Chapter 6

# Herbicide Use and Increased Scourge of *Parthenium hysterophorus* in Vegetable Production in Trinidad and Tobago

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Additional information is available at the end of the chapter

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**Abstract**

This chapter highlights a survey of vegetable-producing areas to determine the occurrence, distribution and importance of *Parthenium hysterophorus* in Trinidad. The weed can significantly reduce crop yields and quality due to its aggressive growth habit, competitiveness and allelopathic interference. Due to its invasive capacity and allelopathic properties, *Parthenium hysterophorus* has the potential to disrupt the natural ecosystem and threaten the biodiversity. It is a difficult weed to manage, and a wide variety of methods, starting with prevention and containment, is necessary to reduce the incidence and spread of this weed. An integrated approach using cultural, physical, chemical and biological techniques is necessary to be successful. Focus is made on specific herbicides currently being used to manage this weed in vegetables. Despite the negative impact of this weed on the biodiversity, this chapter also explores the potential of the beneficial properties of *Parthenium hysterophorous* as a mechanism of management.

**Keywords:** Vegetable production, *Parthenium hysterophorus*, herbicide use, integrated approach

## 1. Introduction

*Parthenium hysterophorus* L., commonly called barley flower [1] and white-head or white-top [2] in the Caribbean, is considered a noxious weed. The plant exhibits wide ecological amplitude, and invades and competes with all types of crops, especially vegetables, with substantial losses in yield [3]. The weed has become problematic in early orchard establishment, and ornamental and greenhouse production, and also invades industrial areas including airport lay-bys.

The weed displays characteristics of profuse seeding ability, photo and thermal insensitivity, non-dormancy, high germination and growth rate and low photorespiratory rate, enormous seed bank, rapid spread and colonization and extreme adaptability in a range of habitats [4] and has spread within the last two decades to all Commonwealth Caribbean countries [2]. It is among the top ten worst weeds of the world and has been listed in the global invasive species [5]. It is now considered one of the worst weeds because of its invasiveness, potential for rapid spread, economic and environmental impacts, its high adaptability to almost any type of environmental conditions and high losses in crop yield and its direct contact with plant or plant parts [5]. As a C3 weed, *Parthenium* uses one of the two types of photosynthetic pathways, which responds to higher levels of $CO_2$ [6]. This enables it to grow more rapidly and become more competitive through increased leaf size, seed size and production, plant toxicity and pollen production [6].

The weed is predominant in the major vegetable-growing areas of Trinidad and has been shown to be effectively controlled by dinitroanilines, e.g. butralin (4- (1, 1-Dimethylethyl)-N-(1-methylpropyl)-2, 6-dinitro-benzenamine) in eggplant (*Solanum melongena* L.), and by the amide herbicide, diphenamid (N, N-Dimethyl-2, 2-diphenyl-acetamide) in cabbage (*Brassica oleracea* var. *capitata* L.) [7]. In pot studies, glufosinate ammonium was shown to give good levels of control [6, 68]. The weed has shown resistance to bipyridylium herbicides in Trinidad and other Caribbean territories and has become dominant on lands where these chemicals are used intensively [2; 6]. The plant has the ability to survive carbohydrate depletion approach to control with rapid regrowth soon after mechanical control [7, 8, 9].

*P. hysterophorous* is deemed a noxious weed in Australia [10] and India [3], where it causes severe skin allergies [11], fever and asthma, and often death among the population [12]. Although no cases of allergies or death have been reported in Trinidad [7], many farmers have, however, reported increased asthma attacks.

In the major vegetable production areas of Trinidad and Tobago, the weed was identified as early as 1956. However, it was not of any significance until the 1960s when the use of paraquat (1, 1′-dimethyl-4-4′-bipyridinium ion) and diquat (6, 7-dihydrodipyrido (1, 2- a: 2, 1-c) pyrazinedium ion) became widespread.

## 2. Biology and ecology

The genus *Parthenium* comprises 15 species, all of which are native to North and South America. *P. hysterophorus* L. has a native range in the neo-tropics from Mexico to Argentina. It is thought that the species originated in the region surrounding the Gulf of Mexico or in central South America, but is now widespread in North and South America and throughout the entire Caribbean [6].

*P. hysterophorus* L. (family *Asteraceae*) is an aggressive and noxious annual herbaceous weed that has spread from tropical America to various tropical and subtropical parts of the world. It is included in the International Union for Conservation of Nature (IUCN) Global Invasive Species database and is rated one of the most serious weeds of the 20th century. This may be attributed mainly due to its vigorous growth and high fecundity in habitats varying from hot and arid, semi-arid to humid and from low- to middle- to high-altitude regions.

*P. hysterophorus* is an annual herb with a tendency to be perennial, growing erect up to 2 m in height. It has a deeply penetrating root system with a stem that is branched and covered with hairy structures or trichomes, bearing dissected pale green leaves that are lobed and hairy. Leaves vary from 6 to 55 per plant and are irregularly dissected and bipinnate, having small hairs on both sides. Trichomes are considered storehouses for one of the toxic chemicals found in the weed known as parthenin [14].

Flower heads are creamy white, about 4 mm across, arising from the leaf fork and forming a capitula. Flowering usually occurs one month after germination with each flower containing five seeds, which are small (2 mm), wedge-shaped, brown to black in colour and bear two thin white scales. Pollen grains are produced in clusters and are pollinated by wind. A single plant can produce around 15,000 seeds or even up to 100,000 seeds. Seeds are mainly dispersed through water currents, animals and the movement of vehicles, machinery, livestock and stock feed, and to a lesser extent by wind. Seeds can remain viable for long periods and are capable of germinating as long as moisture is available [10].

The ideal conditions for growth are high moisture content, high humidity and a temperature of around 25°C. However, it can grow under a wide range of environmental conditions with soil moisture being the only limiting factor for germination and growth. It can grow under a wide range of soil pH (2.5 to 10.0) [15]. Additionally, it grows well in areas where annual rainfall is higher than 500 mm. In Trinidad, this weed grows on abandoned lands, along highways and roadsides, in drains, gardens, plantations and vegetable crop plots. It colonizes disturbed sites very aggressively, possesses allelopathic properties and has no documented natural enemies like insects or diseases.

## 3. Phytochemical analysis of *P. hysterophorus*

Phytochemical analysis of *P. hysterophorus* has revealed that plant parts such as leaves, trichomes, inflorescence and pollens contain toxins such as sesquiterpene lactones (SQL), kaempferol, p-coumaric acid and caffeic acid [16; 17]. These phytochemicals are highly concentrated in the leaves. The SQLs, namely parthenin and coronopilin as well as hymenin and ambrosin, are present in the trichomes of the leaves and stems and are responsible for causing various allergies such as dermatitis, hay fever, asthma and bronchitis. It is also responsible for the inhibition of pasture germination and growth. The allelopathic effect is due to allelochemicals such as phenolic acids and SQLs [18; 19]. Other phytotoxic compounds or allelochemcials are hysterin, flavonoids, such as quercelagetin 3,7-dimethylether, 6-hydroxyl kaempferol 3-0 arabinoglucoside, fumaric acid, p-hydroxy benzoin and vanillic acid, anisic acid, p-anisic acid, chlorogenic acid, ferulic acid, sitosterol and other alcohols [17; 20].

## 4. Incidence of *P. hysterophorus* in vegetable crops

Weed surveys in the main vegetable production areas were conducted in both dry and wet season using seven quantitative measures [21–24] *viz.* visual estimates (VE), abundance (Ap), density (Dp), percentage frequency (Fp), relative dominance (RDi), relative density (RDp) and relative frequency (RFp), which were used to compute the Importance Value Index (IVI) of *P. hysterophorus*.

$$IVI = RDi + RDp + RFp$$

The IVI allowed for comparisons between seasons and years and among crops. However, it does not necessarily represent losses in crop production caused by the weed as crops vary in their competitive ability. The level of losses due to the presence of the weed in various vegetable crops was assessed and the economic importance of the weed determined. Irrespective of the visual estimate (VE) of *P. hysterophorus* infestations in the wet season (Table 1) and dry season (Table 2), the frequency (Fp) in both seasons was greater than 50%.

| Crop | VE | Fp | IVI |
|---|---|---|---|
| Cauliflower[1] | 50 | 90 | 417.1 |
| Cauliflower[2] | 10 | 70 | 262.5 |
| Tomato[3] | 25 | 100 | 274.1 |
| Tomato[4] | 50 | 90 | 430.0 |
| Tomato[5] | 75 | 100 | 562.5 |
| Cabbage[6] | 40 | 100 | 379.9 |
| Cabbage[7] | 50 | 100 | 974.7 |
| Patchoi | 40 | 100 | 382.2 |
| Sweet Pepper | 25 | 50 | 265.4 |
| Hot Pepper | 25 | 50 | 273.5 |
| Spinach | 30 | 90 | 358.0 |
| Okra | 100 | 100 | 880.0 |
| Fallow Field | 100 | 100 | 910.0 |
| Mean | 48 | 87.5 | 489.9 |
| S.E. (+/−) | 7.85 | 5.2 | 72.17 |

2 hand weedings and no herbicide[1]; 1 hand weeding and 1 herbicide application[2]; 2 hand weedings and 1 herbicide application[3]; 3 hand weedings and no herbicides[4]; 2 hand weedings and no herbicide[5]; 2 hand weedings[6]; 1 hand weeding[7]. (VE – visual estimate; Fp – frequency; IVI – Importance Value Index)

**Table 1.** Incidence of *P. hysterophorus* in various vegetables during the wet seasons.

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| Crop | VE | Fp | IVI |
|---|---|---|---|
| Squash | 90 | 100 | 674.9 |
| Tomatoes | 75 | 100 | 836.4 |
| Cabbage | 10 | 50 | 360.0 |
| Spinach | 25 | 100 | 365.6 |
| Bodie Bean | 10 | 100 | 207.8 |
| Cauliflower | 10 | 50 | 215.8 |
| Mean | 36 | 83 | 443.4 |
| S.E. (+/−) | 2.45 | 2.07 | 6.5 |

(VE – visual estimate; Fp – frequency; IVI – Importance Value Index)

**Table 2.** Incidence of *P. hysterophorus* in various vegetables during the dry seasons.

There was no significant difference in the mean Importance Value Index (IVI) of *P. hysterophorus* for the wet (489.9) and dry (443.4) seasons. Also, variations between seasons were minimal under c = similar levels of weed management; cabbage in the wet season had an IVI of 379.9 and in the dry season 360.0; cauliflower 262.5 (wet) and 215.8 (dry) and spinach 358.0 (wet) and 365.6 (dry).

In the wet season (Table 1), there were variations within the same crops due to different levels of weed management, e.g. cauliflower with two hand weedings and no herbicides had a higher IVI (417.1) than a crop of similar age with treatments of one hand weeding and pre-emergence herbicide (262.5); similar trends for tomato and cabbage were observed at the same growth stage, but under different levels of weed management. The application of pre-emergence herbicides reduced the IVI for *P. hysterophorus* by 40 to 50% over the treatment of two hand weedings and no pre-emergent herbicide.

Crops with shrub-type architecture, e.g. hot and sweet peppers, had no competitive plant height advantage over leafy vegetable crops under similar levels of weed management. Both types of crops had an IVI below the mean value recorded for the wet season.

In both the wet and dry seasons, the IVI of leafy vegetable crops was lower than the mean IVI. This is due mainly to the close spacing used at planting and the intensity and thoroughness of the hand-weeding operations practised by the farmers.

A field prepared for planting, but subsequently abandoned, showed an IVI of 910.0 (wet season) and gave an indication of the weed's dominance. The high IVI (880.0) for okra in the wet season was due to the wide spacing as well as the absence of any weed management operations. The *P. hysterophorus* seedlings were the same height as the crop (15–20 cm).

In the fields surveyed, adequate irrigation facilities were available to all farmers during the dry season. Adequate water supply was the main factor determining the lack of shift in *Parthenium* populations between seasons.

### 4.1. Incidence of *P. hysterophorus* during different seasons

There was no significant difference between visual estimates (VE) for *Parthenium* in the wet and dry seasons in the Aranguez district (Table 3) or for the major vegetable-growing areas of Trinidad (Table 4). Visual estimates in the range of 25 to 60% can be considered as moderate infestations [23].

There were no changes in abundance (Ap) between seasons. *Cyperus rotundus* (L.) #CYPRO, 'the world's worst weed' [22], is a serious weed in vegetable crops in India with an abundance of 2.7–9.6 [23]. The Ap for *P. hysterophorus* fell well within this range in both seasons.

Wet season density (Dp) in Aranguez (5.24) did not differ significantly from that of other vegetable-growing areas (5.6). The Dp for *Parthenium* emphasizes predominance of this weed in both seasons. Frequency (Fp) was over 80% in both seasons. Weeds occurring in the frequency levels 75–100 are serious weeds that require some level of control [23].

The IVI indicated that there were no shifts in the *P. hysterophorus* population between seasons (Table 3). Also, there was no significant difference between IVIs for wet season in the major vegetable-growing areas of Trinidad (Table 4). These findings indicate that *P. hysterophorus* is a serious problem in all the major vegetable-growing areas in Trinidad, especially where the IVI is even greater for the dry season.

## 5. Crop loss assessment

*Parthenium* has caused significant losses to the vegetable production in both seasons in almost all Caribbean islands. Most farmers reported that the weed had no effect on the yield of solanaceous crops, if it was effectively controlled while the crop was in the early vegetative stage or prior to flower initiation. However, if weed control was poor, they observed yield reductions of 25 to 30% for the wet season and 20 to 25% for the dry season.

Farmers found that the presence of the weed within or around the field can result in a reduction of the market yield of cabbage and cauliflower. It was observed that damage to marketable curds of cauliflower caused by the larvae of *Plutella xylostella* (L.) (Lepidoptera: Yponomentidae) varied between 75 and 100%. Apparently, the adult pest found *P. hysterophorus* to be a suitable 'resting site'. On nursery beds, failure to remove *P. hysterophorus* seedlings at 3- to 5-day intervals on a regular schedule resulted in a 75 to 100% loss of healthy and vigorous vegetable transplants.

| Parameter | Season | |
|---|---|---|
| | Wet (October–November) | Dry (February–April) |
| VE | 47.69 | 36.66 |
| Ap | 5.77 | 5.25 |

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| Parameter | Season | |
|---|---|---|
| | Wet (October–November) | Dry (February–April) |
| Dp | 5.24 | 3.99 |
| Fp | 87.69 | 83.3 |
| RDi | 58.88 | 56.8 |
| RDp | 415.61 | 340.0 |
| F4RFp | 66.31 | 61.36 |
| IVI | 489.99 | 443.43 |

(VE – visual estimate; Ap – abundance; Dp – density; Fp – frequency; RDi – relative dominance; RDp – relative density; F4RFp – relative frequency; IVI – Importance Value Index)

**Table 3.** Incidence of *P. hysterophorous* during wet and dry seasons for Aranguez, Trinidad.

| Parameter | Season | | | |
|---|---|---|---|---|
| | Wet (October–December) | | Dry (February–April) | |
| | Mean | S.E. | Mean | S.E. |
| VE | 43.87 | 1.78 | 35.58 | 1.23 |
| Ap | 7.46 | 1.11 | 15.50 | 1.67 |
| Dp | 5.6 | 0.66 | 15.04 | 1.68 |
| Fp | 65.32 | 14.96 | 88.4 | 1.15 |
| RDi | 53.02 | 9.04 | 44.4 | 1.81 |
| RDp | 412.0 | 37.46 | 284.73 | 4.51 |
| F4RFp | 58.43 | 5.9 | 59.48 | 1.03 |
| IVI | 491.19 | 37.92 | 378.5 | 4.76 |

(VE – visual estimate; Ap – abundance; Dp – density; Fp – frequency; RDi – relative dominance; RDp – relative density; F4RFp – relative frequency; IVI – Importance Value Index)

**Table 4.** Incidence of *P. hysterophorous* during wet and dry seasons for the major vegetable-growing areas of Trinidad

## 6. Competitive effect of *Parthenium* on selected crops

A high density of *P. hysterophorus* resulted in the total loss of one tomato crop (cv. Calypso), where failure to remove the weed before flower initiation stage or weed had a V.E. of 100% and IVI > 800. *P. hysterophorus* was the only weed present in the field at the time of the survey and was 75 to 100 cm tall and flowering profusely. The farmer had applied paraquat at the pre-plant stage of the crop.

Failure to plant lettuce and celery on *weed*-free plots can result in a 50 to 60% mortality of the transplants. When early hand weeding at 10- to 14-day intervals was not done, mortality in excess of 75% was observed.

No significant reduction in yield was reported by farmers for vining crops, e.g. pumpkin, squash, or cucumber and staked bodibean which withstood the weed competition. However, early hand weeding was essential for bush-type cowpea bodi to prevent yield reductions by 25 to 50%.

Studies conducted on soil amended with unburnt and burnt residues of *P. hysterophorous* revealed phytotoxic effects on test crops, which was attributed to the presence of phenolics [17]. Parthenin has also been reported as a germination and radicle growth inhibitor in several plant varieties and it enters the soil through decomposing leaf litter [17; 19].

The reduction in crop yield and quality is probably due to the competitive ability and allelopathic potential of *Parthenium*. It is noted that although the weed is a $C_3$ plant, low carbon dioxide compensation concentration and photorespiratory rate were observed [24]. This was attributed to the activity of PEP carboxylase. The weed is described as having a lush growth and a high survival potential. It has been reported that *P. hysterophorous* produced allelopathic compounds that influenced pollen germination and tube growth in solanaceous and bean crops, where yield reductions of 27 to 73% were observed [25; 26].

## 7. Weed economic assessment

An economic analysis was performed on *P. hysterophorous* involving a cost–benefit analysis, where several variables were inputted onto a toolkit developed by Landcare Research, New Zealand [27]. The toolkit was developed in an attempt to assign monetary values, where possible, to specific variables in order to conduct cost–benefit analyses on different management options for the control of the weed using four management options *viz*. 'Do Nothing' (DN), 'Current Management' (CM), 'Integrated Management Approach' (IMA) and 'Exploitation of Benefits' (EB). The outcome of the toolkit ranked the management options in terms of Net Present Value (NPV), Benefit-Cost Ratio (BCR) and Cost-Effectiveness (CE). The analysis was done on four proposed management options in order to determine the best suitable one for the control of this invasive weed (Table 5).

Over time, the DN option had the most rapid increase in population, followed by the EB and then by CM. The IMA displayed the slowest increase in the invasive population during that time.

Quantifying the benefits for each management option proposed for the control of *P. hysterophorous* (white-top) took into consideration the value per unit for several categories for benefits and costs of each management option. Benefits are described as the monetary or non-monetary gain received because of an action taken or a decision made. The benefits included agricultural and research crops, human health and biodiversity. The human health variable accounts for visits to the doctor for conditions related to the effect of *Parthenium* such as skin inflammation, eczema, asthma, allergic rhinitis, allergic bronchitis and burning and blistering of the eyes (Table 6).

| Management Option | Description |
|---|---|
| Do Nothing (DN) | · no weed control<br>· allow weed to grow and spread<br>· population density (6% of the carrying capacity) |
| Current Management (CM) | · maintain the *status quo* of the weed population<br>· chemical control of the weeds (paraquat and glyphosate post-emergence) |
| Integrated Management Approach (IMA) | · chemical control<br>· manual<br>· mechanical control methods (hoe and plough, cutting and hand weeding or uprooting of weeds) |
| Exploitation of Benefits (EB) | · determine benefits – medicinal value, enhancement of crop productivity<br>· bioremediation (heavy metals)<br>· dyes and handicraft production |

**Table 5.** Description of the proposed management options for the control of *Parthenium hysterophorus*.

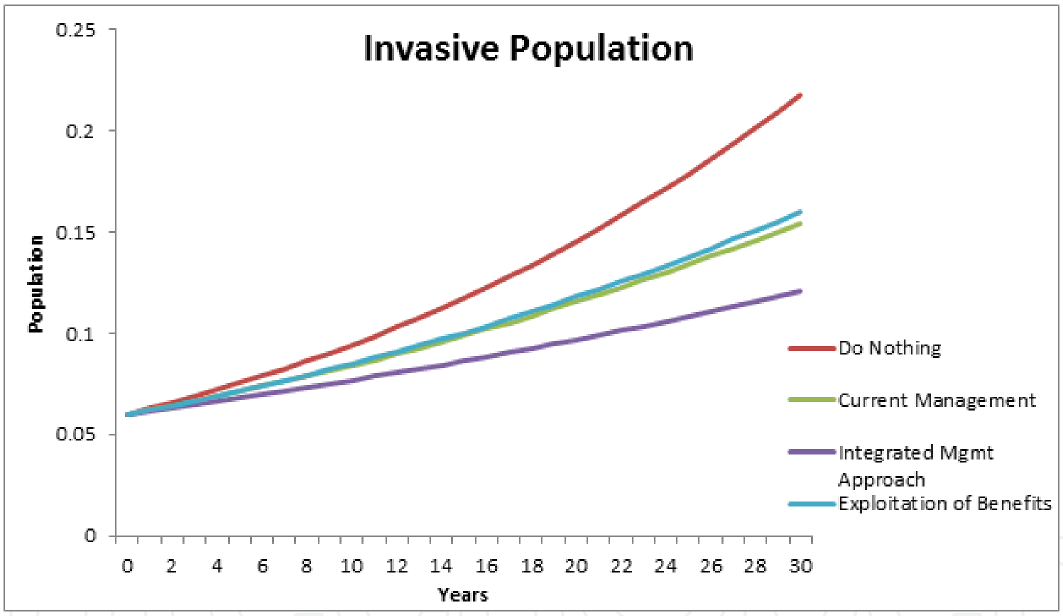


**Figure 1.** The trend of the invasive population for each management option.

The costs associated were different for each management option and included labour and capital costs (tool, safety gear and machinery). Herbicide cost included the purchase of chemicals, based on market prices, and machine service cost included the servicing of the whacker on a per-service basis (Table 6).

The Net Present Value (NPV) represents the overall net benefit of a project to society. The Benefit Cost Ratio (BCR) is the ratio of the NPV of benefits associated with an activity, relative to the NPV of the costs of the same activity. The discounted future costs and benefits to present value used a discount rate of 5% and the project length is assumed to be 10 years. Cost-effective

(CE) analysis is an approach often used to rank intervention options when monetary benefits cannot be derived from key categories in a given project. CE is the NPV of the monetized costs of the intervention divided by the effectiveness of the project option measured in physical units. The smaller the CE ratio, the greater is the cost-effectiveness of an intervention.

| | | | | Units For Initial Period | | | |
|---|---|---|---|---|---|---|---|
| | **Category** | **Units** | **Unit Value ($/units)** | **Do Nothing** | **Current Management** | **Integrated Mgmt Approach** | **Exploitation of Benefits** |
| **Benefits** | Agricultural Crops | $/kg | 10.00 | 335 | 335 | 335 | 335 |
| | Research Crops | $/kg | 25 | 8,087 | 8,087 | 8,087 | 8,087 |
| | Human Health | $/report | 200 | 24 | 24 | 24 | 24 |
| | Biodiversity | $/m$^3$ | 50 | 5,280 | 5,280 | 5,280 | 5,280 |
| **Costs** | Labour | $/day | 200 | 0 | 36 | 72 | 270 |
| | Initial Capital Cost | $/unit | 1 | 0 | 1,775 | 8,670 | 9,000 |
| | Herbicides | $/litre | 20 | 0 | 16 | 16 | 0 |
| | Machine Service | $/service | 200 | 0 | 0 | 3 | 0 |
| | Research | $/hour | 30 | 0 | 0 | 0 | 600 |

**Table 6.** Costs and benefits for each management option.

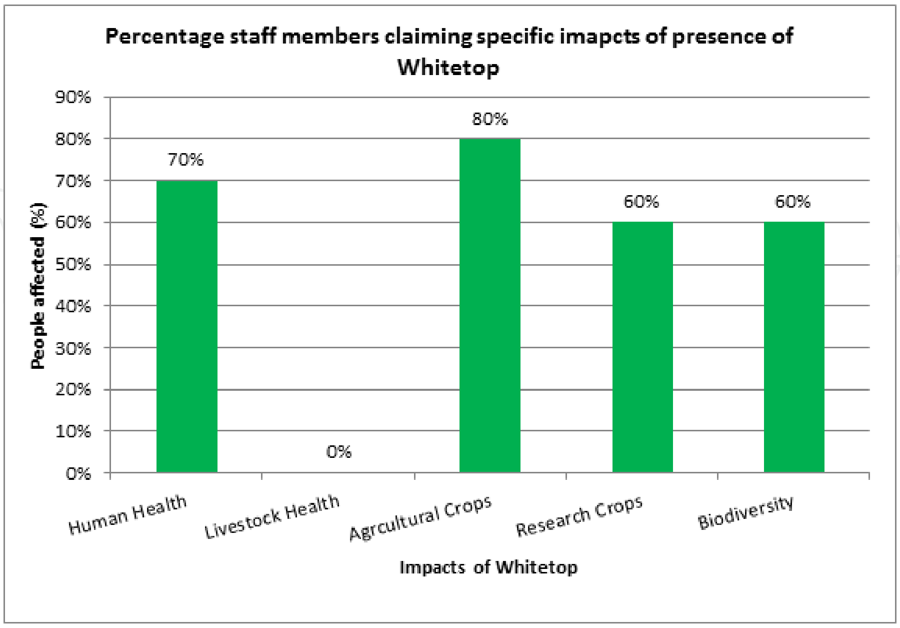


**Figure 2.** Percentage of Waterloo Research Centre (WRC) staff affected by the impact of *Parthenium* (white-top).

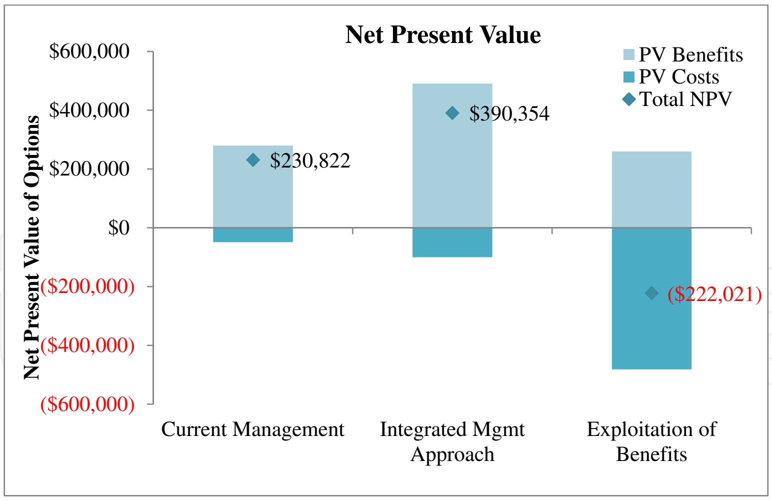


**Figure 3.** Net Present Value for the management options for the control of *Parthenium*.

| Scenario | Total NPV | NPV Rank | BC Ratio | BCR Rank | CE ($/Metric) | CE Rank |
|---|---|---|---|---|---|---|
| Do Nothing | $0 | 3 | 1.0 | 3 | 0 | - |
| Current Management | $230,822 | 2 | 5.7 | 1 | −1,218 | 1 |
| Integrated Management Approach | $390,354 | 1 | 4.9 | 2 | −1,668 | 2 |
| Exploitation of Benefits | −$222,021 | 4 | 0.5 | 4 | −24,079 | 3 |

(NPV – Net Present Value; BCR – Benefit Cost Ratio; CE – Cost-Effectiveness)

**Table 7.** Summary of the Net Present Value, Cost Benefit Ratio and Cost-Effectiveness rankings for the four management options for the control of *Parthenium*.

The cost–benefit analysis for the four different management options disclosed that the CM option yielded the greatest benefit for each dollar of costs and thus was most efficient on funds (Figure 3). The CM option also ranked first in cost-effectiveness being the option with the least cost per physical unit of benefit (Table 6 and 7). The 'Integrated Management Approach' (IMA) ranked first in NPV. Therefore, this option yielded the most benefit to society in terms of managing the spread of *P. hysterophorous*, without considering the costs associated. Both approaches appear to be better than the DN option. The EB option, however, proved to require the largest investment, to yield the least benefits per dollar spent and be the least cost-effective management option compared to the other options.

## 8. Management of *Parthenium hysterophorus*

Because of its negative impact on the natural and agroecosystem, it is necessary to manage *P. hysterophorus* before it sets seed and continues to spread. There are several methods documented for managing this weed. These include preventative, mechanical, cultural, chemical and biological control methods and even includes potential management by proper utilization of the positive attributes of *P. hysterophorus*. However, effective management of *P. hysterophorus* requires an integrated approach. The following outlines some of the successful and potential best management practices used throughout the Caribbean and the rest of the world.

### 8.1. Prevention and containment

The best methods of weed management is prevention and containment. *P. hysterophorus* usually completes its life cycle in 4 weeks; so, it is important to manage the weed before the plant flowers or sets seed and when infestations are small – do not allow the weed to be established. The seeds of *P. hysterophorus* can be spread through flowing water or can be blown by the wind, which further makes prevention of spread difficult. The seed can also stay for years in the soil seed bank and the continuous removal of the weed is required until the seed bank is depleted.

Difficulties in the preventive method could be further exacerbated through the easy spread of seeds through vehicles, machinery, the trading and transport of goods, animals grazing on infested fields and the transportation of sand, soil and compost from infested areas to uninfested areas. These are potential risks for further spread and hence should be controlled through an adoption of quarantine measures involving the adoption of inspection and washdown procedures.

### 8.2. Mechanical control

Manual removal of *P. hysterophorus* by hand weeding before flowering and seed setting is the most effective method, but it is not necessarily practical or economical particularly where there are large infestations. This method, however, may pose a health hazard from allergic reactions and a danger that mature seeds will drop and increase the area of infestation.

Other mechanical treatments, such as grading, mowing, slashing and ploughing, are also considered inappropriate since they may also promote seed spread as well as rapid regeneration from lateral shoots close to the ground [28; 29]. Ploughing the weed before the plants reach the flowering stage may be effective. Although burning is not promoted as a control strategy, it has been used to control the first flush of emergent weeds at the beginning of the rains in Australia but is only considered a short-term control measure [30]. Burning has been shown to create open niches in the landscape, into which larger number of *Parthenium* seeds are able to germinate in the absence of vegetation.

### 8.3. Cultural control

This is considered one of the most cost-effective methods, but it is practical only on small farms or where it is part of an integrated weed management strategy. Farmers have used almost every conceivable practice to reduce the infestation on their holding such as hand weeding, brush cutting and even digging out the weed. In all cases, there is a rapid regrowth from both stumps or re-emergence from the existing seed banks.

Mulching using plant stubble is often used for general weed control, but this is on a limited scale. However, this has not proven to be effective in areas where the seed bank is predominantly *P. hysterophorous* and the soil is moist. This condition stimulates germination and growth through the layer of mulch. Black plastic sheets may also encourage weed germination as the heat produced and the moisture conserved by plastic mulches favour weed seeds germination. And, as a result, weed control is more effective in the solarized plot than in the non-solarized plot. Mulch can not only control weeds but can also affect seedling growth adversely as in the case of onions [31]. Grass clipping mulch has been found to boost the growth of the other broadleaf weeds.

The use of pre-emergence herbicides (pendimethalin, oxyfluorfen or alachlor) and a post-emergence herbicide (propaquizafop) in combination with cultural practices such as hand weeding or black polythene mulch has been shown to be effective. The pre-emergent application of oxyfluorfen followed by soil covering with black polythene mulch recorded the least weed count, dry weight of weeds, higher weed control efficiency and favoured the head initiation, early yield, fresh weight and dry weight of heads and highest economic yield, which was at par with treatment with pendimethalin followed by black polythene mulch [30].

On farms where the soil seed bank was dominated by *P. hysterophorus*, it was observed that mulching coupled with manual weeding during land preparation or ploughing would suppress growth and development of weeds including *P. hysterophorus* and enhance yield of tomato [31].

Other cultural methods include the use of competitive cover crops (*Mucuna pruriens*, *Arachis pintoi* and *Desmodium hysterophorus*), self-perpetuating competitive plants such as *Cornus sericea*, *Tagetus erecta* (marigold) or smother crops (*Vigna unguiculata*).

### 8.4. Chemical control

It is important that *P. hysterophorous* be sprayed early before flowering and seed set. Farmers should scout their fields regularly to check for escaped or untreated isolated infestation. Vegetable farmers prefer a rapid knock-down of weeds before they plant or do cultural control and work towards weed-free plots. Repeated spraying may be required even within a single growing season to prevent further seed production. In this regard, their approach is to use a single herbicide with a broad-spectrum application with the intention to rid the field of grasses, broadleaves and sedges. The most commonly used herbicide over the last 70 years in the Caribbean has been paraquat and diquat. These herbicides work very well and usually give very quick control of most weeds, but sometimes cause severe drift damage. It has been accepted that the overuse of this chemical over the years, in addition to the *P. hysterophorous* metabolic pathways [4; 5; 6], has developed resistance to paraquat and has established the predominance of the weed.

Several herbicides (Table 8) have been used by farmers for control of *P. hysterophorous* based on research by the University of the West Indies, Trinidad and the Ministry of Agriculture, Trinidad [5; 6]. The two most promising herbicides bromoxynil and glufosinate ammonium were applied post-emergence in solanaceous vegetable crops. Both butralin and diphenamid gave good control in the seedling stages as pre-emergence, but these are not very popular amongst farmers. There has been very good control of weeds and *P. hysterophorous* particularly in direct-seeded onions, when oxydiazon and Ioxynil + 2,4-D ester were applied pre-emergence, with no phytotoxicity.

Agricultural Extension Workers have reported for several years the inability of both glyphosate and gramoxone to control *P. hysterophorous*. This apparent resistance, coupled with the high reproductive capacity of the weed and its wide-ecological amplitude, has given rise to the increased scourge of *P. hysterophorous* in vegetable crops in the Caribbean. In other parts of the world, a similar response is obtained with respect to the resistance by both herbicides [Table 9].

| Herbicide | Trade Name | Time of Application | Weed Control Efficiency Rating |
|---|---|---|---|
| Bromoxynil | Buctril | Post-Em | 5 |
| Glufosinate ammonium | Basta | Post-Em | 5 |
| Oxadiazon | Ronstar | Pre-Em | 4 |
| Ioxynil + 2,4-D ester | Actril D | Pre-Em | 4 |
| Paraquat | Gramoxone | Post-Em | 0 |
| Glyphosate | Round-up | Post-Em | 0 |
| Alachlor | Pilarzo | Post-Em | 5 |
| Dinitroaniline | Butralin | Post-Em | 5 |
| Diphenamid | Enide | Pre-Em | 4 |

(Post-Em – post-emergent; Pre-Em – pre-emergent)

**Table 8.** Herbicides used by farmers for the control of *Parthenium hysterophorous* in vegetable crops.

| Herbicide | Time of Application | Weed Control Efficiency Rating | Reference |
|---|---|---|---|
| Oxyfluorfen + Quizalofop ethyl | Pre-Em | 4 | [32] |
| Atrazine + Pendimethalin | Pre-Em | 4 | |
| Pendimethalin fb 2,4-D sodium salt | Pre-Em | 4 | [33] |
| Metsulfuron methyl | Pre-Em | 4 | |
| Oxyfluorfen | Pre-Em | 3 | [34] |
| Glyphosate + Isoproturon | Post-Em | 5 | [35] |
| Chwastox + Buctril | Post-Em | 4 | [35] |
| Imazapyr 6.86 | Post-Em | 3 | |

| Herbicide | Time of Application | Weed Control Efficiency Rating | Reference |
|---|---|---|---|
| Metsulfuron-methyl 36 g a.i. ha-1 3.93 | Pre-Em | 3 | |
| Metsulfuron-methyl 4.6 g a.i. ha-1 2.59 | Post-Em | 3 | |
| Atrazine 2.54 | Post-Em | 2 | |
| Imazapic 240 g a.i. ha-1 2.44 | Post-Em | 22 | |
| Metsulfuron-methyl 36 g a.i. ha-1 1.79 | Post-Em | 2 | |
| Imazapic 1.59 | Post-Em | 2 | |
| 2,4-D (D.M.A. salt) + Dicamba (D.M.A. salt) | Post-Em | 4 | [24] |
| Atrazine + Dicamba | Post-Em | 5 | |
| Atrazine + 2,4-D (D.M.A. salt) | Post-Em | 5 | |
| Atrazine + 2,4-D (Na salt) | Post-Em | 5 | |
| Pretilachlor | Pre-Em | 3 | [33; 34] |
| Oxyfluorfen + 2,4-D | Pre-Em | 3 | |
| Oxadiazon | Pre-Em | 4 | |
| Thiobencarb + 2,4-D | Pre-Em | 4 | |
| Oxyfluorfen | Pre-Em | 4 | |
| Anilofos + 2,4-D | Post-Em | 4 | |
| Butachlor + 2,4-D | Post-Em | 5 | |
| Atrazine | Post-Em | 33 | [30; 32; 33] |
| Metribuzin | Post-Em | 3 | |
| Chlorimuron | Post-Em | 3 | |
| Glufosinate ammonium | Post-Em | 5 | |
| Paraquat | Post-Em | 0 | |
| Glyphosate | Post-Em | 0 | |

**Table 9.** Commonly used herbicides in the control of *Parthenium* in vegetable production in other regions.

### 8.5. Biological control

There are no current biocontrol strategies for the management of *P. hysterophorus* reported in the Caribbean. Biocontrol of *P. hysterophorus* is reported as the most cost-effective, environmentally friendly and ecologically viable method of control. While several organisms exist locally, there is no observable damage to either seedlings or mature plants. The major fungi and insects, which are reported as potential candidates for biological control of this weed, include leaf rust fungus *Puccinia xanthii* Schwein. var. *parthenii-hysterophorae* Seier, H.C. Evans

& Á. Romero (Pucciniaceae), leaf-feeding beetle *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae) and stem-boring weevil *Listronotus setosipennis* Hustache (Coleoptera: Curculionidae) [36].

Other biocontrol agents, which have been reported to show some level of control in Ethiopia, are the stem-galling moth *Epiblema strenuana* (Walker) (Lepidoptera: Tortricidae) and the seed-feeding weevil *Smicronyx lutulentus* Dietz (Coleoptera: Curculionidae) [36; 37]. These have not yet positively been identified but experience elsewhere has demonstrated that a suite of agents is required to achieve effective biological control of *Parthenium* under different environmental conditions and in different regions.

Pathogens such as *Fusarium pallidoroseum, Puccinia melampodii* and *Oidium parthenii* have also been reported as showing good potential as biocontrol agents [38; 39]. *Alternaria alternate, Puccinia abrupt* var. partheniicola (parthenium rust), *P. xanthii* and other rusts are currently being evaluated as potential mycoherbicides for the control of *Parthenium*.

The weed is not grazed by animals or other wild life.

## 9. Allelopathic plant species with potential in controlling *P. hysterophorus*

There are several studies reporting the use of crude extracts, plant residues and purified compounds of allelopathic plants (crops, grasses, broadleaf weeds and trees) for controlling the germination, growth and physiology of *P. hysterophorus* [40–56]. Table 10 outlines the reported plants.

| Name of Plant | Plant Part Studied | Allelochemicals Present | Suppression/Inhibitory Effect(s) | References |
|---|---|---|---|---|
| **A. Crop plants** | | | | |
| *Oryza sativa* | Root and shoot | Momilactones A and B, phenolic acids, 5,7,4′-trihydroxy-3′,5″-dimethoxyflavone and 3-isoprophyl-5-acetoxy cyclohexene-2-one-1 | Reduced germination and root/shoot growth | [40–42] |
| *Sorghum bicolor* | Root and shoot | Benzoic, p-hydroxy benzoic, vanillic, m-coumaric, p-coumaric, gallic, caffeic, ferulic and chlorogenic acids | Reduced germination and root/shoot growth | [40; 41] |
| *Helianthus annuus* | Root and leaves | Phenols and terpenoides | Reduced germination and root growth | [40; 43; 44] |

| Name of Plant | Plant Part Studied | Allelochemicals Present | Suppression/Inhibitory Effect(s) | References |
|---|---|---|---|---|
| **B. Grasses** | | | | |
| *Imperata cylindrica* | Aqueous extracts of all parts, especially root and shoot extracts | Caffeic, ferulic, p-hydroxybenzoic, p-coumaric, vanillic, chlorogenic and syringic acids | Reduced germination and root/shoot growth | [45; 46] |
| **C. Broadleaf plants** | | | | |
| *Amaranthus spinosus* *Amaranthus viridis* | Leaves | | Maximum inhibition of biological activities including seed germination and multiplication | [47] |
| *Cassia occidentalis* | Shoot and root | | Reduced germination, shoot-cut bioassay, seedling bioassay and chloropyll | |
| *Cassia tora* | Leaves | | Reduced vegetative and reproductive growth | [48] |
| *Cannabis sativa* | Leaves | | Reduced germination, biomass, protein and pigment content | [49] |
| *Withania somnifera* | Leaves and roots | Withaferin A | Reduced germination and plant growth | [50; 51] |
| **D. Trees** | | | | |
| *Eucalyptus citriodora* | Leaves | Phenolic acids, tannins, flavonides and eucalypt oils | Reduced germination | [52; 53] |
| *Eucalyptus globulus* | Leaves | Monoterpenes (cineole, citronellol, citronellal and linalool) | Reduced germination and chlorophyll content | [54] |
| *Azadirachta indica* | Leaves | Gallic, benzoic, p-coumaric, p-hydroxybenzoic vanillic, and trans-cinamic acid | Reduced germination and dry biomass | [55] |

(Adapted from [56; 57])

**Table 10.** Phytotoxic effects of allelopathic plants on *Parthenium*.

## 10. Potential for management by utilization

There are reports of innovative uses of *P. hysterophorus.* It is documented as having insecticidal, nematicidal, fungicidal and bioherbicidal (biopesticide) and growth regulator properties [17; 58]. Furthermore, studies have shown that pre- and post-emergent applications of *P. hysterophorous* extracts at high concentrations were effective in significantly decreasing the seed germination and the growth of *Eragrostis* sp. [59]. The plant is also a rich source of nitrogen, phosphorus, potassium, calcium, magnesium and chlorophyll, which makes it suitable for composting. Reports indicate that it aids in moisture conservation, which is good for enhanced root penetration and crop growth [57; 60]. It is also used as a green manure for maize and mung bean [61].

More recently, it has been found to confer many health benefits such as a remedy for skin inflammation, rheumatic pain, diarrhoea, urinary tract infections, dysentery, malaria and neuralgia [17]. Extracts from the flowers have shown significant antitumor activity [62; 63]. It has been used as a remedy for inflammation, eczema, skin rashes, herpes, rheumatic pain, cold, heart problems and gynaecological ailments [17]. It has prospects in nanomedicine to be used in applications of eco-friendly nanoparticles in bactericidal, wound healing and other medical and electronic applications [17]. It has the potential to remove heavy metals such as nickel, cadmium, cresol and dyes from the environment, eradication of aquatic weeds such as salvinia (*Salivinia molesta* Mitchell), water lettuce (*Pistia stratiotes*) and water hyacinth (*Eichhornia crassipes*) and seed germination of lovegrass (Eragrostis) [17]. It can also be used as a substrate for commercial enzyme production [64], as additives in cattle manure for biogas production [65], as a flea repellent for dogs and as a source of potash, oxalic acids and high-quality protein (HQP) in animal feed [66; 67].

## 11. Conclusion

Due to its invasive capacity and allelopathicproperties, *P. hysterophorous* has the potential to disrupt the natural ecosystem and threaten the biodiversity. From an earlier survey, the authors concluded that under systems of intensive vegetable production and where the use of paraquat and glyphosate are widespread, the weed has shown the ability to survive herbicide treatments, except at the seedling stage, regardless of the season and crop or management practices [68]. In addition, biological and cultural control were insignificant in reducing *Parthenium* populations. The weed can significantly reduce crop yield and quality due to its aggressive growth habit, competitiveness and allelopathic interference. It is a difficult weed to manage, and a wide variety of methods, starting with prevention and containment, are necessary to reduce the incidence and spread of this weed. An integrated approach using cultural, physical, chemical and biological approaches are necessary for the successful management of this weed. Integrated approaches following different methods coupled with proper land management and best management practices can effectively

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control this weed. Despite the negative impact of this weed on the biodiversity, there is potential in exploring its beneficial properties as a mechanism of management.

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