Ethiop. J. Agric. Sci. 20:128-150 (2010)

Parthenium Weed (*Parthenium hysterophorus* L.) Research in Ethiopia: Impacts on Food Production, Plant Biodiversity and Human Health

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Abstract

The highly competitive, adaptable and allergenic weed ***Parthenium hysterophorus*** *(Compositae) is an invasive annual weed believed to be introduced to Ethiopia in 1970s. Field surveys, plant biodiversity impacts, and analysis of secondary plant compounds in* ***P. hysterophorus*** *and its possible impact on human health have been studied in Ethiopia since 1998. The weed has invaded a variety of habitats ranging from roadsides to grasslands and crop fields. Infestations were found to be greater than 20 plants per* m^2 *and yield losses in sorghum reached 46-97% depending on the location and year. In grasslands dominated by parthenium, native plant species composition and abundance was found to be low. Manual control of parthenium by farmers resulted in the development of skin allergies, itching, fever, and asthma. These reactions could be attributed to the presence of secondary plant compounds (parthenin, chlorogenic acid, isocholorogenic acid, vanilic acid and caffeic acid) which were found in parthenium with significant variation in their concentrations among the different plant parts, dependent on plant locality, moisture content and plant size. The social cost of parthenium in Ethiopia was measured by Disability Adjusted Life Years and its equivalence in terms of monetary value was estimated at US$ 2,535,887 - 4,365,057. More resources have to be invested to tackle the parthenium problem as the estimated loss is disproportionate to the cost of investment in parthenium research and development activities.*

Introduction

Parthenium hysterophorus L. (hereafter referred to as parthenium) is an invasive herbaceous weed believed to be originated in tropical America, now occurs widely in India, Australia, and east and South Africa. It is a procumbent, diffused leafy herb, 0.5 - 2 m tall, bearing alternate, pinnatified leaves, belonging to the family Compositae.

In Ethiopia, it is believed to have been introduced in 1970s. There is no concrete argument so far with regard to the question of how and when it gets introduced into the country. However, there are two speculations, which indicate that the weed was introduced through wheat seed donated for relief from abroad and that the weed was introduced during the Ethio-Somali war in 1976/77 (Taye, 2002).

Parthenium is one of the worst weeds in countries were it has been introduced. It can cause severe crop yield losses. In India, a yield reduction of 40% in agricultural crops (Khosla and Sobti 1981) and 90% reduction in forage production in grass lands (Nath 1988) were reported. In eastern Ethiopia, Tamado (2001) reported that *Parthenium* is the second most frequent weed (54 %) after *Digitaria abyssinica* (63%) and that sorghum grain yield was reduced from 40 - 97 % depending on the year and the location. Other than direct competition with crops, it poses allelopathic effect on different crops and other plants (Evans 1997) and health hazard to humans (Kololgi et al. 1997) and animals (Chippendale and Panneta 1994). In the Caribbean, *Parthenium* is the fourth most serious weed (Hammerton, 1981) while in Kenya, it was reported as one of the important weed in coffee plantations (Njorge, 1991). It is a human health hazard, causing allergic rhinitis and contact dermatitis that is often associated with secondary plant metabolites found in parthenium such as parthenin, a sesquiterpene lactone (Verma et al 2002).

After its introduction into Ethiopia, it developed to an aggressive weed and spread over the whole country within a few years. Reasons for this fast spreading are the high germination capacity, a high seed production, an easy distribution mechanism, high survival rate and a good adaptation to a wide range of environmental factors (Brahmam 2003, Kohli and Rani 1994). Other reports based this fact to the allelopathic properties of parthenium (Kanchan 1975, Patil and Hegde 1988, Picman and Picman 1984).

Considering its invasion in Ethiopia, studies were conducted through cooperation made between the Ethiopian Institute of Agricultural Research and the Humboldt University of Berlin as MSc and PhD studies. The whole aim of this project cooperation was to avail basic information and devise management technologies against Parthenium. This paper aims to reveal the impacts of parthenium on food production, human health, biodiversity and the social cost due to parthenium in Ethiopia.

Materials and Methods

Field Surveys

Exploratory field surveys were conducted in major *Parthenium* infested areas of Ethiopia: the central farm land and Rift Valley, South and North Wollo, West and East Hararghe, and East Wollega. Surveys were conducted in different habitats: cultivated lands, vacant lands and in grasslands to draw exhaustive inventory of *Parthenium* infestation.

Assessment of parthenium infestation was made at a regular interval (5 – 10 km) along the main roadsides after crop harvest and before harvest. Fields were selected regardless of the size and on the basis of accessibility to the main road. The infestation of *Parthenium* was estimated by counting the number of plants per m^2 following the methods used by Yohannes and Taye (1999) with some modifications. Five counts were taken per field and 3 – 5 fields were assessed per location and then converted into the scale of *Parthenium* infestation developed as 0 – 5: where 0 = no *Parthenium* plants observed in the field, 1 = beginning or presence of *Parthenium* infestation only on roadsides, 2 = presence of *Parthenium* infestation on roadsides and non-crop lands (grass land, gardens, waste land, etc.), 3 = infestation on roadsides, non-agricultural lands, and beginning infestation in crop fields, 4 = infestation in crop fields up to 20 plants per m^2, 5 = severe infestation of *Parthenium* (>20 plants per m^2).

Climatic matching of *Parthenium* infestation in Ethiopia and other countries

Climatic matching of Parthenium infestation in Ethiopia, Australia and America was conducted using climatic data. Locations were clustered using minimum temperature, maximum temperature, their respective standard deviations, average rain fall, and altitude. Multivariate method of clustering is used to group locations based on temperature, rainfall and altitude to clarify the pattern of Parthenium infestation (SAS Institute, 2000).

Impacts on Herbaceous Plant Biodiversity

Impact of parthenium on herbaceous plant biodiversity was conducted on grassland habitat in Fentale District in the Eastern Shewa Zone of the Oromiya Regional State during September to October 2006. Cover method was used in order to determine the impacts following the procedures used by Wittenberg (2004). A fairly extensive (1 Km^2) and uniform study area in terms of slope, drainage aspect and soil type and had variable parthenium densities ranging from completely infested to lightly infested plots were used. In the study area, ten parallel transects, each containing 10 evenly spaced 1 x 1 m sample areas (quadrants), were established. Transects were taken following the procedure of Kevine *et al*. (1991), where the surveyor has randomly pointed out one point within the mapped sample area. The exact spacing of the quadrants along transects was 100 meters.

The number of plants was recorded by species in each $1m^2$ quadrant. A tillered annual grass was considered as a single plant regardless of the number of tillers and for perennial grasses, number of shoots was recorded rather than the number of plants. Those species that were difficult to identify in the field were tagged, pressed, and sent to the National Herbarium of Addis Ababa University. Frequency, abundance and dominance of individual species were computed following the formula described by Taye et al (1998) and regression and/or multiple regression analysis were made using SAS statistical software (SAS, 1986).

Detection of secondary compounds and their possible impact on human health

Parthenium was sampled from different geographic areas in Ethiopia (October – December 2006), India (August 2006) and Taiwan (June 2007) in order to detect secondary plant compounds using HPLC in the Humboldt University of Berlin. Additionally, plants were cultivated in Ethiopia and Berlin under greenhouse conditions and under water stress in order to see changes in quantity and quality of the secondary metabolites profile of parthenium under different moisture regimes. The phenolic acids and parthenin contents were analyzed from samples collected. Furthermore, 64 farmers were interviewed in heavy infested regions in order to find out the health impact of parthenium.

Economic impact assessment framework

The impact of diseases due to Parthenium (such as asthma, skin irritation and hay fever) was analyzed with the help of a framework recommended by Murray (1994). The 'Disability Adjusted Life Year' (DALY) is a measure introduced by the World Bank and the World Health Organization to measure the global burden of disease. DALY indicates years of life lost due to premature death and years lived with a disability of specified severity and duration. One DALY represents one lost year of healthy life. The collected data from the group interviews were used to estimate DALYs that are lost due to diseases from parthenium. To calculate total DALYs for a given condition in a population the two components have to be summed: years of life lost due to premature death (YLL) and years of life lived with disability (YLD) as illustrated by the following formula:

(1) DALY = YLL + YLD

For the case of parthenium we did not calculate YLL considering the plant mainly as a source of disease and not of death. In order to estimate DALYs lost by each case of illness due to Parthenium in Ethiopia for the year 2006 the following formula was used:

(2) $$-\left[\frac{DCe^{-\beta a}}{(\beta+r)^2}\left[e^{-(\beta+r)(L)}(1+(\beta+r)(L+a))-(1+(\beta+r)a)\right]\Big/\ \right]$$

Where, *D* is the disability weight; *C* and *β* are parameters from an age weighting function; *a* is the onset of the disease; *L* is the duration of the disease and *r* is the social discount rate.

Results and Discussion

Naming of Parthenium Weed in Ethiopia

The name parthenium is commonly accepted for *P. hysterophorus* in Ethiopia though it has many different vernacular names used in different regions and in different locations within a region. It is known as "Qinche" in Tigray region; "Qinche Arem" or "Chebchabe" in Amhara region; "Arama Sorgo", "Arama Kuba", "Biyabassa", "Faramssiissa" or "Dayyeessa" in Oromiya region; "Arama Kuba" or "Terekabi" in Afar region; and "Kalignole" in Somalia region. The names imply its introduction and/or invasiveness or morphology. For example, "Arama Sorgo" implies that the weed was introduced from Somalia during the Ethio-Somalia war in 1976/77. "Biyabassa" means leave the place or a region, "Faramssiissa" means sign to leave the land, "Qinche" is a kind of food made of coarse grinned barley or wheat that looks like the white flowers of parthenium, and "Kalignole" means living alone indicating its allelopathic and strong competitive nature.

Morphology of Parthenium Weed in Ethiopia

All *Parthenium* populations that were surveyed in different parts of Ethiopia: Southern Tigray, North and South Wollo, East Wollega, central farmlands of Shewa, Rift Valley, and West and East Hararghe have a rosette leaves that did not elongate until flowering and form white flowers. Hence, they were classified under the white-flowered parthenium group. Based on the flower colour and its rosette stage, it is similar to plants growing in Kenya, Australia, India, Mexico and USA (Dale, 1981; Parker et al, 1994).

Spread and Infestation of Parthenium Weed

Parthenium was observed to grow on roadsides, vacant sites, towns, villages, gardens, waterways, grasslands and in crop fields both during the crop season and after harvest so long as enough moisture is available. Field crops: [maize (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], finger millet [*Eleusine coracan* (L.) Gaertn.], cotton (*Gossypium hirsutum* L.), haricot bean (*Phaseolus vulgaris* L.), tef [*Eragrostis tef* (Zucc.) Trott.]], vegetables [potato (*Solanum tuberosum* L.), tomato (*Lycopersicon esculentum* Mill.), onion (*Allium cepa* L.), cabbage (*Brassica oleracea* L.), and carrot (*Daucus carota* L.)], and orchards [citrus (*Citrus* spp.), mango (*Mangifera indica* L.), papaya (*Carica papaya* L.) and banana (*Musa* spp.)] were found to be infested by parthenium.

Infestation of parthenium in the crop field varied from field to field depending on the time of its introduction into the area and the efforts made by the farmers to control the weed. It became a major weed of crops in the northern and eastern regions of Ethiopia (Tables 1, 2, 3 and 4). In eastern Ethiopia, although it grows as dense stands in every plot of land, farmers were aware of problem. They keep their farmlands almost free of the weed through intensive cultivation, hoeing and hand weeding and use of inter-cropping. However, it grows and reproduces on field borders, roadsides, open lands, grazing lands and their villages from where re-infestation of the fields takes place. High infestation of parthenium (> 20 plants per m^2) was observed in sorghum fields around Kobo, and in sorghum, maize and tef fields around Robit, Gobie, Woldiya, and Kombolcha both during the growing period and after harvest during off season. Similarly, in East Shewa (Wolenchitti, Wonji and Methara), Afar region (Awash, Anano, and Miesso), and West and East Hararghe, heavy infestation of sorghum, maize, tef, haricot bean was observed both during fallow and cropping seasons.

In highly infested areas from Woldiya to Alamata, the original grass and shrub vegetation was very open and the disturbance allowed a dense stand of parthenium to cover thousands of hectares of grazing and cultivated lands. From Sirinka to Mersa and then to Dessie, parthenium was present on the narrow strip along the main road for several kilometres. Occasional dense stands were observed around farm buildings, crop fields and grazing lands especially where overgrazing had taken place. Similarly, from Kamisse down to Shewa Robit, dense infestation was observed along the main road, villages and waterways. Infestation of crop fields (maize, sorghum, tef) around Gubalafto, Ataye and Shewa Robit was also observed.

In many districts of West Shewa: Shoboka, Tibe, Guder, and Wolliso, only localized infestation of *Parthenium* was observed on roadsides and rarely in crop fields. The plant occurred in the towns, usually on roadsides, and vacant sites and grew only at irregular intervals.

Table 1. Distribution and scale of parthenium infestation in northern, central and eastern parts of Ethiopia.

Zone/Region	Location	Altitude (m)	Soil type	Infested habitat*	Scale of infestation (0 - 5)		Importance** (0 – 4)
					Off season	Crop season	
North Wollo	Kobo	1470	Sandy loam	All	5	5	4
	Robit	1500	Loam	All	5	5	4
	Gobie	1580	Loam	All	5	5	4
	Woldiya	1880	Sand	All	5	5	4
	Mersa	2300	Sandy loam	1, 2 and 3	3	3	3
South Wollo	Kombolcha	1900	Sandy loam	All	5	5	4
	Kamissie	1440	Sandy loam	1, 2 and 3	3	3	2
North Shewa	Ataye	1520	Sand	All	4	4	3
	Shewa Robit	1250	Sandy loam	All	4	4	4
West Shewa	Shoboka	1750	Loam	1	3	-	1
	Ambo	2225	Black clay	All	4	4	3
	Wolliso	2000	Black clay	1, 2 and 3	-	3	1
East Shewa	Debre Zeit	1900	Black clay	1, 2 and 3	2	2	2
	Mojo	1870	Black clay	1, 2 and 3	3	3	2
	Qoqa	1600	Loamy sand	1, 2 and 3	3	3	2
	Nazareth	1620	Loamy sand	1, 2 and 3	4	4	3
	Wolanchitti	1450	Loamy sand	All	5	5	4
	Wonji	1250	Sandy loam	All	5	5	4
	Matahara	970	Loamy sand	All	5	5	4
Afar	Awash	920	Loamy sand	All	5	5	4
	Anano	1200	Loamy sand	All	5	5	4
	Miesso	1400	Loamy sand	All	5	5	4
West Hararghe	Asebe Teferii	1900	Sandy loam	All	4	4	3
	Hirna	2050	Loam	All	5	5	3
	Chelenko	2350	Sand	All	5	5	3
	Qobo	2250	Sandy	All	5	5	3
East Hararghe	Qulubii	2000	Sandy loam	All	5	5	3
	Qarsa	2000	Sandy loam	All	5	5	3
	Dire Dawa	1360	Sand	All	5	5	4
	Tony farm	1260	Loamy sand	All	5	5	4
	Alemaya	1450	Loamy sand	All	5	5	4

Key:

* Infested habitats: 1 = road sides; 2 = range lands; 3 = gardens and villages; 4 = crop fields; all = all habitats

** Importance of Parthenium in the area: 1 = no Parthenium in the crop field; 2 = not serious (present at low density); 3 = serious (moderate yield loss); 4 = very serious (heavy yield loss)

Parthenium was observed to grow in different habitats from hot arid and semi-arid low altitude to humid high-mid-altitude (900 - 2500 m) in the survey area. It grows on any type of soil (sand, loam or clay) and in different habitats (roadsides, wastelands, rangelands, villages and gardens, and crop fields) indicating its adaptability to different climate and soil types (Tables 1, 2, 3 and 4). Infestation of parthenium on these areas in Ethiopia is similar to that in India. Mhadevappa (1997) reported that the weed finds access to any type of land in India (grasslands, orchards, vegetables and field crops) apart from its growth on roadsides and wastelands.

From this study, it was noted that parthenium population is high in places where the soils are disturbed constantly for purposes of construction of roads and buildings. Regular maintenance of verges along the highways and narrow gravel roads of several kilometres are carried out frequently in Ethiopia. Therefore, the extensive dense stands along roadsides in Ethiopia might be due to the routine disturbance and grading of road verges and transportation of sands and gravel from parthenium infested to non-infested areas. This might have helped the dispersal of the weed thereby contributing to severe infestation and invasion of parthenium in Ethiopia. In Australia, parthenium is more common on roadsides and grasslands due to regular disturbance of road verges and in natural grasslands where overgrazing has taken place like in Ethiopia but not a problem in crop fields probably due to good management of the crop fields (Adkins et al., 1997). In Texas and Mexico, however, Dale (1981) reported that parthenium was found normally very scattered and present in limited areas on roadsides because in America regular reworking of the verges which disturbs the vegetation is not present. It is found in natural grasslands becoming dominant only in most overgrazed areas, and in crop fields, it appeared more prominently during the fallow (Dale, 1981).

Therefore, the spread of the plant onto large areas of grazing land in Ethiopia might also be due to severity of overgrazing of natural pastures which provide suitable conditions for growth of parthenium. It forms extensive stands in grasslands and gardens where the land is overgrazed or mechanically cleared of natural vegetation because disturbance of the vegetation allows parthenium to be the first coloniser of the land. Hence, proper management of the grazing land and development of vegetation stand in disturbed areas is mandatory to reduce its severe infestation.

Hence, it can be concluded that the disturbance and clearing of very large areas through road construction, overgrazing and ploughing which originally contained native grasses and bushes and subsequent poor management might have resulted in large areas of bare ground with negligible grass cover that leads to colonisation of parthenium. The presence of neutral to alkaline soils in most parts of Ethiopia and the absence of natural enemies and competing vegetation might have also provided ideal conditions for the development of a large stands all over the country.

In crop fields, it can be eliminated along with the regular weeding process (hand pulling and/or hoeing) where intensive cultivation is practised as observed in West and East Hararghe. However, it grows profusely on the field borders and roadsides from which re-infestation takes place. In fruit orchards e.g., Tony farm near Dire Dawa and around Shewa Robit Town in North Shewa, it grows as a dense stand because weeding is not done as frequently and systematically as in field crops (Taye, 2002).

Table 2. Spread and status of *Parthenium* infestation in Oromiya, Amhara and Tigrai Regional States

'Wereda' (District)	Record of initial infestation		Infestation level	Areas infested**
	Year	Place*		
West Harerge Zone				
Mesela	1988	Roadside	High	1,2,3,4,5,6,7
Doba	1990	NR	High	1,2,3,4,5,6,7
Ciro	1989	Roadside	High	1,2,3,4,5,6,
Xulo	1988	Hirna town	High	1,2,3,4,5,6,7
Darolebu	1987	Mechara	High	1,2,3,5,6,7
Kuni	1979	NR	High	1,2,3,4,6,7
Goba Koricha	1980	NR	High	1,2,3,4,5,6,7
Mieso	1985	Roadside	High	1,2,3,4,5,6,7
Habro	1987	NR	High	1,2,3,4,5,6,7
East Harerge Zone				
Kurfachelie	1985	Roadside	Low	2
Melka Bolo	1989	Roadside	High	1,2,3,4,5,6,7
Kombolcha	1991	Roadside	High	1,2,3,4,5,6
Jarso	1990	Roadside	High	1,2,3,4,5,6,7
Alemaya	1995	Roadside, Grazing land	High	1,2,3,4,5,6
Babilie	1977	NR	High	1,2,3,4,5,6,7
Dedder	1996	NR	High	1,2,3,4,5
Kerssa	1988	NR	High	1,2,3,4,5,6
Bedeno	1987	NR	High	2,5
Gurogutu	1977	NR	Low	1,2,3,4,5
Goloda	1990	CARE Store	High	1,2,5,7
Gursum	1978	Jijiga road	High	1,2,3,4,5
Meta	1985	Roadside	High	1,2,3,4,5,6,7
Girawa	1977	NR	Low	2,4,5,7
Fedis	1977	NR	High	1,2,3,4,5,6,7
East Shewa Zone				
Boset	1991	NR	High	1,2,3,4,5,6,7
Lumie	1993	NR	High	1,2,3,4,5,6,7
Adaliben	1989	Roadside	High	1,2,3,4,5,6
Fentalie	1996	NR	Medium	1,3,7
Akaki	1994	Roadside	Medium	2,5,6,7
West Shewa Zone				
Woliso	Unknown	NR	Low	1,2,3,4,5,6,7
Ambo	1997	NR	Medium	1,2,3,4,5
Tolie	1994	Roadside	Medium	1,2,3,4,5,6
Ameya	Unknown	NR	Low	2,5
Becho	Unknown	Roadside	Low	1,2,3,4,5
Arsi Zone				
Hetosa	1998	NR	Low	1,2
Merti	1993	Town area	Medium	1,2,4,5,6,7
Dodota Sire	1989	NR	Medium	1,2,3,5,6,7
Bale Zone				
Ginir	1997	NR	Medium	1,2,5
Mena	1998	NR	Medium	2,6,7
Illbabor Zone				
Darimu	1988	Market area	Low	6
Haluburie	1997	Market area	Low	3, 6

*NR = Not recorded

**1 = Cultivated land 2 = Roadside 3 =Grazing areas
4 = Non-cultivated land 5 = Rural villages 6 = Urban areas 7 = Riverside

Table 3. Spread of *Parthenium* in Amhara Regional State

Zonal Administration	No. of infested		Total area infested (ha)
	'Weredas'(District)	*'Kebeles'*(PA)	
Wag Hamra	2	9	62.5
North Welo	5	81	34,134.0
South Welo	6	42	1,671.0
Oromia	4	23	649.0
North Shewa	7	42	532.0
West Gojjam	3	4	55.0
Awi	1	1	0.125
South Gonder	1	3	1.5
Total	29	205	37,105.0

Table 4. Spread and status of *Parthenium* in Tigrai Regional State at '*Wereda*' level

'Weredas' (District)	PAs* (no.)	Area coverage (ha)				
		Crop land	Forest area	Urban areas & roadsides	Riverside	Total
Alamata	11	10,000	52.0	58.0	-	10,110
Raya Azebo	12	110.5	29.75	20.0	83	243.25
Ofla	2	-	-	8.75	-	8.75
Endamehoni	1	-	-	5.0	-	5.0
Enderta	1	-	-	1.5	-	1.5
South Tembien	3	53	2.50	1.85	36.50	93.85
Upper Maichew	1	8	-	2.0	-	10.0
Ahferom	1	-	-	0.062	-	0.062
Mereb Lehe	1	-	-	0.005	-	0.005
Adwa	1	0.50	-	2.5	-	3.0
Tahtay Keraro	1	-	-	0.063	-	0.63
Wukro	1	.0004	-	0.274	-	0.274
Ganta Afeshum	1	-	-	0.25	-	0.25
T/Abergele	1	-	-	8.0	-	8.0
H/Wajrat	1	-	-	0.5	-	0.50
Mekele	20	-	-	10.0	-	10.0
Total	59	10,172	84.25	118.75	119.5	10,495

* PAs = Peasant Associations

Parthenium also grows in the fallow period in fields where only one crop is grown in a year though its growth and reproductive ability is affected by the amount of rain fall and soil fertility. It has been observed in the field germinating and growing alone even during dry periods with one or two showers. This might be due to its relatively little moisture requirement for germination and its drought resistance capacity thereby suppressing other plant species.

Climatic Matching of Parthenium Infestation in Ethiopia and Other Countries

Climatic variables, i.e., mean minimum and maximum temperature, and mean monthly and yearly total precipitation calculated over 5 years for some parthenium infested areas in Ethiopia were compared with the climatic variables for areas in South, Central and North America, and Australia using the data reported by Dale (1981). The lowest mean minimum temperature in the surveyed areas in Ethiopia is 4 °C at Alemaya during the month of December and the highest mean maximum temperature is 35 °C at Dire Dawa during the months of April to May. However, parthenium infestation was very low at high altitudes and was not observed on mountains. It was observed to grow from low altitude (912 m) to high-mid-altitude (2500 m) in the study areas.

Similarity of the climatic variables of Parthenium infested areas in Ethiopia and other infested areas in Austaralia and America was conducted using cluster analysis. The Pseudo F and t2 statistics of the average lineage and centriod clustering methods (SAS, 1986) strongly recommended four clusters for this data set. Thus, the two main branches of the dendrogram are splitted into two sub-branches each (Figure 1). Membership of locations to different clusters is shown. Majority of the locations belong to the fourth cluster, which is characterized by high average rainfall, high altitude and small variability among the minimum and maximum temprature. These were Hirna, Kulubi, Mojo, Asebe Teferi, Ambo, Harar Kombolcha, Alemaya, Awassa, and Mersa. In contrary, the third cluster is characterised by locations with small average rainfall, low altitude and high variability for minimum and maximum tempreature.This constituted Twin Hills and Roma locations in Australia, and San Luisza, Monterry, Catamarca and Mendoza locations in Argentina. Locations clustered into the first and second classes are characterized by high rainfall-low altitude and low rainfall-high altitude, respectively. Location with observation number four was not considered in cluster analysis by the SAS program because of the missing rainfall data.

It appears to have the potential to adapt, spread and survive under different altitude, rainfall, temperature, and soil regimes. It favours the areas with heavy clay soils like in Ambo area and alluvial soils like in Merti Yrju and Nura Era Farms where it grows up to 2 meters height. But, it also grows on other types of soils: sandy and brown soils in Ethiopia although its growth is limited to soils with a neutral to high pH in America and Australia as reported by Dale (1981).

The rainfall in parthenium infested areas in Ethiopia is within the range in which it normally occurs in Brazil, Mexico and USA but greater than that of Australia (Data not shown). This suggests that the probable direction of expansion of parthenium in Ethiopia would be to the higher rainfall areas. Currently, it exists mainly in arid and semi-arid regions of Ethiopia where the mean annual rainfall is 300 - 1400 ml per annum (Taye

2002). This might be due to its first introduction into these areas and absence of natural vegetation especially during the long dry period that favours it to have a competitive advantage. Similarly, in Queensland, Dale (1981) reported that parthenium can also exist under low rainfall conditions where deep heavy clay soils occur for the extra water storage in the soil may allow the plant to grow.

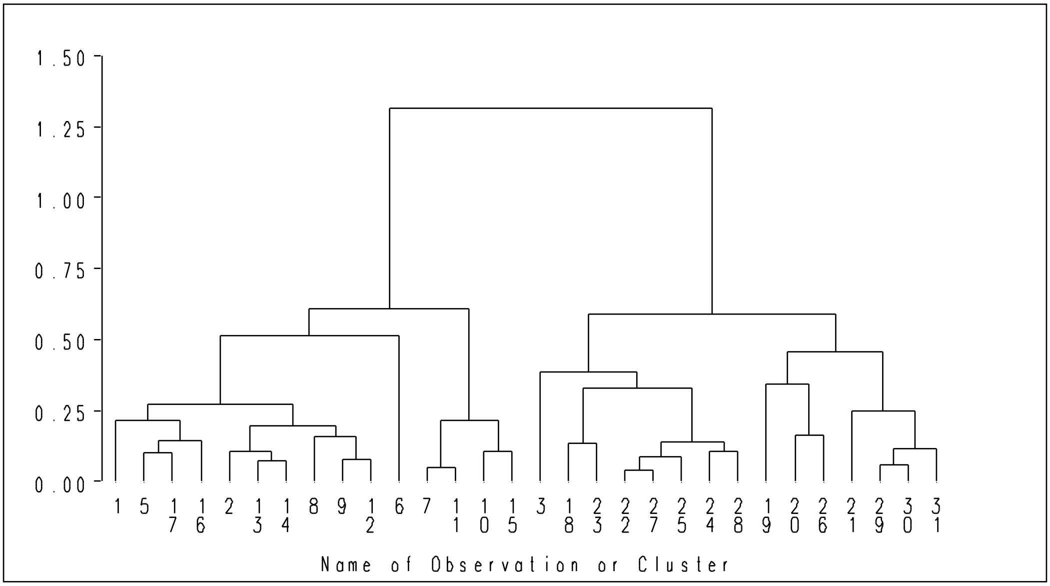


Figure 2. Dendrogram and membership of locations in the cluster analysis

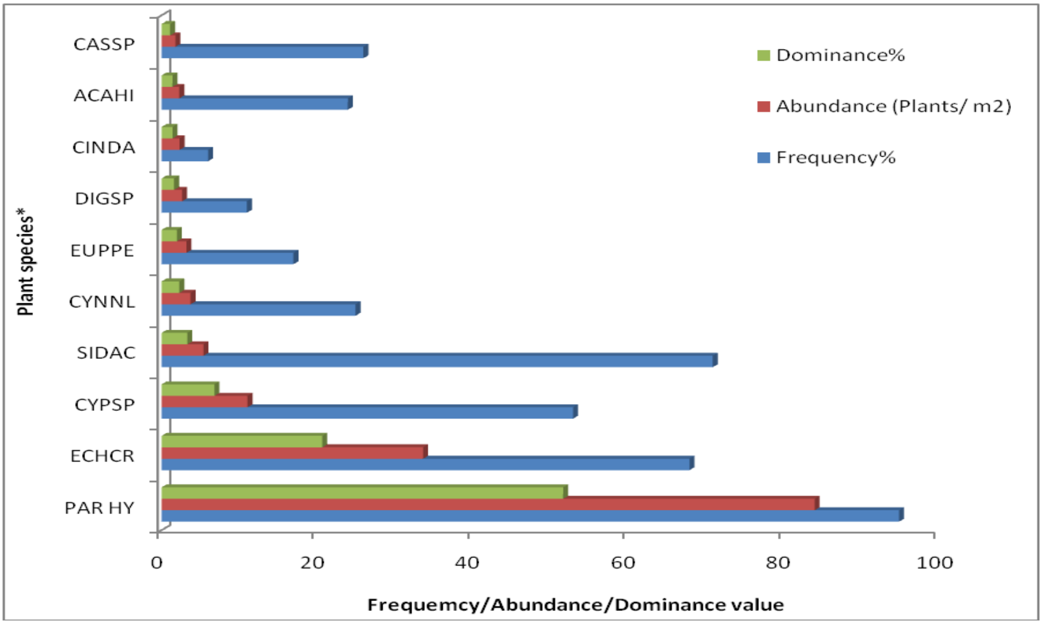
Memebership of locations to the four clusters							
S.N	**Location**		**Cluster**	**S.N**	**Location**		**Cluster**
	Observ-ation	**name**			**Observation**	**name**	
1	22	Argentina: Precidencia	1	16	20	Argentina: SanLuisza	3
2	27	Mexico: Tampico	1	17	26	Mexicol: Monterrey	3
3	25	Mexicol: Merida	1	18	21	Argentina: Catamarca	3
4	24	Brazil: Corumba	1	19	19	Argentina: Mendoza	3
5	28	USA: Houston, Texas	1	20	13	Ethiopia: Hirna	4
6	18	Bolivia: Santa Cruz	1	21	14	Ethiopia: Kulubi	4
7	23	Argentina: Tucuman	1	22	9	Ethiopia: Mojo	4
8	3	Ethiopia: Tibe	1	23	12	Ethiopia: Asebe Teferi	4
9	7	Ethiopia: Ziway	2	24	5	Ethiopia: Ambo	4
10	11	Ethiopia: Miesso	2	25	17	Ethiopia: Harar	4
11	10	Ethiopia: Nazareth	2	26	2	Ethiopia: Combolcha	4
12	15	Ethiopia: Dire Dawa	2	27	16	Ethiopia: Alemaya	4
13	29	Australia: Clermont, Queensland	3	28	8	Ethiopia: Awassa	4
14	30	Australia: Twin Hills, Queensland	3	29	1	Ethiopia: Mersa	4
15	31	Australia: Roma, Queensland	3	30	6	Ethiopia: Wolkite	4

In comparison to Brazil, Mexico and USA mean minimum temperature in Ethiopia is lower, but greater than in Australia (Data not shown). Mean maximum temperature, however, is in the same range as in Brazil, Mexico and USA suggesting that temperature is most unlikely to limit the plant in Ethiopia. Similarly, Tamado (2001) reported that temperature is not a limiting factor for germination of parthenium seeds in Ethiopian cropping situations as its seeds could germinate and grow at fluctuating (12/2 °C to 35/25 °C) temperatures. However, low temperature in high altitudes (> 2500 m) areas might reduce its growth and reproduction as it does not normally occur in these areas. Similarly, in India, parthenium was observed growing sparsely in high altitudes and on hilly regions and the interior of forests (Mahadevappa, 1997). The absence of winter period in Ethiopia that limits its growth in America and Australia might also be one of the factors for its severe expansion and aggressiveness in Ethiopia. Dale (1981) also stated that temperature does not prevent the growth of parthenium in any parts of Mexico except at the highest altitude. The same author explained that its distribution in Australia is affected by factors similar to those limiting the plant in its area of origin (e.g. temperature and rainfall) but because of differences in land management, soils and climate the plant covers much greater areas and can be a far more significant problem in Ethiopia.

Effects on Herbaceous Plant Diversity

A total of 71 different plant species were collected and identified from the surveyed study site. Out of these specimens, 60 were identified at species level. The remaining eleven specimens were identified only at the generic level. These species composition was distributed in 45 genera within 14 families. The large majority of these, 51 species were dicotyledonous species, 18 grasses, and two sedges. The five major families, based on the number of taxa were: Poaceae (18), Asteraceae (10), Fabaceae (8), Solonaceae (6) and Ipomeaceae (4) accounted for 65% of the total plant composition.

The major plant species having a dominance level greater than 5% were *Parthenium hysterophorus*, *Echinochloa crus-galli*, *Cyperus* sp., *Sida acuta*, *Cynodon nlemfuensis*, *Euphorbia peplus*, *Digitaria* sp, *Cynodon dactylon*, *Acanthospermum hispidum*, and *Casia* sp. Though these species were dominant in the study site, parthenium exhibited higher frequency, abundance as well as dominance over the other weed species (Figure 2).



Key:
Plant species* (BAYER CODE)
PARHY = *Parthenium hysterophorus*, ECHCR = *Echinochloa crusgalli*, CYPSP = *Cyperus* sp., SIDAC = *Sida acuta*, CYNNL = *Cynodon nlemfuensis*, EUPPE = *Euphorbia peplus*, DIGSP = *Digitaria* sp, CYNDA = *Cynodon dactylon*, ACAHI = *Acanthospermum hispidum*, CASSP = *Casia* sp.

Figure 2. Frequency, abundance and dominance of the top ten plants

The average parthenium density recorded was 96 plants m^{-2}, and the average broad leaved plants, grasses and sedges were 69, 47 and 25 plants m^{-2}, respectively. This showed that parthenium is considered to be aggressive and serious enough to adversely affect plant density and even able to cause flora shift from grasses to broad-leaved plants, by reducing the local annual grass species in rangeland.

On the other hand, regression analysis result indicated that parthenium density had a strong polynomial regression with broad leaf, grass and sedge density. Moreover, about 91.5%, 90.3% and 77.5% variation in density of broadleaf, grass and sedges, respectively, were accounted for the density of parthenium (Figure 3). Hence, as the density of parthenium increases, the density of broad leaf, grass and sedges decreases.

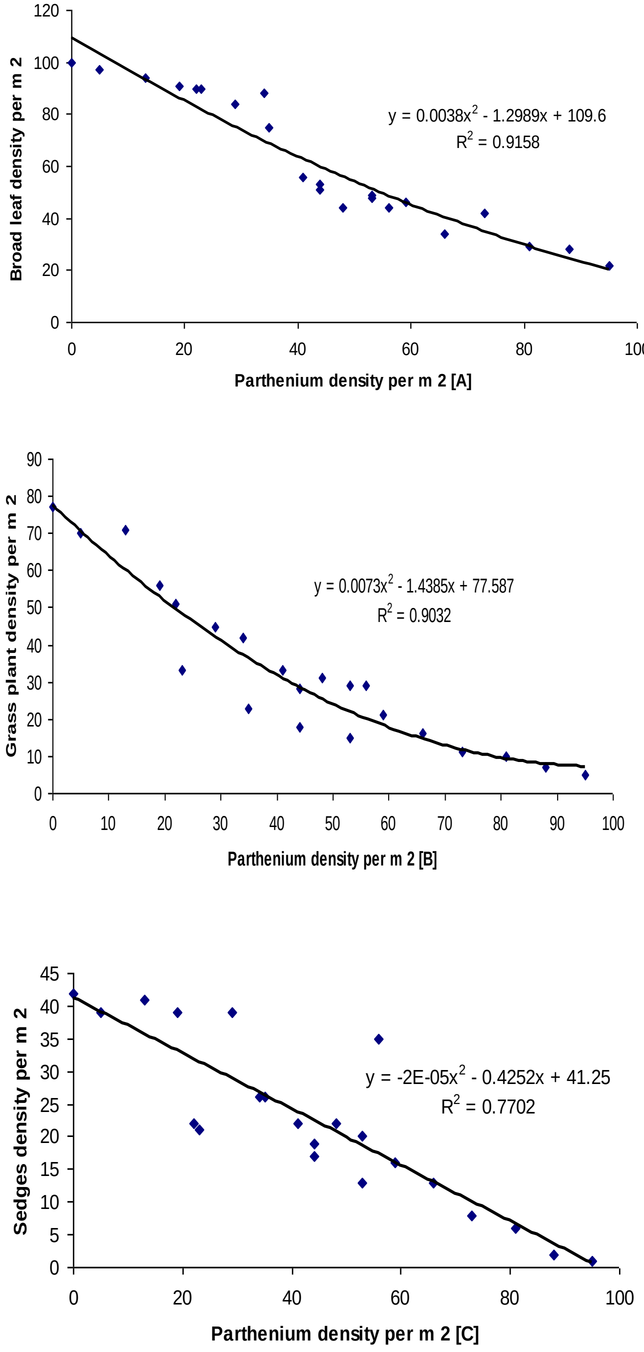


Figure 3. Effect of parthenium density on [A] broad leaf, [B] grass and [C] sedges

Detection of secondary compounds in parthenium

Parthenin is not the only dominant secondary plant compound in parthenium as it is often cited. Wiesner (2008) indicated that the major acids in parthenium were identified as vanillic acid, chlorogenic acid, caffeic acid, cumaric acid and cinnamic acid derivatives which were identified as isochlorogenic acid. Analysis of secondary plant metabolites from parthenium samples collected from different locations showed significant differencec in concentrations of phenolic acids and parthenin. These variations were also observed among the different plant parts, locations, moisture treatment and plant size. Concentration of total phenolic acid was highest in flowers followed by leaves and roots. The highest total phenolic acid concentration was observed at the mid altitude (1450 m) followed by higher altitudes (Figure 4). Concentration of total phenolic acid, however, increased with plant size and irrigation frequency (data not shown).

Analyse of parthenin, the major sesquiterpene lactone in parthenium, are quite different to that of phenolic acids. The concentration of the samples differs not in such range but they tend to be decrease with declining altitude (Figure 5).

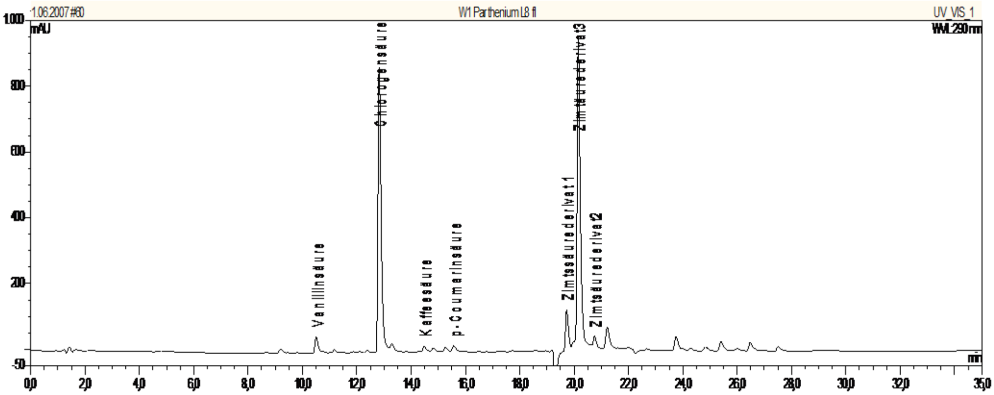


Figure 4. Chromatogram of HPLC of phenolic acids in parthenium sample: detection of vanillic acid, chlorogenic acid, caffeic acid, coumaric acid, cinnamic acid derivatives 1, 2 and 3 and some unknown phenolic acids.

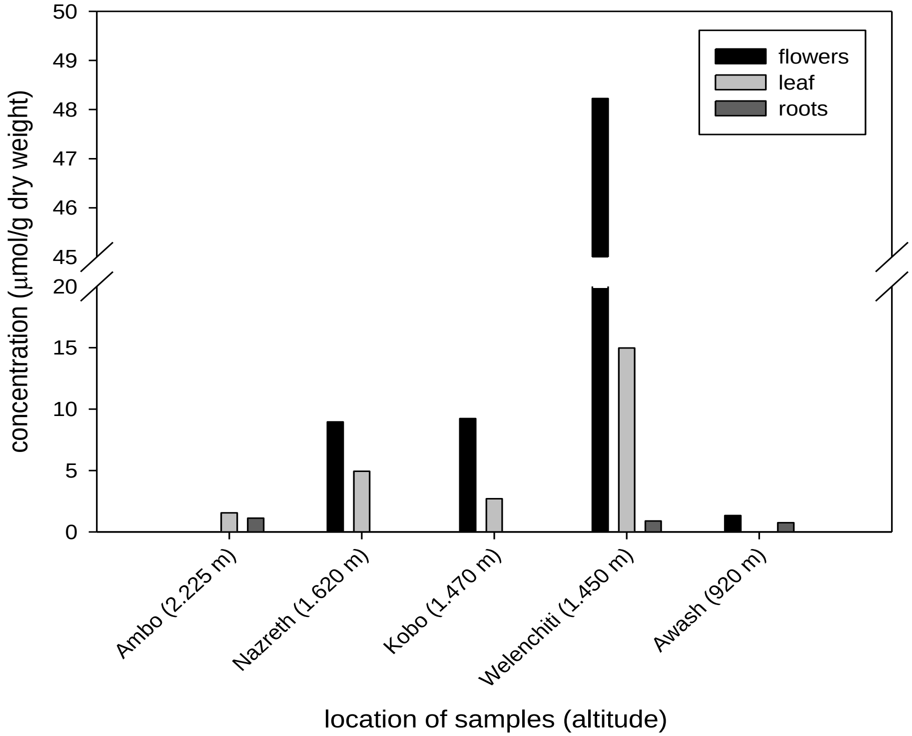


Figure 5. Concentration of total phenolic acids of plant parts of parthenium plants of different locations

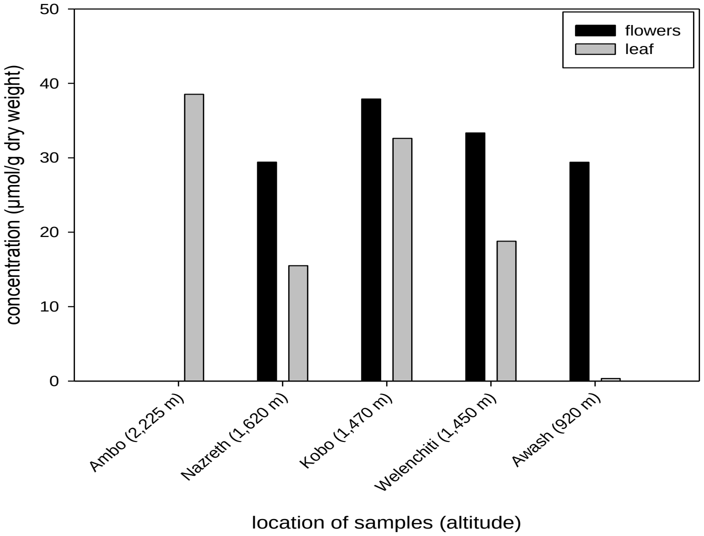


Figure 5. Concentration of parthenin in Parthenium plants of different locations

Parthenium is known in Ethiopia to cause direct losses to the grazing industry. Farmers reported that parthenium suppresses natural grass vegetation and that cattle do not prefer to graze unless they are forced to especially during dry season. According to the interviewed farmers, milk and meat get a bitter taste if animals graze on parthenium infested fields. They can not sell the milk to the market although the tainted meat is eaten. Besides, they reported that animals grazing on parthenium infested field have to be sold to the market with lower weight and poor health status that result in lower price. Similar reports from Australia by Chippendale and Panneta (1994) stated a decline in milk production (estimated to 60%) on parthenium infested lands. Similarly, a study from India also indicates that 22% of the interviewed farmers believed that parthenium cause reduced milk production (Angiras and Kadhane, 2005). In Ethiopia, decline in production and productivity of animals in parthenium infested areas is not only associated to parthenium. Overgrazing, and repeated droughts might also have significant contribution and exacerbate parthenium infestation. In line with this, Shashe (2007) reported that 68% of the surveyed pastoralists mentioned overgrazing is the main cause of parthenium infestation.

Impacts on human health

The responses obtained from 64 interviewed farmers (age between 19 and 44 years) in the four highly infested areas in Ethiopia indicated that all of them have health problems of different symptoms especially during weeding and harvesting. The major allergenic symptoms caused by parthenium were reported as sneezing, coughing, running noses, itching of eyes and the skin, headaches, stomach ache and fatigueness.

But, they told that the symptoms vanished when they washed their hands after work. Other farmers had health problems like cracks on palms of the hand, fever and prickle on the whole body, skin irritations, and asthma. Figure 6 indicate the response of the interviewed farmers. They had to stop their work for 3 to 4 days to recover, but after every new contact the cycle restarts. The results show that 80% of the interviewed farmers complain about hay fever and general indisposition while about 30% reported that they suffer from skin irritations.

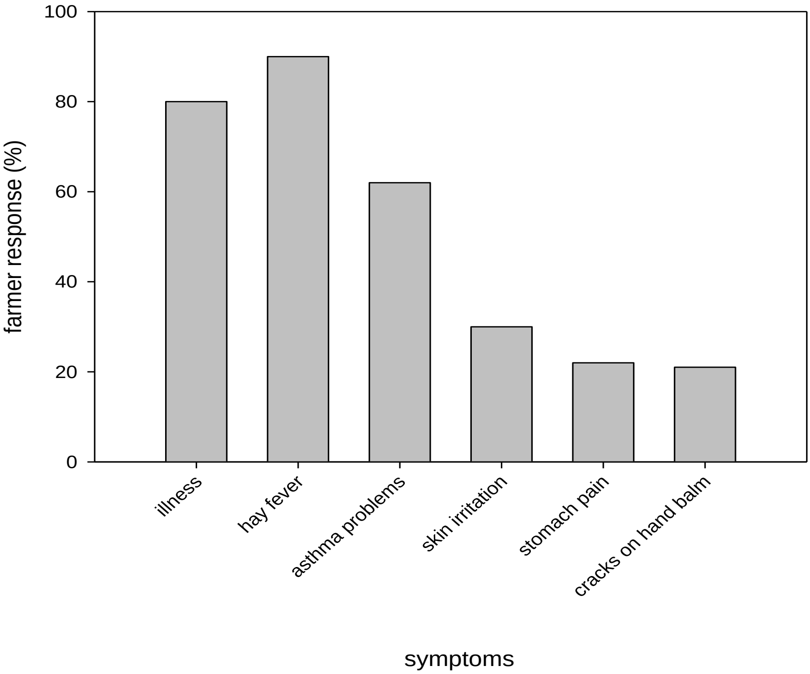


Figure 6. Response of farmers on health hazards caused by parthenium in highly infested areas (n=64).

Social cost of parthenium in Ethiopia

A DALY model for Ethiopia was run using input parameters that were achieved during the group interviews. The average onset (*a*) and duration (*L*) for each kind of disease were collected during the interviews. The remaining parameters were fixed within the model, respectively, can be found on overviews of the DALY framework. Calculations were made for the three diseases. The `overall indisposition` and `stomach ache` had to be left out because no disability weights were available.

The total number of years lost to parthenium in Ethiopia in 2006 is DALYs 16467. DALYs for the specific diseases and the regional states for the productive period of live (ages 11-59) are given in Table 5. The total loss in productive years in 2006 was estimated at 12,000. To calculate the loss in production resulting from parthenium, we multiplied the sum of DALYs in Table 5 by the average Ethiopian labour productivity of US $ 156 per person and year. The share of labour in Ethiopia is about 72, 8 %. Therefore, the social loss due to the diseases caused by Parthenium ranges between US $, 2, 535,887 and 4,365,057.

Table 5. Aggregate measures of Years of Productive Life (ages 11-59) lost to diseases due to Parthenium in Ethiopia in 2006

Region	Asthma (mild)	Asthma (severe)	Skin irritations	Hay fever	Total
Tigray	120	150	264	138	672
Afar	215	269	471	247	1202
Amhara	330	412	722	378	1843
Oromia	878	1098	1922	1007	4904
Somali	261	326	571	299	1458
SNNPR	331	413	724	379	1847
Total	**2136**	**2669**	**4674**	**2448**	**11927**

Human health impact is often associated with secondary plant metabolites found in parthenium. Its being human health hazard, causing allergic rhinitis and contact dermatitis was also reported by Bhutani and Rao (1978), Handa et al. (2001) and Verma et al (2002). Farmers reported that they loose an average of 10 working days due to hay fever, 7 days due to asthmatic problems and 3 days due to skin irritations caused by parthenium. Correspondingly, Weise et al (2007) reported that parthenium that parthenium affected persons too take 5 days per person per season off work in Queensland, Australia. Health centers are not aware of the severe health impacts of parthenium and treat patients from parthenium caused diseases. Farmers in Ethiopia basically control parthenium by hand pulling, hoeing, mowing, or slashing. But these methods were proved to be uneconomical and cause vulnerability of man to various kinds of allergies caused by the weed (Bhan et al., 1997; Kololgi et al., 1997). In some places in Ethiopia, farmers control parthenium on roadsides and wastelands by manual methods using campaign. If effective campaign is to be done, the whole plant should be uprooted before flowering by wearing hand gloves when the soil is moist to ease uprooting and this activity should be carried out repeatedly.

Qualitative and quantitative data on the extent of health effects due to parthenium in Ethiopia were obtained from group interviews and expert interviews. Both farmers and experts confirmed to a large extent the harsh effects onto human health, i.e., hay fever, asthmatic problems and skin irritations. Similarly, different studies verified impacts of parthenium on human health worldwide. In India, of the people living in parthenium infested area, 40% suffer from hay fever, 12% from Asthmatic problems and 56% from skin irritations (Suba Rao et al 1977, Rao et al 1985, Sriramarao et al, 1991). In Australia, 10-20% of the population develops allergenic reactions due to parthenium (McFadyen, 1995). The proportion of affected people obtained in the group interviews in Ethiopia is partly higher than that of India (twice for hay fever and five times higher for Asthmatic problems). But, the amount of people suffering from skin irritation in Ethiopia is lower than in India while the number for Australia is considerably lower than India and Ethiopia. The reason for this differences might be due to samples (N) for Ethiopia (N= 64), India (N=300 and 1,294, respectively for Suba Rao et al (1977) and Sriramarao et al (1991). Both authors in India used medical or clinical patch tests to analyze the impact of parthenium on people whereas this study is based on empirical data from group interviews. It is important to mention that estimating the effects on human health caused by invasive species is not easy because the connection between the source and effect is often not obvious. The presumable bias that may occur in interviews was taken into consideration during the meeting although a mix with symptoms of the most common disease like HIV/AIDS, malaria, diarrhea, and tuberculosis can not always be excluded.

It is calculated that the direct losses due to illness of workers who are allergic to parthenium ranged between US $, 2, 535,887 and 4,365,057 in 2006. However, this is still an underestimate since the model requires accurate data inputs on the extent of parthenium invasion in Ethiopia, the proportion of affected persons in Ethiopia and the average duration of disability and medication costs. This range of loss has led to a loss of about 0.04-0.07% of the Ethiopian gross domestic product in 2006. HIV/AIDS in Ethiopia led to a decline of the gross domestic product in the range of 3.7-7.4% in 1999 (Zerfu, 2002). A similar study in Queensland, Australia by Weise et al (2007) indicated that direct loss due to illness of workers who are allergic to parthenium including medication cost resulted in total cost of AU $26.3 million.

Besides, direct and indirect losses which arise due to parthenium in agriculture and biodiversity were ignored in this study. This study concludes that parthenium is an important problem for a rural population living in infested areas in Ethiopia. Due to its negative characteristics, the weed harms human health and leads to severe effects on productivity in agriculture and biodiversity at large. Hence, more resources have to be supplied to tackle the problem in Ethiopia as the estimated loss is disproportionate to the investment in parthenium research and development.

References

Adkins, S.W., S.C. Navie, G.C. Gerham, and R.E. McFadyen 1997. Parthenium weed in Australia: research underway at co-operative research centre for tropical pest management. In: Mahadevappa, M and Patil, V.C. (eds), *Proceedings of the 1st International Conference on Parthenium Management*, 6-8 October 1997, University of Agricultural Sciences, Dahrwad, India, pp. 63-69.

Angiras, N.N. and R. Kumar 2005. Problems of *Parthenium hysterophorus* L. and strategies to manage Himachal Pradesh, India. In: *Proceedings of the second international conference on parthenium management*, 5-7 December 2005, University of Agricultural Sciences, Bangalore. pp 155 – 159.

Bhan, V.M., S. Kumar, and M.S. Raghuwanshi, 1997. Future strategies for effective parthenium management. In: Mahadevappa, M. and Patil, V.C. (eds), *Proceedings of the 1st International Conference on Parthenium Management*, 6 - 8 October 1997, University of Agricultural Sciences, Dahrwad, India, pp 90-95.

Bhutani, L.K., and D.S. Rao. 1978. Photocontact Dermatitis Caused by *Parthenium hysterophorus*. *Dermatologica* 157:206-209.

Brahmam, M. 2003. Congress grass (*Parthenium hysterophorus*) - A Fast Spreading Biological Pollutant [Online]. Available by www.iprng.org http://www.iprng.org/.

Chippendale, J.F., and F.D. Panneta. 1994. The cost of Parthenium weed to the Queensland cattle industry. *Plant Protection Quarterly* 9: 73-76.

Dale, I.J. 1981. Parthenium weed in Americas. A Report on the Ecology of *Parthenium hysterophorus* in South, Central and North America. *Australian weeds* 1: 8-14.

Evans, H.C. 1997. *Parthenium hysterophorus:* A review of its weed status and the possibilities for biological control. *Biocontrol News and Information* 18: 89-98.

Hammerton, J.L. 1981. Weed problems and weed control in the commonwealth Caribbean. *Tropical Pest Management* 27: 379-387.

Handa, S., B. Sahoo, and V.K. Sharma. 2001. Oral hypo-sensitization in patients with contact dermatitis from *Parthenium hysterophorus*. *Contact Dermatitis* 44:279-282.

Kanchan, S.D. 1975. Growth-Inhibitors from Parthenium-Hysterophorus Linn. *Current Science* 44: 358-359.

Kevine V., M. Mccully, G. Sampson, and A. Watson. 1991. Weed Survey of Nova Scotia Lobush Blueberry (*Vacinum angustifolium*). *Weed Science* 39:180-185

Khosla, S.N., and S.W. Sobti. 1981. Effective control of *Parthenium hysterophorus* L. *Pesticides* 15: 18-19.

Kohli, R., and D. Rani. 1994. *Parthenium hysterophorus* - a review. Res. Punjab Univ 44:105-149.

Kololgi, P.D., S.D. Kololgi and N.P. Kololgi. 1997. Dermatological hazards of Parthenium in human beings. In: Mahadevappa, M., and Patil, V.C. (eds), *Proceedings of the First International Conference on Parthenium Management*, 6 - 8 October 1997, University of Agricultural Sciences, Dahrwad, India, pp 18-19.

Mahadevappa, M. 1997. Ecology, distribution, menace and management of parthenium. In: Mahadevappa, M., and Patil, V.C. (eds), *Proceedings of the 1st International Conference on Parthenium Management*, 6 - 8 October 1997, University of Agricultural Sciences, Dahrwad, India, pp 1-12.

McFadyen, R.E. (1995) Parthenium weed and human health in Queens land. *Australian Family Physician* 24: 1455–1459.

Murray, C.J.L. 1994. Quantifying the burden of disease: the technical basis for disability-adjusted life years. Bulletin of the World Health Organization 72(3): 429-445.

Nath, R. 1988. *Parthenium hysterophorus* L. - a general account. *Agricultural Review.* 9: 171-179.

Njoroge, J.M. 1991. Tolerance of *Bidens pilosa* and *Parthenium hysterophorus* L. to paraquat (Gramaxone) in Kenya coffee. *Kenya-Coffee* 56: 999-1001.

Parker A, ANG Holden, and AJ Tomley. 1994. Host specificity test and assessment of the pathogenicity of the rust, Puccinia abrupta var. partheniicola, as a Biological Control of Parthenium Weed (Parthenium hysterophorus). Plant Pathology 43: 1-16.

Patil, T.M., and B.A. Hegde, 1988. Isolation and Purification of a Sesquiterpene Lactone from the Leaves of *Parthenium hysterophorus* L - Its Allelopathic and Cyto-toxic Effects. *Current Science* 57:1178-1181.

Picman, J., and A.K. Picman. 1984. Autotoxicity in Parthenium-Hysterophorus and Its Possible Role in Control of Germination. Biochemical Systematics and Ecology 12:287-292.

Rao. M., O.M. Prakash, and P.V. Subba Rao, 1985. Reagenic allergy to parthenium pollen: Evaluation by skin test and RAST. *Chemical allergy* 15:449-45.

SAS Institute, 1986. SAS/STAT guide for personal computers, version 6 edition.

Shashe A. 2007. The impact of *Parthenium hysterophorus* L. on the range ecosystem dynamics of the Jijiga rangeland, Ethiopia, *MSc Thesis*, Haramaya Univesity, Haramaya, Ethiopia.

Sriramarao, P., S. Nagpal, B.S.S. Rao, O. Prakash and P.V.S. Rao. 1991. Immediate Hypersensitivity to *Parthenium hysterophorus* 2. Clinical-Studies on the Prevalence of Parthenium Rhinitis. *Clinical and Experimental Allergy* 21:55-62.

Subba Rao, P.V., A. Mangala, B.S. Rao, and K.M. Parkash. 1977. Clinical and immunological studies on persons exposed to *Parthenium hysterophorus* L. *Experientia* 33:1387-1388

Tamado, T. 2001. Biology and management of Parthenium (*Parthenium hysterophorus* L.) in Ethiopia. PhD *thesis*. Swedish University of Agricultural Sciences, Uppsala.

Taye, T., L. Yohannes, and A. Belayneh. 1998. Qualitative and quantitative determination of weed occurrence in wheat in west Shewa zone of Ethiopia. *10th regional wheat workshop for eastern, central and southern Africa.* Sept. 14-18, 1998, University of Stellenbosch, South Africa, pp 160-172.

Taye Tessema. 2002. Investigation of Pathogens for Biological Control of Parthenium (*Parthenium hysterophorus* L.) in Ethiopia. PhD Thesis. Humboldt–Universitat zu Berlin, Landwirtschaftlich-Gartnerischen Fakultat, Berlin. 152 pp.

Verma, K.K., C.S. Sirka, M. Ramam, and V.K. Sharma 2002. Parthenium dermatitis presenting as photosensitive lichenoid eruption. *Contact Dermatitis* 46:286-289.

Weise, R.M., B.W. van Wilgen, M.P. Hill, F. Schulthess, D. Tweddle, A. Chabi-Olay and H.G. Zimmerman. 2007. The economic impact of appropriate management of selected invasive Aliens species on the African Continent. Report for Global Invasive Species Programme.

Wiesner, M. 2008. Veränderung gesundheitsrelevanter sekundärer Inhaltsstoffe in *Parthenium hysterophorus* L. in Abhängigkeit von der Pflanzenentwicklung. MSc Thesis, Humboldt–Universitat zu Berlin, Landwirtschaftlich-Gartnerischen Fakultat, Fachgebiet Phytomedizin, Berlin, Germany.

Wittenberg, R. 2004. Instruments and Tools for Assessing the Impact of Invasive Alien Plant Species in Africa. Report submitted under the PDF-B phase of the UNEP/GEF Project: Removing Barriers to Invasive Plant Management in Africa. CAB International Africa Regional Centre, Nairobi.

Yohannes, L. and T. Taye, 1999. Incidence and distribution of Striga spp in maize in Ethiopia. Ethiopian Weed Science Society 4th Annual Conference, 3-4 April 1999, Addis Ababa, Ethiopia.

Zerfu, D. 2002. The microeconomic impact of HIV/AIDS in Ethiopia. Department of Economics, Addis Ababa University.