5 *Ageratum conyzoides*: an Alien Invasive Weed in India

Shalinder Kaur[1], Daizy R. Batish[2], R. K. Kohli[2] and H.P. Singh[1]

[1]*Department of Environment Studies, Panjab University, Chandigarh, India;* [2]*Department of Botany, Panjab University, Chandigarh, India*

Introduction

Worldwide, invasion by exotic alien plants has caused a significant change in structure and composition of vegetation leading to homogenization of flora (Cushman and Gaffney, 2010). Due to increased globalization and burgeoning human population, there has been an unprecedented increase in movement (both intentional and unintentional) of species beyond their natural biogeographical range into new environments. In fact, the spread of invasive species is occurring at an exceptionally high rate throughout the world and is amongst one of the major threats to global biodiversity. It has greatly enhanced the interest of scientists in studying the magnitude of occurrence and impact of invasive species (Davis, 2009). Invasive plants damage ecosystems both economically and ecologically and, out of these, ecological impacts are more difficult to assess than economic effects (Pimentel *et al.*, 2005). Invasive plants affect native plants directly by competition for soil resources, light and space, as well as indirectly through alteration of ecosystem processes, services and ecological functioning such as soil nutrient cycling and pollination, etc. (Goodell, 2008; Weidenhamer and Callaway, 2010). Invasive species reduce the number of native species and may even lead to their extinction owing to competitive exclusion, niche displacement and hybridization (Mooney and Cleland, 2001). Furthermore, invasive plants reduce biodiversity via degradation of wildlife habitat, thus adversely affecting productivity, ecosystem properties and ecosystem development at the global level (Masters and Sheley, 2001; Kolb *et al.* 2002; Davies and Svejcar, 2008).

India is one of the richest centres of biodiversity due to its wide range of climatic conditions and geography (UNEP/WCMC, 2000). It hosts three biodiversity world hot spots, namely the Western Ghats, the Eastern Himalayas and the Indo-Burma region, regions showing high levels of endemism and species diversity. However, during the last few decades, these are under enormous threat due to various anthropogenic pressures such as tourism, industrialization and urbanization, in addition to the widespread introduction of invasive exotic species by humans. A number of exotic plant species either introduced deliberately or having entered accidentally have negatively affected ecosystem functions, reducing the effective habitat of endemic species and, in turn, have made the restoration of native species difficult.

In India there are a number of invasive weeds which have caused havoc with native biodiversity (Kohli *et al.*, 2009). It is very important to know and understand their biology, ecology and factors imparting

 Invasive Alien Plants: An Ecological Appraisal for the Indian Subcontinent (eds J.R. Bhatt *et al.*)

invasiveness in order to manage them. This chapter provides details regarding *Ageratum conyzoides*, an invasive alien weed in India.

Ageratum conyzoides

Ageratum conyzoides (family *Asteraceae*) is one such rapidly colonizing invasive alien species that has become a troublesome weed over a wide range of ecosystems in tropical and subtropical countries (Batish, 2008; Batish *et al.*, 2009a, b). It is one of about 30 species of the genus *Ageratum*, all of which originated in America (Okunade, 2002). The genus *Ageratum* is widely distributed throughout America, although most taxa have been reported in Mexico, Central America, the Caribbean and Florida (Ming, 1999). The literal meaning of *Ageratum* is non-ageing (referring to the longevity of its flowers or of the whole plant), with its origins in the Greek word *ageras*, whereas the species name *conyzoides* is derived from *konyz*, the Greek name for *Inula helenium* L., which it resembles (Kissmann and Groth, 1993). The English names of the plant, *goat weed* or *billy goat weed*, derive from its peculiar odour like that of male goat (Okunade, 2002). Johnson (1971) divided the taxon *A. conyzoides* into two subspecies, i.e. *latifolium* and *conyzoides*, of which *latifolium* is found throughout the Americas whereas *conyzoides* has a pantropical distribution.

The plant is now found as a weed of over 36 crops (including plantations) in 46 different countries (Holm *et al.*, 1977). It has been ranked as 19th of the world's worst weeds (Holm *et al.*, 1977). Waterhouse (1993) ranked *A. conyzoides* as the 15th most troublesome weed of South-east Asia and the Oceanic Pacific.

Global distribution of *Ageratum conyzoides*

Ageratum conyzoides, a native of Central America and the Caribbean, is now found throughout the world (Xuan *et al.*, 2004). The alien range of *A. conyzoides* includes West Africa, Australia, Colombia, Costa Rica, Ecuador, Fiji, French Polynesia, the Guam Islands, the USA (Hawaiian Islands), Tonga, Vanuatu, Palau, Mauritius, Nicaragua, the Solomon Islands, Papua New Guinea, Samoa and South-east Asia (including China, India, the Philippines, Singapore, Thailand, Vietnam, Cambodia, Malaysia and Indonesia), Brazil and Korea (Kong *et al.*, 2004; Kohli *et al.*, 2006; Sankaran, 2007; Batish *et al.*, 2009a).

In Hawaii, *A. conyzoides* grows up to 1300 m above sea level (Wagner *et al.*, 1999). In Pacific islands the weed has been found growing in different habitats such as crops, pastures, plantations, wastelands and roadsides (Swarbrick, 1997; PIER 2008). In Fiji, *A. conyzoides* is cultivated but it has now become invasive and naturalized in grasslands, forests, forest clearings and along roadsides and trails up to an elevation of 950 m (Smith and Albert, 1991; Sankaran, 2007). It has been reported to be a weed of plantations and waste areas in Tonga (Yuncker, 1959) and Guam (Stone, 1970). In New Guinea, *A. conyzoides* is spread up to 2000 m above sea level in both waste and cultivated lands, in plantations, pastures and along roadsides (Henty and Pritchard, 1975).

In the Galapagos Islands the plant can be seen in moist uplands (McMullen, 1999). The species has been reported to be one of the most dominant weeds of upland crops throughout South-east Asia (Kato-Noguchi, 2001). In Central Sulawesi (Indonesia), *A. conyzoides* was recorded as an invasive weed in coffee and cacao plantations and in the submontane rain forests of Lore Lindu National Park (Siebert, 2002; Ramadhanil *et al.*, 2008).

In South Africa, *A. conyzoides* was introduced in 1949 as an ornamental plant and has now become invasive in many parts, including reserves and protected areas like Kruger National Park (Foxcroft *et al.*, 2008). It grows as an exotic herb in the riparian zones of South African rivers (Hood and Naiman, 2000). Nel *et al.* (2004) conducted a survey of riparian zones in South Africa and concluded that *A. conyzoides* is one of the most widespread and abundant invasive riparian weeds.

In China, the species was first recorded in *The Flora of Hong Kong* by Bentham in 1861, and later in late 19th century in southern Yunnan Province (Yan *et al.*, 2001). It was introduced as an ornamental plant, and has now invaded the ruderal habitats and croplands of central China, South China, Xizang and the lowlands, mountains, plains and hills of Yangtze Drainage (Yan *et al.*, 2001; Huang *et al.*, 2009).

In Australia, *A. conyzoides* has been reported to be a major invasive weed of crops, pastures and disturbed sites in northern Queensland and the Northern Territory (Holm *et al.*, 1977; Jessup, 2002). In Lord Howe Island (Australia), *A. conyzoides* originated as a cultivated plant but has now become a common weed (GISD, 2010). In Zimbabwe, the weed is invasive in nature and is commonly found in abandoned and disturbed sites, open woodlands and along stream and seepage zones at an altitude range of 700–1660 m (Hyde and Wursten, 2010). Akter and Zuberi (2009) reported *A. conyzoides* as an invasive weed in different habitats such as fallow lands, homesteads, roadsides and railway tracks in Bangladesh.

Additionally, the weed is also found/listed as invasive in several other countries (Table 5.1).

Table 5.1. Global distribution of *Ageratum conyzoides*.

Region	Reference(s)
Continental Australia, Pacific offshore islands, Indian Ocean offshore islands, Christmas Island Group, Norfolk Island (Australia)	Holm *et al.* (1977); Orchard and Anthony (1994); Swarbrick (1997); Wagner *et al.* (1999)
Commonwealth of the Northern Mariana Islands, Lehua Island, Molokai Island, Maui Island, Hawaiian Islands, Guam Island, Virgin Island (America)	Fosberg *et al.* (1975); Wagner *et al.* (1999); PIER (2008); USDA-ARS (2009)
Chuuk Islands, Kosrae Island (Federal States of Micronesia)	Manner and Mallon (1989); Josekutty *et al.* (2002)
Society Islands, Polynesia, Marquesas Islands (French Polynesia)	Sachet (1983); Welsh (1998); Lorence and Wagner (2008)
Offshore islands, Bonin (Ogasawara) Islands (Japan)	Toyoda and Takeshi (2003); PIER (2008)
Nauru Island (Nauru)	Thaman *et al.* (1994)
New Caledonia Islands, Îles Loyauté (Loyalty Islands) (New Caledonia)	Gargominy *et al.* (1996)
Niue Island (Niue)	Yuncker (1943); Whistler (1988); Space *et al.* (2004)
Rock Islands, Angaur Island, Koror Island, Babeldaob Island, Malakal Island, Ngerkebesang Island (Palau)	Space *et al.* (2003, 2009)
Philippine Islands (Philippines)	Waterhouse (1993)
Savai'i Island, Upolu Island, Western Samoa Islands (Samoa)	Space and Flynn (2002); PIER (2008)
Tonga Islands, Tongatapu Island (Tonga)	Yuncker (1959)
Wallis and Futuna Islands (Wallis and Futuna)	Meyer (2007)
Kingdom of Cambodia (Cambodia)	Waterhouse (1993)
People's Republic of China (China)	Li-ying *et al.* (1997)
Republic of Indonesia (Indonesia)	Waterhouse (1993)
Republic of Singapore (Singapore)	Waterhouse (1993)
Taiwan Island (Taiwan)	Li-ying *et al.* (1997)
Kingdom of Thailand (Thailand)	Waterhouse (1993)
Socialist Republic of Vietnam (Vietnam)	Waterhouse (1993)
La Réunion Island (France)	MacDonald *et al.* (1991)
Maldive Islands (Maldives)	Fosberg (1957)
Mauritius and Rodrigues Islands (Mauritius)	Holm *et al.* (1977)

Source: GISD (2010).

Distribution in India

In India, *A. conyzoides* has been reported as existing prior to 1882 in *The Flora of British India* (Hooker, 1882). It was probably introduced as an ornamental plant in the 1860s (National Focal Point for APFISN, India, 2005), later attained a weedy habit and turned harmful to mankind. Its invasion and spread has caused ecological havoc to indigenous floristic composition in various regions of India, including the north-west Himalayas, eastern Himalayas, central India and Western Ghats (Yoganarnarasimham, 2000; Silori and Mishra, 2001; Kohli *et al.*, 2006; Reddy *et al.*, 2008).

The weed has been reported as one of the major invasive species, growing to an elevation of 2400 m in Himachal Pradesh (Kohli *et al.*, 2004; Dogra, 2008); in fact, around 50% of the area in Himachal Pradesh state is said to be infested by this obnoxious weed (Batta, 1988). It has been reported to be one amongst the ten most dominant herbs in forest grassland edge, weed-infested areas and low-lying wet grassland of the Jim Corbett tiger reserve, Terai and Bhabar regions (Rawat *et al.*, 1997) and in the wetlands of Samaspur Bird Sanctuary (Reddy *et al.*, 2009) in Uttar Pradesh, India. Sit *et al.* (2007) surveyed the eastern Himalayan region of West Bengal (India) and reported *A. conyzoides* as one of the most widely distributed weeds in various crop lands and palm gardens.

Negi and Hajra (2007) studied flora of the Doon Valley, north-west Himalaya and reported *A. conyzoides* as one of the invasive exotics. The species has been reported to occur in Veerapuli and Kalamalai forest reserve (Swamy *et al.*, 2000), tropical wet evergreen forests and the Anamalai Hills (Muthuramkumar *et al.*, 2006) of the Western Ghats of Tamil Nadu. *A. conyzoides* has been found to be a weed of disturbed sites in the tropical forest of Little Andaman Island in the Bay of Bengal (Rasingam and Parthasarathy, 2009). It has been found to be one of the dominant species in Agrakhal-Hindolakhal, Garhwal Himalaya, Uttaranchal (Bughani and Rajwar, 2005). In addition, *A. conyzoides* has been reported to be a major invasive weed on both the slopes and wetlands of Mothronwala swamp in the Doon Valley, Uttaranchal (Gupta *et al.*, 2006). Recently, *A. conyzoides* was found to be one of the most predominant weeds in Mandhala watershed in Himachal Pradesh (Rana *et al.*, 2010).

The plant has also been found as a major weed in the littoral and swamp forests of Assam (DOEF, 2010). In Arunachal Pradesh, *A. conyzoides* is one of the major weeds in West Siang (Singh *et al.*, 2002) and the most dominant weed under canopy of *Dendrocalamus hamiltonii* in tropical forests (Arunachalam and Arunachalam, 2002). In addition, the weed has also been reported in north-eastern and southern India (Rao, 2000) and the forests of the Gandhamardan Hills range, Orissa (Reddy and Pattanaik, 2009).

Spread of *A. conyzoides* in different habitats

Ageratum conyzoides is a serious problem of cultivated lands in the hilly tracts of north-western India (Bansal, 1988), where it forms dense thickets in commonly grown crops such as chickpea, rice, maize and wheat, and adversely affects crop yields (Kohli *et al.*, 2006). Due to its enormous seed-producing capacity, fields left fallow are rapidly invaded and colonized by the weed. In Himachal Pradesh the weed starts appearing at the tassel stage in maize, produces flowers and sets seeds by the time crop is harvested (Kanwar and Kharwara, 1988).

A study conducted by Reddi *et al.* (1977) demonstrated that *A. conyzoides* is a major weed in ratoon sugarcane crop fields with a population of 250–400 plants/m^2. In maize fields, its population has been observed to be 1000 plants/m^2, thereby completely covering the ground surface (Anonymous, 1986–1987). Kanwar and Kharwara (1988) studied the population of *A. conyzoides* in various fields and wastelands in Himachal Pradesh (India). The population of *A. conyzoides* was greatest in kitchen gardens (50 plants/m^2) followed by maize fields (20 plants/m^2) and was least in meadows

(5 plants/m^2). *Ageratum conyzoides* was also found to be a common weed of habitats such as grasslands, forest/plantation areas, water channels and wastelands in Chandigarh (Arora, 1999), with maximum plant density and dominance in forests (Table 5.2).

In the hilly tracts of north-western India, particularly in the lower and middle Himalayas, weed infestation is increasing at an alarming rate and it has severely hampered the growth of native plants. Dogra (2008) carried out an extensive survey of areas ranging from the lower or Shivalik Himalayas, (300–1500 m) to higher ranges of altitude (1500–2400 m, middle Himalayas) to investigate the spread and invasion by *A. conyzoides* in north-western India. It was documented that the density of weed was greater in the lower Himalayas compared with the middle Himalayas. However, the upper Himalayas (2400–3800 m) were found to be free of the weed (Dogra, 2008). A survey conducted in Shimla and Kinnaur (Shivalik hills) showed that *A. conyzoides* constituted 21.42% of the total herb species (Rana and Sharma, 2009). Recently, it has been observed that infestation by *A. conyzoides*, along with *Cynodon dactylon* and *Parthenium hysterophorus*, constituted 75% of the total population in Mandhala watershed in Himachal Pradesh (Rana *et al.*, 2010).

The weed not only invades agricultural/arable field, but also severely infests disturbed sites. Due to its strong competitive ability and fast propagation, it has covered all terrain not under intensive use, care and managed efficiently, and causes significant ecological damage. Figures 5.1 and 5.2 show huge monocultures of *A. conyzoides* on wasteland and around a wheat field, respectively.

Habitat and characteristic features

Physiognomically, *A. conyzoides* is an annual erect aromatic herb that shows considerable variation in shoot height (59–120 cm) in a stand at maturity stage (Table 5.3); however, the average height of plant is ~1 m (Kumar and Singh, 1988). The stem is erect, branched, cylindrical and decumbent, and covered with fine, white hairs. Leaves are opposite, ovate and triangular, and pubescent with the long petiole (1.5–2.0 cm or even up to 3.2 cm), covering an area of ~31 cm^2 and bearing trichomes (56 in number) on both surfaces (Kirtikar and Basu, 1984; Arora, 1999). Plants have a shallow tap root system with a radius of spread of ~8 cm. The plant bears blue–violet terminal inflorescence (Fig. 5.3) and a capitulum of homogamous disc florets (>70 capitula per plant) arranged in corymbose racemes (Kumar and Singh, 1988; Arora, 1999). The inflorescence changes colour from blue when young to white at maturity. The number of florets per head varies in the range 56–86 (Anonymous, 1988; Table 5.3).

The flowering period of the weed is long, and flowers retain their violet colour for a longer period of time. The fruit is a typical achene with pappus and easily spread by wind and animal hair. Seeds are minute (<1 cm), black and extremely light in weight, elliptical, bear a pappus, are produced in great numbers (Table 5.3) and are transported up to hundreds or thousands of miles. Arora (1999) reported that in Chandigarh, wild-growing plants produce on average ~5000 seeds. However, Rodriguez and Cepero (1984) reported a total of 94,772 seeds per plant. The weed completes its life cycle in about 10–12 weeks, and seeds are shed, resulting in tremendous increase in

Table 5.2. Distribution of *Ageratum conyzoides* in different habitats (Chandigarh, India).

Habitat	Density (%)	Frequency (%)	Dominance (%)	Importance value index (IVI) (%)
Grassland	59.98	22.24	57.96	140.18
Forest	81.73	15.79	83.67	181.19
Water channel	61.94	20.18	60.24	142.36
Wasteland	61.00	21.69	80.10	162.79

Fig. 5.1. Monoculture of *Ageratum conyzoides* on wasteland.

Fig. 5.2. *Ageratum conyzoides* around a wheat field.

its intensity next season (Bansal and Singh, 1986). The propagation of the weed through seeds is so rapid that it covers almost any terrain not under intensive use or abandoned. *Ageratum conyzoides* is a shade-tolerant plant and flourishes well in any type of garden soil such as clayey, sandy or loamy with wide range of pH. Soils rich in moisture, minerals and air are best suited to its growth.

In hilly tracts of subtropical to temperate environment, the weed is present throughout the year. However, in the plains, it emerges during the onset of winter and remains till early summer. In shady and moisture-rich areas the weed is also seen during the summer rainy season; however, in such areas it has a relatively shorter life span and reduced density (Kohli *et al.*, 2006).

Invasive potential of *A. conyzoides*

Ageratum conyzoides has become an invasive weed in a wide variety of natural and man-

Table 5.3. Morphological features of *Ageratum conyzoides.*

Parameter	Value
Shoot height (cm)	82.60 ± 20.29
Radius of spread (cm)	8.01 ± 0.50
Root length (cm)	7.70 ± 0.82
Basal area (cm^2)	1.92 ± 0.68
Shoot:root ratio	10.72 ± 3.59
Biomass (g)	3.56 ± 0.20
Trichomes (per cm^2)	
• leaf	55.5 ± 11.7
• stem	32.0 ± 9.3
Length of leaf petiole (cm)	1.75 ± 0.61
Leaf lamina	
• shape	Broadly ovate or rhomboid ovate to triangular
• length (cm)	7.69 ± 3.24
• width (cm)	5.07 ± 2.64
• perimeter (cm)	20.81 ± 10.14
• area (cm^2)	30.54 ± 16.34
• transpiration rate (µg/cm^2/s)	79.36 ± 10.21
• diffusion resistance (s/cm)	0.046 ± 0.011
• relative humidity (%)	44.48 ± 5.96
Peduncle length (cm)	0.64 ± 0.11
Flower colour	Sky blue to violet when young, white on maturity
Inflorescence	
• type	Capitulum made up of homogamous disc florets
• number	69.00 ± 3.92
• diameter of head (mm)	6.1 ± 0.5
• number of florets per head	71.50 ± 10.13
Seed	
• colour	Black, bearing pappus
• number	4935.13 ± 77.08
• length (cm)	3.4 ± 0.5
• width (cm)	0.33 ± 0.01
• weight (µg)	5.06 ± 0.18

Fig. 5.3. Inflorescence of *Ageratum conyzoides.*

made ecosystems ranging from forests and grasslands to farmland. It is a prolific ephemeral herb with great morphological variations and easily adapts to different ecological conditions (Sauerborn and Kock, 1988). The weed has been recognized as one of the most serious pests of modern agriculture, one that has encroached on almost all other types of lands, i.e. waste-lands, natural forest, plantations, vegetable gardens, overgrazed pastures, orchards, range/grasslands, riparian zones, ruderal/ disturbed sites, shrub/shrublands, tea orchards, meadows, water courses, fresh landslides or areas with deep gullies and wetlands, and also along roadsides (Kanwar and Kharwara, 1988; Rao, 2000; Kunwar *et al.*, 2001; Kohli *et al.*, 2006; Sankaran, 2007; Batish *et al.*, 2009a, b; GISD, 2010).

Features imparting invasiveness

Attributes for successful invasion of *A. conyzoides* include:

- fast growth and rapid spread due to potential to become well established;
- wide ecological amplitude;
- high reproductive potential (both sexual and vegetative);
- long flowering and fruiting periods;
- absence of natural predators/enemies/competitors;
- resistance to predators;
- unpalatable due to high phytotoxin content; and
- resource competition along with novel weapons such as allelopathy.

Impacts of *A. conyzoides*

Different ecosystems

FORESTS. The shade-tolerant nature of *A. conyzoides* allows it to become established under tree canopies in developed forests. It has become an aggressive colonizer that can maintain dense populations within the understorey during its growing period (Arora, 1999). The tree canopy in forests and plantations provides favourable conditions such as shade for growth. The tree plantations of *Acacia catechu* and *Eucalyptus* spp., *Pinus* forests and mixed-culture tree plantations in the lower Himalayas of Himachal Pradesh have been observed to be occupied by *A. conyzoides* (Dogra, 2008). Native plant species growing in various plantations have been facing threats due to invasion by this exotic weed; this species was observed as the most frequently and densely growing under *Eucalyptus* and mixed-tree plantations (Dogra, 2008). Reddy and Pattanaik (2009) reported *A. conyzoides* among 64 exotic species posing a serious threat to the dense interior forests of the Gandhamardan Hill range, Orissa. The weed was found to encroach on the littoral and swamp forests of Assam, retarding/preventing natural succession and reforestation, so much so that some forests have lost their identity (DOEF, 2010).

GRASSLANDS. The fast-spreading stolons of *A. conyzoides* greatly enhance its potential to cover large areas of grassland. Once established, the weed displaces and replaces native grasses/plants and reduces grazing areas, resulting in fodder scarcity. The density, diversity and biomass of associated vegetation are severely affected in weed-infested grassland compared with weed-free areas in Chandigarh (Arora, 1999; Table 5.2). Furthermore, it reduces the carrying capacity of pastures, causes thinning of floral diversity and may lead to the disappearance of threatened and endemic species (Kohli *et al.*, 2004, 2006).

CULTIVATED LANDS. Agriculture ecosystems are most seriously affected by *A. conyzoides*, ecologically as well as economically. Due to the fast-spreading nature of *A. conyzoides*, it hinders field practices such as ploughing and field preparation, thereby increasing the maintenance cost of agricultural fields. It adversely affects the growth and production of major staple annual and perennial crops in India (Kohli *et al.*, 2006; Batish *et al.*, 2009a, b), and forms dense monocultures and interferes with the establishment of many crops such as maize, chickpea, rice and wheat (Kohli *et al.*, 2006; Batish *et al.*, 2009a, b). Additionally, it acts as a host for many crop diseases (Kashina *et al.*, 2003; Ekeleme *et al.*, 2005).

In the lower Shivalik range of the Himalayas this weed infests cultivated lands to such a serious extent that farmers may have to abandon their fields (Kohli and Batish, 1996; Batish *et al.*, 2004a). Due to this type of heavy infestation, nothing is left in areas where it has invaded – it is known as *Ujaroo* (the one that destroys everything) in this area (Negi, 1988).

Roder *et al.* (1995, 1998) reported *A. conyzoides* as one of the major weeds in rice fields in Asia, causing severe reduction in rice yield following invasion. It is considered as one of the worst weeds of paddy fields in Pokhra (Thapa and Kayastha, 1998) and Kirtipur in Nepal (Manandhar *et al.*, 2007). Manandhar *et al.* (2007) reported reductions in rice grain (25–47%) and straw (13–38%) yields due to infestation by *A. conyzoides*. It

has been reported to be one among the problematic weeds associated with *Gladiolus* cultivation, adversely affecting productivity as well as product quality (Riaz *et al.*, 2007).

Many workers have attributed the observed loss in crop produce and quality to the allelopathic potential of the weed (Singh *et al.*, 2003; Batish *et al.*, 2006, 2009a, b; Manandhar *et al.*, 2007; Batish, 2008). However, Ekeleme *et al.* (2005) opined that shoot competition for light may also be one of the major causes of its interference with crops.

Soil nutrients

Ageratum conyzoides directly or indirectly affects soil chemistry and composition, ecosystem functions and creates a novel environment for native species. Heavy infestations of the weed modify the soil environment through root exudation, affecting soil structure and mobilizing or chelating nutrients (Singh *et al.*, 2003). Furthermore, it causes depletion of soil nutrients because of resource competition, rendering it unfit for effective growth of crops and making sustainability difficult. Manandhar *et al.* (2007) reported a significant reduction in soil nitrogen and phosphorus in paddy fields due to weed infestation. On the other hand, Batish *et al.* (2009a, b) reported that weed residues enriched soil nutrient content despite the negative effects on crop growth.

Native vegetation and biodiversity

The Himalayas in India is a global hot spot zone and has an exceptionally high level of biodiversity. However, the spread of *A. conyzoides* along with other exotics has remarkably altered the communities and ecosystem by depleting the indigenous species (Kohli and Batish, 1996; Kohli *et al.*, 2006; Dogra *et al.*, 2009a, b). Invasion of *A. conyzoides* is a matter of serious concern, as it causes a reduction in niche or habitat for growth and establishment of valuable plants. In fact, the, rapid spread of this exotic is a serious concern for foresters, farmers, ecologists, environmentalists, shepherds, orchardists, horticulturists and animal scientists.

Once established, it dominates large areas, disrupts nutrient cycles and alters the pattern of plant succession in the native ecosystems. Invasion by *A. conyzoides* results in negative interactions with native species for food and other natural resources, causing extinction of associated vegetation and thereby declining species richness. Kohli *et al.* (2004) observed a huge loss in plant diversity and density (~50–64%) of native flora after invasion by *A. conyzoides* in the Shivaliks, North India. The indices of richness and evenness were significantly less in weed-infested areas compared with weed-free areas, indicating the reduced numerical strength and uneven distribution of native flora. Weed-free areas exhibited higher plant diversity (Shannon's index), indicating heterogeneity in the communities. Compared with this, invasion by *A. conyzoides* resulted in a severe loss of plant diversity, and consequent homogeneity in communities. On the other hand, the index of dominance was higher in areas invaded by *A. conyzoides*, showing its dominance (occurrence of a single species) in the community (Kohli *et al.*, 2004). The homogenous nature of a community leads to instability that further aggravates the potential for invasion by opportunistic species, especially those with wider ecological amplitude. This changing pattern of vegetation in weed-occupied areas in comparison with weed-free areas may be attributed to the allelopathic nature of the weed, apart from other factors (Batish, 2008).

Dogra (2008) reported a decline in valuable indigenous medicinal plants such as *Achyranthes aspera*, *Trifolium repens*, *Centella asiatica*, *Zizyphus jujuba*, *Dichanthium annulatum*, *Murraya koenigii*, *Adhatoda vasica*, *Carissa* spp. and *Colebrookea* spp. in the Shivaliks of Himachal Pradesh (India) following invasion by *A. conyzoides*. Some species such as *Sonchus oleraceus*, *Sonchus asper*, *Vernonia cinerea*, *Abutilon indicum*, *Agave americana* and *Medicago lupulina* were not found in weed-infested areas, while they were found to be growing abundantly in weed-free areas (Dogra, 2008).

Batish (2008) revealed that *A. conyzoides* causes reduction in growth of other grasses and weeds measured in terms of dry biomass (up to 50%) and total number of species (up to 30%). Its dense monoculture-forming growth habit places it in the category of invasive species that can transform the integrity of community and ecosystems visually, structurally and chemically. A recent study showed that ~20% of the vegetational area in the lower Shivalik Hills of the Himalayas was occupied by *A. conyzoides*, along with other invasive plants; however, this weed accounted for ~30% reduction in plant species (Dogra *et al.*, 2009a, b).

Dogra *et al.* (2009b) investigated the impact of invasion by *A. conyzoides* along with other invasive species on the structure and composition of communities in the lower Himalayas. Following weed infestation, alpha diversity was reduced by ~40%. The number of abundant and very abundant species, index of evenness, and fresh and dry biomass of vegetation were also drastically reduced in areas infested by *A. conyzoides* compared with weed-free areas. All these observations show the homogenous nature of the ecosystem and loss of productivity in weed-infested areas (Dogra *et al.*, 2009a, b). Furthermore, fresh and dry biomass was also reduced in *A. conyzoides*-infested areas compared with weed-free areas, thus making those areas less productive (Dogra *et al.*, 2009a, b). *Ageratum conyzoides* has also been reported as being among the three most invasive weeds that have altered the community structure and population dynamics of native flora and fauna in the Shivalik Hills (Rana and Sharma, 2009). Recently, it has been reported that the undesirable effects of *A. conyzoides* – along with those of other plants – resulted in unevenness and instability of herb layers in the Mandhala watershed in Himachal Pradesh (Rana *et al.*, 2010).

Even the reserve parks/wildlife sanctuaries/protected areas have also been observed to be affected by this weed, resulting in disruption and loss of natural vegetation; for example, the Jim Corbett tiger reserve (Rawat *et al.*, 1997), the Veerapuli and Kalamalai forest reserve in the Western Ghats (Swamy *et al.*, 2000) and the Mudumalai wildlife sanctuary (Silori and Mishra, 2001) have been observed to be infested by *A. conyzoides*.

Humans and animals

Not only does *A. conyzoides* affect farmers and scientists, but it also has adverse effects on human and animal health. People in contact with this weed suffer from nausea, giddiness, irritation and asthma (Kohli and Batish, 1996; Negi and Hajra, 2007). Livestock do not feed on it as it causes ulceration and toxicity.

Role of allelopathy in invasion potential of *A. conyzoides*

Allelopathy is a type of biotic interference in which plants release bioactive molecules into the surrounding environment and that negatively affects the growth of nearby vegetation. In fact, allelopathy has been adopted as a successful strategy for the spread, establishment, domination and colonization of alien environments by invasive weeds, thereby replacing native vegetation (Bais *et al.*, 2004; Kohli *et al.*, 2004, 2006; Hao and Qiang, 2005; Batish, 2008). A number of aggressive weeds have been reported to exhibit allelopathy as a mechanism of interference, which provides them competitive advantage over other plants (Qasem and Foy, 2001). *Ageratum conyzoides* has been reported to have adopted allelopathy as a strategy to out-compete native flora and suppress growth of crops. There is much evidence regarding the allelopathic nature of *A. conyzoides* providing it with selective advantage (Kong *et al.*, 1999; Batish *et al.*, 2009a, b). It has been demonstrated that root and shoot aqueous extracts of *A. conyzoides* are phytotoxic to seed germination and seed vigour in maize and soybean (Singh *et al.*, 1989) and to growth in wheat and rice (Jha and Dhakal, 1990; Prasad and Srivastava, 1991). Acetone extracts of *A. conyzoides* shoot residues inhibited the germination and growth of roots and shoots of *Amaranthus caudatus*,

Digitaria sanguinalis and *Lactuca sativa* (Kato-Noguchi, 2001).

Leaf debris and even soil entangled with the roots of *A. conyzoides* (rhizosphere soil) were also observed negatively to affect roots, shoot length and biomass accumulation in rice by ~18–30% (Batish *et al.*, 2009a). Apart from living tissues, leftover residues collected at the end of the growing season in the area of weed invasion also interfered with maize and rice (Batish *et al.*, 2004b). However, the allelopathic potential of *A. conyzoides* varies depending on organ, developmental stage and habitat (Hu and Kong, 1997).

Soil inhabited by the weed has been reported to be rich in non-volatile allelochemicals (Singh *et al.*, 2003) and to be phytotoxic to growth of other plants. Radicle and coleoptile lengths of crop plants were severely suppressed when grown in field soil previously infested with *A. conyzoides* (Kalia, 1998; Singh *et al.*, 2003). This may have been due to water-soluble phytotoxins present in *A. conyzoides* that interfere with the process of nutrient uptake (Batish, 2008; Batish *et al.*, 2009a, b).

Batish *et al.* (2006) demonstrated the allelopathic effect of *A. conyzoides* against chickpea and observed a severe reduction in the number of nodules, nodule weight and the leghaemoglobin content of the nodules of chickpea grown in soil amended with weed residues. Later, it was found that weed-infested soil and leaf extracts deleteriously affected the growth of rice, which was attributed to water-soluble phytotoxins, i.e. phenolics (Batish *et al.*, 2009a). Leaves were demonstrated to exhibit a greater inhibitory effect than stems and roots (Xuan *et al.*, 2004).

Even the extracts of isolated and purified precocene I and II, the major chromenes of *A. conyzoides*, also possessed allelopathic potential towards tomato, ryegrass and radish (Kong *et al.*, 1998a, b). Kong *et al.* (1999, 2002) demonstrated that volatile leaf oils from *A. conyzoides* inhibited seedling growth and reduced the chlorophyll content of *Cucumis sativus*, *Lolium ultiforum*, *Raphanus sativus*, *Phaseolus aureus*, *Triticum aestivum* and *Lycopersicon* sp. Greater inhibition was observed in response to volatile oils compared with pure constituents, thus demonstrating the synergistic effect of allelochemicals (Kong *et al.*, 1999). Furthermore, the allelopathic potential of the weed is enhanced when plants are grown under stress conditions such as nutrient deficiency (Kong *et al.*, 2002).

Phytochemistry

Since *A. conyzoides* possesses diverse biological and physiological characteristics it has been explored intensively, particularly for its secondary metabolites (Gonzalez *et al.* 1991; Wiedentold and Roder, 1991). A wide range of secondary metabolites from different classes are found in *A. conyzoides*, including flavonoids, alkaloids, chromenes, phenolics and essential oils (Gonzalez *et al.*, 1991; Sharma and Sharma, 1995). Among these secondary metabolites, many are allelochemicals and inhibit the growth of other organisms (Pari *et al.*, 1998; Okunade, 2002). These allelochemicals are released either through leaching or volatilization into the soil or environment in bioactive concentrations, and retard the growth of other plants and organisms (Singh *et al.*, 2003; Batish *et al.*, 2009a, b).

Volatile compounds

Almost every part of a plant contains volatile oils; the leaves and roots of *A. conyzoides* contain volatile oils in the range of 0.11–0.58% and 0.03–0.18%, respectively, depending on the season (Wandji *et al.*, 1996). As many as 51 constituents, including a number of mono- and sesquiterpenoids, have been identified from its volatile oils (Okunade, 2002). The chromenes 7-methoxy-2,2-dimethylchromene (precocene I), 6,7-dimethoxy derivative, ageratochromene (precocene II) and their derivatives (Burkill, 1985; Rastogi and Mehrotra, 1990; Kissmann and Groth, 1993; Kong *et al.*, 1998a, b) are the major constituents of leaves and flower oils, and possess biological activities (Bowers *et al.*, 1976). These allelochemicals are

released from *A. conyzoides*, accumulate in the soil with the passage of time and were found to be responsible for growth suppression of weeds and reducing the population of soil-borne pathogenic fungi in intercropped citrus orchards (Kong *et al.*, 2004). Kong *et al.* (1999, 2002) demonstrated that fresh leaves and volatile oils of *A. conyzoides* exhibited adverse effect on crops, and they attributed this to the presence of precocenes and their derivatives, i.e. precocene I, precocene II, 3,3-dimethyl-tert-butylindone and β-caryophyllene, and several mono-terpenes and sesquiterpenes.

Non-volatile compounds

In addition, *A. conyzoides* is very rich in poly-oxygenated flavonoids such as kaempferol, quercetin and their glucosides, and small quantities of triterpenoids and sterols (Okunade, 2002). A number of phenolic acids such as gallic, coumalic, protocatechuic, benzoic, sinapic, *p*-hydroxybenzoic and coumaric acid have been reported as active compounds in *A. conyzoides* (Xuan *et al.*, 2004). Batish *et al.* (2009a, b) reported the non-volatile components catechin and phenolic acids (gallic acid, coumalic acid, protocatechuic acid and *p*-hydroxybenzoic acid) from leaves and soil inhabited by the weed. However, the level of allelochemicals and hence allelopathic potential depends upon the growth stage and type of habitat (Kong *et al.*, 2004). Its seeds have also been known to yield fatty oils (Ambasta, 1992). These allelochemicals show a synergistic effect, and their allelopathic potential is intensified on exposure to various environmental stresses (Josep and Joan, 1997; Kong *et al.*, 2002; Batish *et al.*, 2009a, b).

Uses of *A. conyzoides*

Although this weed is becoming a serious concern for farmers, horticulturalists, foresters, land managers, ecologists and environmentalist, the plant also has some useful aspects, including the following.

Medicinal value

Ageratum conyzoides is an integral part of traditional medicine in many countries of world, particularly in tropical and subtropical regions. The extracts and metabolites of *A. conyzoides* have been used as a bacteriocide, antidysentric and antilithic (Borthakur and Baruah, 1987; Okunade, 2002) by traditional communities in India, South America and Africa. In Central Africa, Brazil and Congo it is used to cure pneumonia, wounds and burns (Ming, 1999). Its decoction is given to treat headache, fever and rheumatism (Kirtikar and Basu, 1984; Okunade, 2002). A crude material from leaves of species possesses *in vitro* antibacterial activity against *Staphylococcus aureus* and is also used for wound healing (Durodola, 1977). In Cameroon, aqueous extracts of the whole plant are known for their anti-diabetic properties (Tsabang *et al.*, 2001).

Insecticidal/bactericidal/antifungal value

The oil obtained from its leaves and inflorescence has insect-repellent properties (Saxena *et al.*, 1994; Nogueira *et al.*, 2010). Traditional communities in Asia, South America and Africa use the aqueous extracts of the species as a bactericidal (Borthakur and Baruah, 1987; Ekundayo *et al.*, 1988). Leaf volatile oils of *A. conyzoides* have been reported to kill the maize grain weevil, *Sitophilus zeamais* (Bouda *et al.*, 2001). The weed has also been reported to have natural fungicidal potential (Pu *et al.*, 1990; Gravena *et al.*, 1993).

Herbicidal value

Ageratum conyzoides has been reported as a natural herbicide for weed control in paddy fields (Xuan *et al.*, 2004). Application of *A. conyzoides* at 2 t/ha served as an effective herbicide in controlling paddy weeds such as *Echinochloa crus-galli* var. *formosensis*, *Monochoria vaginalis* var. *plantaginea* and *Aeschynomene indica*. Ramakrishna *et al.* (2006) reported that a mulch of *A. conyzoides* had good potential in checking the growth of weeds and enhancing crop yield.

Others

A mulch of *A. conyzoides* has been reported to prevent loss of soil moisture and reduce erosion (Ramakrishna *et al.*, 2006). It can serve as good biological waste for the preparation of manure and biogas. Dried plant material from *A. conyzoides* is used for pest control (Vallador *et al.*, 1994). *Ageratum conyzoides* planted as a riparian wetland herb on the banks of the Rihand River in Renukoot plays a positive role in reducing erosion of organic carbon and cationic nutrients and helps in soil conservation (Kumar *et al.*, 1996). Recently, it has been observed that *A. conyzoides* helps in maintaining the texture and fertility of soil along the River Damodar riparian zone in Bhowra, as soil erosion was minimized to a great extent following its planting compared with bare areas (Srivastava *et al.*, 2009).

Control/management of *A. conyzoides*

To date, a number of strategies including physical, chemical and ecological methods have been tried, though none has been found completely to control or manage the weed.

Physical methods

These include manual uprooting, mowing, cutting with machete or burning of live plants. In general, these are of some use when the plant is at the vegetative stage. However, certain limitations are associated with these methods, for example the high cost of labour, ill-effects on workers' health, vegetative regeneration from stolons, etc. (Batish *et al.*, 2004a). Furthermore, at the maturity stage, uprooting of plants results in dispersal of seeds to other areas.

Chemical methods

Pre-emergence application of commercial herbicides such as atrazine, diuron, methazole, metribuzin or simazine is an effective control strategy. For established infestations, the application of 2,4-D and 2,4,5-T provides excellent control of this weed (Rao, 2000). However, due to toxicological implications, synthetic herbicides are not recommended as a good method of controlling *A. conyzoides*.

Field and crop management

To optimize weed control, farmers are required to know the time of emergence of weed seedlings relative to the crop, apart from any use of commercial herbicides (Ekeleme *et al.*, 2005). In northern Laos, increased fallow periods in slash-and-burn rice production systems have resulted in reduced weed infestation (Roder *et al.*, 1998).

Ecological methods

The use of eco-friendly compounds such as natural plant products and other plant-based formulations offers a safer strategy for effective weed control. Volatile monoterpenes such as cineole and citronellol have been found to have considerable effects on germination, growth, chlorophyll content and cellular respiration of *A. conyzoides*, suggesting much potential for weed management (Singh *et al.*, 2002a). A study conducted by Batish *et al.* (1997) and Singh *et al.* (2002b) revealed that parthenin, a sesquiterpene lactone from *Parthenium hysterophorus*, negatively affected the growth and physiology of *A. conyzoides* and has potential for use as a novel agrochemical.

Role of community

The methods outlined above cannot achieve successful weed control and management on their own; an integrated approach, incorporating all the above approaches, is essential. Furthermore, fallow lands likely to be invaded by the species should be put to some use such as planting of native grasses and fodder. To this end, local communities play a significant role (Anonymous, 2003). Local populations need to learn about environmental issues, the ecological hazards of *A. conyzoides* and the identification of the

species so that it may be uprooted at an early stage before it spreads. Furthermore, organic compost and vermicompost may be useful to control and manage the weed (Batish *et al.*, 2004a).

Conclusions

From the above discussion, we conclude that *Ageratum conyzoides* is one of the most harmful exotic weeds in a wide variety of habitats and adversely affects many facets of ecosystem function. The weed possesses many physiological, ecological and morphological features that help in its successful invasion. Therefore, efforts should be made to manage this weed through an integrated approach involving different management strategies in combination with community participation.

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