Remediation

Parthenium weed has ability to absorb and accumulate heavy metals from contaminated soils. It acts as a hyperaccumulator [64] which means it can help in the remediation of polluted or contaminated soil by removing toxic elements.

As a Mulching

The dense growth of *Parthenium* weed can be used as mulching materials in agriculture. It helps in conserving soil moisture, reducing weed growth, preventing erosion and maintaining stable soil temperature. *Parthenium* weed can be cut and spread as mulch around crops to provides these benefits. A field experiment was carried out using *Parthenium* weed mulching which reduced the infestation of weed by its allelopathic effect and increased the yield of soyabean under sub humid agro climatic condition [65].

Conclusion

Parthenium weed has limited practical uses due to its invasive nature and harmful effects on ecosystem, livestock and human health. However, numerous studies explored its potential uses in bioremediation, composting and as a source of biofuels or natural pesticides. Composting of *parthenium* weed is a good method for controlling the weeds. Similarly, the nutrient composition of composted *Parthenium* is higher than FYM. However, further research and careful management are necessary to mitigate its detrimental effects and explore its potential in a controlled and sustained manner.

Acknowledgements

Authors acknowledged the enormous help received from the researchers whose articles are cited and included in references of this manuscript. The authors wish to express their sincere gratitude to authors/editors/ publishers of all those articles, journals and books from where this article has been reviewed and discussed.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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