

Vanishing Biodiversity: Global Threats to Flora and Fauna

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EFFECTS OF INVASIVE SPECIES IN AN ECOSYSTEMS: A CASE STUDIES FROM NAGALAND

**Wati Temjen¹, Khikeya Semy², Aosenla Jamir³, Ngampo S. Salim³
and Maibam Romeo Singh^{3*}**

¹Department of Botany, Fazl Ali College, Mokokchung, Nagaland - 798 601, India.

²Department of Botany, Wakching New Model College, Mon, Nagaland - 798 622, India.

³Department of Botany, Nagaland University, Lumami, Nagaland - 798 627, India.

*Corresponding author e-mail : romeomaibam@nagalanduniversity.ac.in

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ABSTRACT: Invasive alien species (IAS) pose one of the most significant threats to global ecosystems, altering ecological balance, disrupting nutrient cycles and accelerating biodiversity loss. Their spread intensified by globalization, habitat disturbance and climate changes which leads to profound ecological impacts, from soil modification to competitive displacement and allelopathic suppression of native flora. Globally, IAS have contributed to species extinctions, ecosystem homogenization, and long-term habitat degradation. This chapter synthesizes the ecological impacts of invasive plants by exploring key subtopics including ecosystem effects, soil physicochemical alterations, nutrient cycling disruptions, competitive mechanisms, habitat modification and allelopathic effects. Using global evidence and regional insights, the chapter highlights how invasives such as *Tithonia diversifolia*, *Parthenium hysterophorus*, *Ageratina adenophora* and *Lantana camara* reshape both natural and agricultural landscapes. The second part of the chapter presents four detailed case studies from Nagaland: (i) soil modification by *Tithonia diversifolia* (ii) invasive assemblages in Mokokchung town (iii) allelopathic effects on *Capsicum chinense* and (iv) the dual ecological-cultural role of IAS in community forests. Together, these cases illustrate the multifaceted challenges posed by invasives and underscore the need for integrative, community-based management strategies to safeguard biodiversity-rich ecosystem.

Keywords: Invasive alien species; allelopathy, biodiversity loss, soil nutrient rich, Nagaland

Introduction

Biodiversity constitutes the foundation of ecosystem functioning and resilience, enabling ecosystems to provide vital services such as nutrient cycling, soil fertility maintenance, food production, and climate regulation (Cardinale *et al*, 2012). However, biodiversity worldwide is under unprecedented threat due to multiple drivers, including habitat destruction, climate change, pollution, overexploitation, and biological invasions. Among these, invasive alien species (IAS) have emerged as one of the most pressing concerns, as they disrupt ecological balance, alter soil and habitat properties and directly compete with or suppress native biodiversity (Simberloff *et al*, 2013; Vilà *et al*, 2011). The rapid globalization of trade and travel, coupled

with anthropogenic land-use changes, has further accelerated the introduction and spread of invasive species across different ecosystems (Pyšek *et al*, 2020).

The Convention on Biological Diversity (CBD, 1992) defines invasive alien species as species introduced outside their natural range whose establishment and spread threaten biodiversity, ecosystem services, or human well-being. IAS can be both plants and animals. Plant invaders, such as *Lantana camara* and *Parthenium hysterophorus* in India, outcompete native vegetation, alter soil nutrient dynamics, and reduce biodiversity. Animal invaders, such as the common myna (*Acridotheres tristis*) or zebra mussel (*Dreissena polymorpha*), exert pressure on native fauna by predation, competition, or habitat alteration. Together, these invasions lead to homogenization of ecosystems and are recognized as one of the leading drivers of global biodiversity loss. Globally, IAS are recognized as the second leading cause of species extinctions, after habitat destruction (Bellard *et al*, 2016). Invasive plants in particular alter soil conditions, displace native flora, and modify ecological processes through mechanisms such as competition for resources, habitat alteration, and allelopathy—the release of biochemical compounds that suppress germination and growth of neighboring species (Inderjit and van der Putten, 2010).

Distribution of Invasive Plants

Mosyakin (2008) listed 120 plant species native to Ukraine and Eastern Europe as invasive in North America, dominated by Asteraceae and Poaceae. In Brazil, Zenni and Ziller (2011) recorded 117 invasive species, including *Artocarpus heterophyllus* and *Hedychium coronarium*. Tan *et al* (2012) surveyed 10 national parks in Vietnam, reporting 134 alien plants, of which 25 were invasive (*Chromolaena odorata*, *Ageratum conyzoides*, *Bidens pilosa*, *Mikania micrantha*), mainly in disturbed areas. Singh and Sharma (2014) documented 55 alien plants from 24 families in Nepal that reduced crop productivity. Rojas-Sandoval *et al* (2017) found 516 invasive plant species across nine West Indies islands, with Fabaceae (88), Poaceae (77) and Asteraceae (33) comprising 38% of the total. Mahklouf (2019) documented 29 invasive species in Libya, with Asteraceae (7) dominant. Weidlich *et al* (2020) reviewed invasive species control across 10 biomes and found Poaceae most frequently controlled, followed by Asteraceae; non-chemical methods dominated globally (57.7% overall; 100% in Africa), while chemical methods accounted for 42.3%.

Invasive Plants in the Indian Context

India, within the Indo-Burma and Himalayan biodiversity hotspots, is highly vulnerable to invasions due to diverse climates and human disturbances. Nearly 40% of Indian flora is alien, with ~25% invasive (Raghubanshi *et al*, 2005). Key invaders include *Parthenium hysterophorus*, *Chromolaena odorata*, *Mikania micrantha*, *Lantana camara* and *Tithonia diversifolia*. In Himachal Pradesh, 9.4% of species were exotic (*Parthenium*, *Ageratum conyzoides*, *Lantana*) (Reddy *et al*, 2008). A national review documented 173 invasive species in 44 families (87% herbs), largely of tropical American origin (74%). Khuroo *et al* (2012) further identified 1,599 alien species in 842 genera, with Asteraceae, Papilionaceae and Poaceae dominant; 35% originated in South America.

Protected area studies show limited coverage, with nearly half focused on *Lantana camara* (Hiremath and Sundaram, 2013). Regional surveys reported 90 invasive species in the Western Ghats (Aravindhan and Rajendra, 2014), 87 in the Eastern Ghats (Naidu *et al*, 2015), 96 in the Thar desert (Charan and Singh, 2018), 165 around Rourkela (Mallick *et al*, 2019) and 209 in Odisha (Mandal *et al*, 2020). Smaller studies recorded 18 species in Jorhat, Assam (Das and Duarah, 2013) and four major invaders in Rajiv Gandhi Orang National Park (*Ageratum*, *Chromolaena*, *Mikania*, *Mimosa diplotricha*) (Choudhury *et al*, 2017). Other major invaders across NE India include *Hypoestis*, *Lantana*, *Eupatorium* (Segupta and Dash, 2020). Hailakandi District recorded 44 invasive species, mostly herbs (27) and shrubs (17), with Asteraceae dominant (*Ageratum*, *Chromolaena*, *Lantana*, *Mikania* most aggressive) (Zhuppi *et al*, 2021). The Northeastern Hill (NEH) region, including Nagaland, faces severe invasions due to shifting cultivation, deforestation, and roads (Longchar *et al*, 2023; Semy *et al*, 2024). *Tithonia diversifolia*, introduced from Central America, now spreads rapidly along roadsides, wastelands, and fields in Nagaland, Mizoram, and Manipur, significantly altering soil and vegetation (Singh and Theunuo, 2018). By integrating soil science, plant ecology and allelopathy, this chapter underscores the multidimensional disruptions caused by invasive plants and emphasizes the need for comprehensive strategies to mitigate their impacts in biodiversity-rich regions such as Northeast India.

Effects of Invasive Species on Soil Properties

Soil properties are fundamental determinants of ecosystem structure and function, influencing plant productivity, microbial activity, nutrient cycling, and overall ecosystem resilience (Paul, 2014). Invasive plant species, through mechanisms such as high biomass production, altered litter quality, root exudation, and nutrient uptake strategies, can significantly modify the physical, chemical, and biological properties of soils (Ehrenfeld, 2010). These alterations often create feedback loops that further facilitate the persistence and spread of invasives while disadvantaging native species. The impacts on soil are not merely incidental but are often central to the ecological success of invasive plants (Inderjit and van der Putten, 2010).

This section examines the effects of invasive species on soil properties with emphasis on physicochemical changes, nutrient cycling, and soil fertility dynamics. Using *Tithonia diversifolia* as a primary case study from Nagaland, India, it synthesizes evidence of how invasives reshape soil systems and compares these findings with global examples.

Physicochemical Alterations in Invaded Soils

One of the most consistently reported impacts of invasive plants is the modification of soil physicochemical properties. Invasives often increase soil organic matter and nutrient content due to their high litter production and rapid decomposition rates (Ehrenfeld, 2003). In Nagaland, Singh and Theunuo (2018) demonstrated that soils invaded by *Tithonia diversifolia* exhibited significantly higher pH, moisture content, organic carbon, and organic matter compared to non-invaded plots within the Lumami campus of Nagaland University. Soil samples from 0–15 cm depth showed that invaded sites retained more moisture (average 25.36%) than

non-invaded sites (19.7%), which enhanced microbial activity and nutrient availability. Organic carbon and organic matter contents were also elevated in invaded soils, suggesting greater fertility potential. Similar observations were made in another comparative study in Nagaland, which confirmed that *Tithonia* invasion improved soil nutrient availability but concurrently reduced species richness (Singh and Theunuo, 2018).

Soil pH Modulation

Soil pH regulates nutrient solubility, microbial activity, and plant nutrient uptake. Invasive plants can alter soil pH through root exudates, organic acid release, and litter decomposition. Singh and Theunuo (2018) observed that *Tithonia diversifolia* increased soil pH in invaded sites compared to non-invaded sites in Lumami. This finding is consistent with the reports of Jama *et al* (2000) in Africa, where *Tithonia* litter decomposition neutralized acidic soils, making them more favorable for crop cultivation. Other invasives show varied impacts: *Parthenium hysterophorus* often decreases soil pH due to the release of phenolic acids (Kohli *et al*, 2006), whereas *Ageratina adenophora* increases pH in some invaded ecosystems due to alkaline litter inputs (Cai *et al*, 2025). Such contrasting outcomes highlight that the direction of pH change depends on invasive species' litter chemistry and decomposition processes.

Organic Carbon and Organic Matter content

Invasive plants with high litter input substantially influence soil organic carbon (SOC) and organic matter dynamics. *Tithonia diversifolia* produces large quantities of biomass that decompose rapidly due to its favorable carbon-to-nitrogen (C:N) ratio (Jama *et al*, 2000). As shown in Nagaland, SOC and organic matter contents were markedly higher in *Tithonia*-invaded sites compared to adjacent uninvaded sites (Singh and Theunuo, 2018).

Such increases in SOC are ecologically significant, as they enhance soil fertility and water-holding capacity (Temjen *et al*, 2022a). However, they may also alter microbial community structure in ways that disadvantage native plant species. Globally, *Spartina alterniflora* invasion in coastal marshes has been shown to increase SOC storage (Huang *et al.*, 2022). Conversely, *Parthenium hysterophorus* invasion in India decreases SOC due to allelopathic inhibition of native vegetation and reduced litter return (Kohli *et al*, 2006). These contrasting examples suggest that while some invasives enhance SOC, others deplete it, depending on their biomass production and interactions with native flora.

Moisture Dynamics

Soil moisture is critical for plant growth and microbial activity. In Nagaland, *Tithonia diversifolia*-invaded plots retained more soil moisture than non-invaded plots (Singh and Theunuo, 2018). This could be attributed to increased organic matter improving soil structure and water retention capacity. Higher moisture levels also favor microbial decomposition, releasing nutrients more efficiently and creating favorable conditions for *Tithonia* dominance. Globally, invasive grasses such as *Bromus tectorum* in North America alter soil moisture regimes by changing litter input and water infiltration patterns (Bradley *et al*, 2006). *Lantana camara* invasion in India has similarly been linked to increased soil moisture due to dense canopy cover and litter deposition (Sharma and Raghubanshi, 2011). Such changes reinforce

the ecological dominance of invasives by creating soil microclimates more favorable for their growth than for native species.

Nutrient Cycling and Fertility Enhancement

The ability of invasives to modify nutrient cycling processes is well documented. *Tithonia diversifolia* has been widely studied as a green manure in Africa due to its high nutrient content. Its biomass contains approximately 3.5% nitrogen, 0.37% phosphorus, and 4.1% potassium, making it a rich source of nutrients upon decomposition (Jama *et al*, 2000). In Nagaland, similar nutrient enrichment was observed, with invaded soils showing higher levels of nitrogen and organic matter than non-invaded soils (Singh and Theunuo, 2018).

However, such fertility enhancement often benefits the invasive species more than the native flora. By altering nutrient availability, invasives create positive feedback loops: higher fertility supports faster invasive growth, which produces more litter and further enriches soils (Ehrenfeld, 2003). This cycle contributes to invasive persistence and exclusion of native species. Other invasives exhibit similar nutrient-enrichment dynamics. For instance, *Acacia mearnsii* invasion in South Africa increases soil nitrogen through symbiotic nitrogen fixation, profoundly altering local nutrient regimes (Yelenik *et al*, 2004). In contrast, some invasives such as *Parthenium hysterophorus* immobilize soil nutrients through allelopathic effects, reducing fertility for native plants (Kohli *et al*, 2006).

Soil Biological properties

Soil microbial communities mediate key processes such as decomposition, nutrient cycling, and organic matter stabilization. Invasives often restructure microbial communities to their advantage (Temjen *et al*, 2022a; Dixit *et al*, 2024). While detailed microbial studies on *Tithonia diversifolia* in Nagaland remain limited, global evidence suggests that invasive species frequently alter soil microbial biomass and enzyme activity. For instance, *Ageratina adenophora* invasion in China significantly altered microbial community composition, increasing fungal dominance relative to bacteria (Zhao *et al*, 2019). *Parthenium hysterophorus* invasion reduced arbuscular mycorrhizal fungi in Indian soils, thereby suppressing the growth of native grasses (Kumar and Rohatgi, 1997). Such microbial alterations reinforce invasive species' ecological success by creating soil conditions unfavorable for natives but beneficial for invasives.

Case Study 1: *Tithonia diversifolia* as a Soil Modifier in Nagaland

Tithonia diversifolia (syn. *Mirasolia diversifolia*), commonly known as Mexican sunflower, is a vigorous invasive species of the family Asteraceae. Originally introduced into West Africa as an ornamental plant (Akobundu, 1987), it has since spread widely into Asia, including the humid savannas and forest edges of India. In Nagaland, *T. diversifolia* has rapidly colonized abandoned lands, roadsides, and even cultivated fields, displacing native vegetation. Its success is attributed to clonal growth, prolific seed dispersal, adaptability to a wide range of soils, and a high rate of vegetative turnover, making it a candidate for soil modification and, in some cases, soil rejuvenation (Obatolu and Agboola, 1993). The following is the report from Singh and Theuno (2018).

Soil Moisture

Field observations showed that soil moisture content was consistently higher in invaded sites compared to non-invaded ones. Moisture peaked at 36.4% in October 2015 at invaded sites, while the lowest was only 10.5% in February 2016 at non-invaded sites. On average, moisture was 25.36% in invaded sites versus 19.7% in non-invaded sites. This suggests that *Tithonia* invasion enhances soil water-holding capacity, likely due to increased litter deposition and lower bulk density, corroborating earlier findings by Atayese and Liasu (2001).

Soil pH

The soils at invaded sites showed a slightly more alkaline character. Across the study period, pH ranged from 7.30 to 7.90 in invaded soils compared to 6.55 to 7.30 in non-invaded soils. The average pH was 7.48 in invaded sites, compared to 7.15 in non-invaded sites, aligning with results by Oludare and Muoghalu (2014). Thus, *Tithonia* alters soil chemistry, creating less acidic conditions that may favor its own growth and alter competitive dynamics.

Organic Carbon

Organic carbon content was notably higher in invaded soils. In *Tithonia*-dominated areas, organic carbon ranged from 1.38% to 2.25%, while in non-invaded sites, it ranged from 0.24% to 1.95%. On average, invaded sites maintained 1.93% organic carbon versus 1.16% in non-invaded sites. These findings exceed earlier reported values in Nigeria (Odudare and Muoghalu, 2014), confirming that *Tithonia* contributes substantial organic inputs through leaf litter and rapid decomposition.

Organic matter

Table 1 : Associated species found in the invaded and non-invaded site of *Tithonia diversifolia* (Singh and Theunuo, 2018).

Plant name	Family	Non-invaded	Invaded
<i>Thunbergia grandiflora</i> Roxb.	Acanthaceae	+	–
<i>Bidens pilosa</i> L.	Asteraceae	+	–
<i>Stachytarpheta indica</i> (L.) Vahl	Lamiaceae	+	–
<i>Urena lobata</i> L.	Malvaceae	–	+
<i>Eupatorium odoratum</i> L.	Asteraceae	–	+
<i>Ageratum conyzoides</i> (L.) L.	Asteraceae	+	–
<i>Mucuna pruriens</i> (L.) DC.	Fabaceae	+	+
<i>Melastoma malabathricum</i> L.	Melastomataceae	+	–
<i>Cuphea balsamona</i> Cham. & Schltdl.	Malvaceae	+	–
<i>Glochidion</i> sp.	Euphorbiaceae	+	–
<i>Oxalis corniculata</i> L.	Oxalidaceae	+	+
<i>Crassocephalum crepidioides</i> (Benth.) S. Moore	Asteraceae	+	–
<i>Maesa</i> sp.	Myrsinaceae	+	–
<i>Blumea</i> sp.	Asteraceae	+	–
<i>Mikania scandens</i> (L.) Willd.	Asteraceae	–	+

+ indicate the presence of species; - indicate the absence of species

Similarly, organic matter content was consistently greater in invaded soils. Maximum values reached 4.34% (September 2015) in invaded sites, compared to 3.41% in April 2016 in non-invaded soils. Average organic matter content was 3.36% in invaded areas, far surpassing 2.0% in non-invaded areas. This increase is linked to *Tithonia*'s high litterfall and rapid decomposition rates, supplying abundant organic residues enriched in N, P and K (Olabode *et al*, 2007).

Plant Diversity and Ecological impact

While soil fertility improved, plant diversity declined sharply in invaded habitats. Only 5 species (4 families) were recorded in invaded sites, compared to 12 species (10 families) in non-invaded areas (Table 1). The homogenization of plant communities, driven by *Tithonia*'s dominance, reduces habitat for dependent fauna and threatens medicinally important native species. These results align with Oludare and Muoghalu (2014), who observed similar declines in Nigeria. *Tithonia diversifolia* in Nagaland exemplifies the dual role of invasive species as both soil improvers and biodiversity threats. Its invasion increases soil moisture, pH, organic carbon, and organic matter, suggesting potential as a green manure or composting resource. However, these soil modifications also suppress native plant diversity, destabilize ecological balance, and threaten long-term ecosystem resilience. Management strategies should therefore focus on controlled utilization of its biomass for soil fertility enhancement, while preventing its unchecked spread in natural ecosystems.

Case Study 2: Invasive Plant Assemblages in Mokokchung Town, Nagaland (Aosenla and Singh, 2021)

IAS are now recognized as the second greatest threat to global plant diversity after habitat loss (Hobbs and Humphries, 1995). They alter ecosystem structure, function, and nutrient cycles, ultimately driving declines in native biodiversity (Clout and Poorter, 2005). Their successful establishment is attributed to traits such as wide ecological tolerance, prolific seed production, aggressive root systems, and rapid growth (Reddy *et al*, 2008). A recent survey in Mokokchung town (Aosenla and Singh, 2021), Nagaland, documented 50 plant species belonging to 26 families and 49 genera, of which 37 were invasive alien plants and 13 were associated, non-invasive species (Table 2). The Asteraceae emerged as the dominant family (15 species), reflecting global patterns of Asteraceae dominance in invasion ecology (Richardson *et al.*, 2000). Phytosociological analysis identified *Galinsoga parviflora* as the most dominant invasive (IVI = 26.66), followed by *Ageratum conyzoides* (19.78), *Eupatorium adenophorum* (= *Ageratina adenophora*) (19.11), and *Bidens pilosa* (16.63). In contrast, *Cuscuta reflexa* recorded the lowest IVI (0.89). Density and frequency data similarly showed *G. parviflora* (density = 11.8; frequency = 100%) as the most aggressive colonizer, while *C. reflexa* exhibited minimal establishment. These invasives were found primarily along roadsides and disturbed habitats, confirming that propagule pressure and disturbance regimes are key drivers of invasion success (Rai, 2015). Notably, many of these invasives trace their nativity to Tropical America, which is the largest contributor of invasive species in Indian flora (Reddy *et al*, 2008). Their dominance threatens local biodiversity by displacing native flora, disrupting successional trajectories, and altering nutrient cycles (Sharma and Raghubanshi, 2011). Management of invasives in Mokokchung requires integrated strategies, including ecological

Table 2 : List of invasive plants and associated non-invasive plants found in the studied sites (Aosenla and Singh, 2021).

Invasive plant species	Family	Associated non-invasive species	Family
<i>Ageratum conyzoides</i>	Asteraceae	<i>Centella asiatica</i>	Apiaceae
<i>Galinsoga parviflora</i>	Asteraceae	<i>Gomphrena globosa</i>	Amaranthaceae
<i>Plantago asiatica</i>	Plantaginaceae	<i>Persicaria capitata</i>	Polygonaceae
<i>Ipomea carnea</i>	Convolvulaceae	<i>Tagetes</i> sp.	Asteraceae
<i>Spilanthes acmella</i>	Asteraceae	<i>Colocasia esculenta</i>	Araceae
<i>Oxalis corniculata</i>	Oxalidaceae	<i>Pseudognaphalium affine</i>	Asteraceae
<i>Cuphea hyssopifolia</i>	Lythraceae	<i>Coreopsis</i> sp.	Asteraceae
<i>Dichrocephala integrifolia</i>	Asteraceae	<i>Thunbergia alata</i>	Acanthaceae
<i>Bidens pilosa</i>	Asteraceae	<i>Solanum lycopersicum</i>	Solanaceae
<i>Cyperus rotundus</i>	Cyperaceae	<i>Verbena officinalis</i>	Verbenaceae
<i>Drymaria cordata</i>	Caryophyllaceae	<i>Fragaria</i> sp.	Rosaceae
<i>Erigeron karvinskianus</i>	Asteraceae	<i>Zephyranthes candida</i>	Amaryllidaceae
<i>Crassocephallum crepidioides</i>	Asteraceae	<i>Houttuynia cordata</i>	Saururaceae
<i>Eupatorium adenophorum</i>	Asteraceae		
<i>Mikania micrantha</i>	Asteraceae		
<i>Alternanthera philoxeroides</i>	Amaranthaceae		
<i>Tithonia diversifolia</i>	Asteraceae		
<i>Lantana camara</i>	Verbenaceae		
<i>Mimosa pudica</i>	Mimosaceae		
<i>Cuscuta reflexa</i>	Cuscutaceae		
<i>Chromolaena odorata</i>	Asteraceae		
<i>Eleusine</i> sp.	Poaceae		
<i>Conyza Canadensis</i>	Asteraceae		
<i>Sphagneticola trilobata</i>	Asteraceae		
<i>Pilea microphylla</i>	Urticaceae		
<i>Peperomia pellucida</i>	Piperaceae		
<i>Cardamine hirsuta</i>	Brassicaceae		
<i>Mirabilis jalapa</i>	Nyctaginaceae		
<i>Hypoestes phyllostachya</i>	Acanthaceae		
<i>Rorippa dubia</i>	Brassicaceae		
<i>Youngia japonica</i>	Asteraceae		
<i>Sonchus arvensis</i>	Asteraceae		
<i>Solanum americanum</i>	Solanaceae		
<i>Impatiens balsamina</i>	Balsaminaceae		
<i>Amaranthus viridis</i>	Amaranthaceae		
<i>Stachytarpheta cayennensis</i>	Verbenaceae		
<i>Catharanthus roseus</i>	Apocynaceae		

restoration with native species, mechanical and crop-competition methods, and cut-root-stock control combined with the introduction of native legumes and grasses. Chemical and biological control options have also been proposed (Singh and Theuno, 2018). Without timely intervention, invasive species such as *A. conyzoides*, *G. parviflora*, and *E. adenophorum* may further entrench their dominance in urban and peri-urban ecosystems of Nagaland, exacerbating biodiversity loss.

Case study 3: Allelopathic Effects of *Tithonia diversifolia* Extracts on *Capsicum chinense* Germination and Growth (Ngampo and Singh, 2025)

Allelopathy is a key mechanism by which invasive alien species IAS suppress native and cultivated plants, altering community composition and nutrient cycling (Inderjit and Callaway, 2003). *Tithonia diversifolia* (Mexican sunflower), a highly invasive species in tropical Asia and Africa, has been reported to release secondary metabolites such as sesquiterpene lactones that inhibit seed germination and seedling establishment of crop plants (Kato-Noguchi, 2020). To evaluate these effects, a controlled experiment was conducted on *Capsicum chinense* Jacq., an agriculturally important chili species widely cultivated in Northeast India.

Germination and Early Seedling Response

Seeds of *C. chinense* exposed to fresh shoot extract (FSE) of *T. diversifolia* showed accelerated initiation of germination, but subsequent growth was anomalous. Radicle elongation in controls steadily increased from 1.2 cm to 2.5 cm over 12 days, while FSE-treated radicles peaked at 1.7 cm and then declined to 1.5 cm. Plumule development was more severely inhibited: control seedlings reached 2.0 cm, whereas FSE-treated seedlings stagnated at 0.6 cm. Statistical analysis confirmed that plumule length was significantly reduced in the treated group ($T = 3.239$, $P = 0.011$), indicating strong allelopathic inhibition. These findings echo Suzuki *et al* (2017), who identified tagitinine C in *Tithonia* extracts as a phytotoxic compound suppressing maize seedling growth.

Vegetative Growth and Morphology

Over a five-week monitoring period, shoot height in controls increased progressively from 0.88 cm to 4.00 cm. FSE-treated seedlings displayed an aberrant growth trajectory, with an initial surge to 6.11 cm in week two, followed by a sharp decline and stunted growth thereafter (3.0 cm by week five). While vertical growth was suppressed, leaf area was consistently larger in FSE-treated plants, peaking at 10.27 cm² compared to 7.12 cm² in controls. This suggests biomass reallocation toward lateral growth, a stress-induced compensatory mechanism also reported in maize by Ochekwu (2022).

Chlorophyll Content and Photosynthetic response

Chlorophyll measurements revealed contrasting patterns. FSE-treated seedlings exhibited higher chlorophyll a levels in later weeks (0.304 mg/g vs. 0.099 mg/g in controls at week five) and elevated chlorophyll b in early stages (3.254 mg/g at week two vs. 0.348 mg/g in controls). Total chlorophyll content also exceeded controls in weeks one and four. This suggests that allelochemical stress may stimulate chlorophyll synthesis or retention as an adaptive response, corroborating observations by Oyerinde *et al* (2009), who found enhanced chlorophyll

accumulation in maize exposed to *Tithonia* extracts despite growth inhibition.

Ecological and Agronomic implications

Overall, the study demonstrates that while *T. diversifolia* extracts can stimulate germination and leaf expansion in the short term, they significantly impair plumule growth, radicle stability, and balanced seedling development. These disruptions are likely due to allelochemical interference with cellular division at the radicle tip and hormonal imbalances affecting shoot elongation (Kato-Noguchi, 2020). The findings highlight the dual role of invasive allelopathy: creating opportunities for the invader by suppressing sensitive crops like *C. chinense*, while simultaneously destabilizing agroecosystem productivity.

Mechanisms of Native Plant Displacement

Resource competition

Invasive plants often possess rapid growth rates, extensive root systems, and high resource-use efficiency. These traits enable them to monopolize resources, leaving fewer opportunities for native species. For instance, *Tithonia diversifolia* forms dense stands with high leaf area index, intercepting sunlight and shading out understory vegetation (Singh and Theunuo, 2018). Its aggressive root system further depletes soil moisture and nutrients, intensifying competition with neighbouring plants.

Habitat alteration

Invasives can change habitat structure, thereby making conditions unsuitable for native species. *Tithonia diversifolia* increases soil fertility through litter input, favoring generalist species but disadvantaging specialists adapted to nutrient-poor soils (Singh and Theunuo, 2018). Such habitat homogenization reduces niche diversity, contributing to species loss.

Disruption of Mutualisms

Some invasives disrupt plant–pollinator and plant–mycorrhizal interactions. By dominating landscapes, invasives reduce floral resource availability for pollinators, indirectly suppressing reproduction of native species. While specific studies on *Tithonia* in Nagaland are limited, similar disruptions are reported elsewhere: *Impatiens glandulifera* alters pollinator visitation patterns, disadvantaging native plants in Europe (Chittka and Schürkens, 2001). *Ageratina adenophora* reduces arbuscular mycorrhizal fungi abundance in Indian soils, lowering the competitive ability of native grasses (Du *et al*, 2022).

Allelopathic Interactions

Many invasives release secondary metabolites that inhibit germination and growth of neighboring plants. While this will be elaborated in the next section, it is worth noting that allelopathy synergizes with competitive superiority, further accelerating native species decline (Inderjit and van der Putten, 2010).

This case study underscores the phytotoxic potential of *T. diversifolia* in agricultural landscapes of Northeast India. While it may temporarily enhance certain physiological traits such as chlorophyll accumulation, its overall effect is detrimental to seedling establishment and crop performance. *Capsicum chinense*, being highly sensitive to environmental stressors,

Table 3 : Invasive plant species at the community protected forest (CPF) and anthropogenic disturbed forest (ADF) (Semy *et al*, 2024)

Species	Family	CPF	ADF
<i>Ageratum conyzoides</i> L.	Asteraceae	Δ	+
<i>Alternanthera philoxeroides</i> (Mart.) Griseb.	Amaranthaceae	Δ	+
<i>Ageratina riparia</i> (Regel) R. M. King & H. Rob.	Compositae	+	Δ
<i>Bidens pilosa</i> Linn. var. <i>Radiata</i>	Asteraceae	Δ	+
<i>Crassocephalum crepidioides</i> (Benth.) S. Moore	Asteraceae	+	+
<i>Cyperus iria</i> L.	Cyperaceae	Δ	+
<i>Chromolaena odorata</i> (L.) R. M. King & H. Rob.	Asteraceae	+	+
<i>Eclipta prostrata</i> (L.) L.	Asteraceae	+	Δ
<i>Eupatorium adenophorum</i> Spreng.	Asteraceae	Δ	+
<i>Euphorbia hirta</i> L.	Euphorbiaceae	Δ	+
<i>Galinsoga parviflora</i> Cav.	Asteraceae	Δ	+
<i>Gomphrena celosioides</i> Mart.	Amaranthaceae	+	Δ
<i>Imperata cylindrica</i> (L.) Raeusch.	Poaceae	+	+
<i>Impatiens latiflora</i> Hook. f. & Th.	Balsaminaceae	+	Δ
<i>Ludwigia perennis</i> L.	Onagraceae	+	+
<i>Mimosa pudica</i> L.	Mimosaceae	+	+
<i>Spermacoce latifolia</i> Aubl.	Rubiaceae	+	+
<i>Stachytarpheta cayennensis</i> (Rich.) Vahl	Verbenaceae	+	+
<i>Triumfetta rhomboidea</i> Jacq.	Malvaceae	+	+
<i>Triumfetta pilosa</i> Wall.	Malvaceae	+	+
<i>Torenia violacea</i> (Blanco) Pennell	Linderniaceae	+	Δ
<i>Synedrella nodiflora</i> (L.) Gaertn.	Asteraceae	Δ	+
<i>Solanum torvum</i> Sw.	Solanaceae	Δ	+
<i>Cassia hirsuta</i> (L.) H. S. Irwin & Barneby	Fabaceae	Δ	+
<i>Gnaphalium coarctatum</i> Willd.	Asteraceae	+	+
<i>Lantana camara</i> L.	Verbenaceae	Δ	+
<i>Sida acuta</i> Burm. f.	Malvaceae	Δ	+
<i>Mikania micrantha</i> Kunth	Asteraceae	Δ	+
<i>Oxalis debilis</i> var. <i>corymbosa</i>	Oxalidaceae	Δ	+
<i>Peperomia pellucida</i> (L.) Kunth	Piperaceae	Δ	+
<i>Rorippa dubia</i> (Pers.) H. Hara	Brassicaceae	+	+

proves to be a suitable bioindicator species for evaluating allelopathic interactions of invasive plants. These results reaffirm the importance of timing, dosage, and management when considering organic amendments derived from invasive biomass, as improper application could undermine food security rather than support it.

Case study 4: Invasive Alien Plants as Bioresources in Forests of Nagaland (Semy *et al*, 2024)

Although, IAS alter ecosystem processes, displace native flora, and reduce ecological resilience (Vilà *et al*, 2011). Yet, in some traditional societies, IAS are simultaneously integrated into local livelihoods as bioresources, particularly in regions where access to modern healthcare and agricultural inputs is limited (Tripathi *et al*, 2020). This dual ecological and cultural role is particularly evident in Nagaland, India, where indigenous Naga communities rely heavily on plant-based resources for medicine, fodder, and cultural practices. Semy *et al*. (2024) conducted a comparative survey in Changki, Mokokchung district, sampling invasive plants from a community protected forest (CPF) and an anthropogenically disturbed forest (ADF). The study revealed that IAS abundance was significantly higher in disturbed forests (26 species) compared to protected sites (16 species) (Table 3), echoing findings from other landscapes where human activity accelerates biological invasions (Dyderski and Jagodzinski, 2018). A total of 31 IAS representing 18 families were recorded (Table 3) with Asteraceae (10 species) emerging as the dominant family. Notably, species such as *Chromolaena odorata*, *Mikania micrantha*, *Lantana camara* and *Ageratum conyzoides*—all notorious invaders across the tropics—were abundant in disturbed areas. These results underscore how forest degradation and fragmentation facilitate invasion.

Ecological and Socioeconomic Implications

The findings illustrate the paradox of IAS in tribal landscapes: they threaten native biodiversity but simultaneously serve as vital bioresources. By incorporating IAS into healthcare, fodder and daily subsistence, local communities mitigate some of the negative impacts of invasion while reducing pressure on declining native flora. However, unchecked proliferation of IAS may still destabilize ecosystem structure and composition (Kohli *et al*, 2004). Semy *et al* (2024) emphasize that recognizing the bioresource potential of IAS could support dual management strategies:

- **Ecological control** by harvesting IAS for medicinal or commercial purposes, thereby reducing their abundance and competition with native species.
- **Livelihood enhancement** by integrating IAS-based remedies and products into local health and economic systems, supported by government and NGO initiatives.

Conclusion

Invasive plant species represent one of the most pressing ecological challenges of the 21st century, profoundly altering soil properties, suppressing native vegetation, and exerting allelopathic effects that destabilize natural and agricultural ecosystems. This chapter has examined these processes with emphasis on the invasive shrub *Tithonia diversifolia* in the context of Nagaland, India, supported by comparative global evidence. The invasion of *Tithonia diversifolia* was shown to significantly alter soil physicochemical characteristics. While some studies indicate marginal increases in soil organic matter and nutrient availability due to high biomass input, the overall trend reflects nutrient imbalance, increased soil acidity, and shifts in microbial communities. These changes disrupt natural nutrient cycling, reduce soil fertility in the long term, and enhance the invader's capacity to monopolize ecological niches. The dominance of *Tithonia diversifolia* suppresses the recruitment and growth of native flora. By

forming dense stands, it reduces light availability, competes aggressively for water and nutrients, and modifies habitat structure. The resultant decline in species richness contributes to ecological homogenization and the displacement of culturally significant and ecologically valuable plant species. Allelopathy further amplifies invasion success. The case study of *Tithonia diversifolia* extracts on *Capsicum chinense* demonstrated a dual influence—initial stimulation of germination followed by pronounced inhibition of seedling growth and root elongation. Such allelochemical interference reduces crop productivity and hinders native regeneration, thereby creating feedback loops that strengthen invasive dominance. These effects mirror the allelopathic strategies of other invasives such as *Parthenium hysterophorus*, *Lantana camara*, and *Ageratina adenophora*. Collectively, the evidence highlights that invasive plants reshape ecosystems not through a single pathway but through interconnected mechanisms—soil modification, competitive exclusion, and allelopathic suppression. These processes result in profound ecological, agricultural, and socioeconomic consequences for regions such as Northeast India, where biodiversity and subsistence farming are both critical to livelihoods.

Future perspectives

Addressing the challenges posed by invasive species requires integrative approaches that combine ecological research, community participation, and adaptive management strategies. Several future perspectives are outlined below:

- **Mechanistic Research on Allelopathy :** Greater efforts are needed to isolate and characterize allelochemicals in *Tithonia diversifolia*. Advanced metabolomic and proteomic techniques can identify bioactive compounds, clarify their modes of action, and evaluate dose–response thresholds. Such research will deepen understanding of allelopathy and support both invasive management and potential biotechnological applications.
- **Soil Microbial Mediation studies :** The influence of invasives on soil microbiota remains underexplored. Future research should investigate microbial community dynamics under *Tithonia* invasion, particularly shifts in beneficial mycorrhizal fungi and nitrogen-fixing bacteria. Linking allelopathy with microbial ecology may reveal synergistic processes that reinforce invasion success.
- **Restoration Ecology and Native Species selection :** Management must prioritize the reintroduction of resilient native species capable of withstanding allelopathic stress and nutrient imbalances. Studies should focus on identifying “allelopathy-tolerant” natives or crop varieties, enabling targeted restoration and sustainable agriculture in invaded landscapes.
- **Integrated Management Strategies :** Conventional methods such as manual uprooting and herbicide application are often ineffective or environmentally damaging. A combination of mechanical control, biological agents and community-led monitoring may provide sustainable alternatives. Incorporating local ecological knowledge is essential in regions like Nagaland, where indigenous practices shape land management.

- **Socioeconomic Considerations** : Future interventions must evaluate the socioeconomic impacts of invasives on smallholder farmers. For example, reduced productivity of *Capsicum chinense* due to allelopathic suppression has direct economic implications. Developing incentive-based schemes for invasive removal and livelihood support can align conservation goals with community well-being.
- **Climate Change Interactions** : Climate change is likely to exacerbate invasion dynamics by altering temperature, rainfall, and disturbance regimes. Research should anticipate how shifting climatic conditions may expand *Tithonia diversifolia*'s range, intensify allelopathic impacts, and further challenge native ecosystems. Scenario-based modeling will be crucial for proactive management.
- **Potential Utilization of Invasive Biomass** : While primarily problematic, invasive species also present opportunities. Biomass from *Tithonia diversifolia* can be evaluated for composting, green manure, or bioenergy production. However, utilization strategies must be carefully balanced to prevent unintentional promotion of the species. Similarly, allelochemicals, once isolated, could serve as templates for developing natural herbicides, reducing reliance on synthetic chemicals.

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