Research Article

A Review of Grass Allelopathy and its Role in Tropical Grassland Management

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Abstract | Allelopathy is the term for chemical interactions in which organisms, especially plants, release biochemicals that affect other species' ability to grow, survive, and reproduce. Over 2000 plant species have been found to have allelopathic effects and ecological significance. Allelopathy is essential to plant competitiveness, biodiversity management, and soil health in grasslands, which make up around 37% of the planet's land area. Numerous allelochemicals, including phenolics, flavonoids, and terpenoids, are released by grasses and have an effect on nearby plant species as well as soil microbial communities. Strong allelochemicals produced by invasive species frequently disturb natural ecosystems, lower biodiversity, and change the way nutrients are cycled. Allelopathic interactions must be taken into account more in grassland management techniques like rotational grazing, regulated burning, and restoration projects in order to preserve ecosystem productivity and resilience. Allelopathy can help or offended management objectives. It can be a natural way to eliminate weeds, but it can also cause problems by encouraging invasive dominance. Reducing reliance on chemical pesticides, improving biodiversity, and creating sustainable plans for the protection and restoration of tropical grasslands all depend on an understanding of allelopathic processes. In order to support ecological balance and long-term sustainability, future studies should concentrate on incorporating allelopathic information into grassland management.

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Introduction

The term allelopathy was defined by Molisch first time in 1937 as a chemical interaction of plants, sometimes microbes and higher plants (Chon *et al.*, 2003). Allelopathy is a common biological phenomenon, where an organism generates biochemicals that can affect other organisms' development, growth, reproduction and survival (Cheng and Cheng, 2015). It occurs when a species produces and releases chemicals that have an impact on other species, either directly or indirectly, negatively or positively (Serajchi, 2017). The (Table 1) shows the positive and negative values of allelopathy.

The capacity to generate and excrete allelopathic compounds into the environment, as well as the ability to withstand allelochemicals emitted by other plants, can significantly influence a species' survival and reproductive success (Muzell Trezzi *et al*., 2016). Allelochemicals may be used as growth regulators, herbicides, insecticides, and antimicrobial agricultural treatments (Cheng and Cheng, 2015). Allelopathy is an efficient and environmentally friendly substitute which can be used in weed control and it has beneficial or detrimental effects on target organisms (Jabran *et al*., 2015; Cheng and Cheng, 2015). It can be used to accomplish sustainable weed management through allelopathic interactions and the use of allelochemicals as natural herbicides. Strong allelopathic effects are exhibited by about 2000 plant species in 39 families (Amist *et al*., 2019). A large number of allelochemicals can suppress the growth of other plant species, have been identified in various weeds. Weed species also produce allelochemicals and they are supposed to be more toxic because weeds normally grow under stress conditions (Marwat *et al*., 2008; Farooq *et al*., 2020).

Table 1: *Positive and negative effects of allelopathy (Cheng and Cheng, 2015; Zimdahl, 2018)*

Positive Effects	Negative Effects
Increasing donor survival and naturally suppressing weeds, lowering the need for herbicides	Inhibits crop germination and the growth
Promotes biodiversity through intransitive networks and improves soil nutrient cycling	Creating invasive monocultures, reducing native diversity and habitat quality
Low doses of allelochemicals stimulate receiver growth (hormesis) and aids stress tolerance	Disrupting enzymes, membranes, hormones and induces Reactive Oxygen Species (ROS) and apoptosis.
Cover crops provide bioherbicides. (*Sorghum sorgoleone* controls weeds)	Altering soil microbes, causing long-term fertility reduction.

Allelochemicals are chemical substances secreted by plants that can influence the growth, behavior, and population dynamics of various organisms, including interactions between plants and between plants and animals. In recent years, ongoing research and advancements in science and technology, particularly in the fields of chemistry and biology, have significantly enhanced the study of allelochemicals (Chengxu *et al*., 2011). Allelochemicals are present in varying concentrations across different plant parts, including leaves, roots, stems, rhizomes, pollen, seeds, and flowers. The mechanisms by which these compounds are released into the environment differ among species (Sangeetha and Baskar, 2015). Allelochemicals encompass a range of chemical families and are categorized into 14 distinct groups according to their chemical similarities. They are water-soluble organic acids, straight chain alcohols, aliphatic aldehydes, and ketones; simple unsaturated lactones; long-chain fatty acids and polyacetylenes; benzoquinone, anthraquinone and complex quinones; simple phenols, benzoic acid and its derivatives; cinnamic acid and its derivatives; coumarin; flavonoids; tannins; terpenoids and steroids; amino acids and peptides; alkaloids and cyanohydrins; sulfide and glucosinolates; and purines and nucleosides (Rice, 1974). Numerous weed phytotoxins have been discovered in root exudates, leaf volatiles, leachates, decomposed weed plants and weedy soil (Xuan *et al*., 2016). Allelopathy is a significant factor in biological invasion. Research indicates that certain exotic invasive weeds can achieve high population densities in the areas they invade, while maintaining low densities in their native habitats. To explain this phenomenon, the "novel weapons" theory has been introduced. This theory suggests that some exotic plants emit biochemical compounds into the newly invaded ecosystem that inhibit local flora and soil microbes, yet these compounds are relatively ineffective against their native counterparts, which have adapted over time (De-Albuquerque *et al*., 2011).

Grasslands

About 70% of the earth's surface area is made up of forests and grasslands, which are essential parts of the global ecology. Both serve as the essential global biodiversity pool that provides a variety of different species, and their sustainability and productivity influence worldwide change (Xu *et al*., 2023). As the basis for the growth of grassland husbandry, grasslands are essential ecological barriers and the backbone of terrestrial ecosystems (Guo *et al*., 2023). Numerous definitions of 'grasslands' exist, yet a common element in nearly all of them is the presence of Gramineae (Poaceae) species along with a maximum threshold of tree cover in the canopy. Grasslands can be found in various regions across the world and in nearly all climatic zones, with the exception of the polar regions, the highest mountain ranges, and extremely arid areas. Consequently, grasslands rank as the second most significant ecosystems worldwide, following forests (Starrs *et al*., 2018). Grasslands play a significant role in the global ecosystem, encompassing 37% of the Earth's land surface. However, numerous factors, primarily linked to overgrazing, have led to issues such as soil erosion and the invasion of weeds, resulting in the deterioration of many natural grasslands worldwide (O'Mara, 2012). Grasslands serve as a vital source of forage for grazing animals, which in turn yield a variety of high-quality food products. Furthermore, these animals contribute additional resources, including fertilizer, transportation, traction, fiber, and leather. Beyond their role in livestock production, grasslands offer essential services such as water catchment, biodiversity preservation, and support for cultural and recreational activities. They also hold the potential to act as carbon sinks, helping to mitigate greenhouse gas emissions. However, it is important to recognize that these various functions may sometimes conflict with the management practices aimed at optimizing livestock production (Boval and Dixon, 2012). In this review, tropical grasslands are mainly considered. Tropical grasslands play a crucial role in the sustainable intensification of agriculture in the decades ahead. The rich ecosystem services offered by these grasslands, along with the desire to prevent additional deforestation, elevate the sustainable intensification of tropical grasslands to a significant policy priority (Boval *et al*., 2017). In contrast to temperate ecosystems, there has been a limited number of comprehensive evaluations regarding canopy features and related grazing behaviors in cultivated tropical grasslands (Sollenberger and Burns, 2001). Tropical grasslands, which occur naturally, cover a large portion of the Earth's surface. Significant expanses of these grasslands are located in the Llanos region of Colombia, the Cerrado in Brazil, the Sahel of sub-Saharan Africa, and beneath the broad, open Miombo woodlands found in Zambia, Zimbabwe, and neighboring nations (Boval *et al*., 2017). Although the tropical and subtropical grasslands (savannas) occur mostly in Africa and Australia, they can be found in the north of South America, in the southern United States, South Asia, and Southeast Asia (Petermann and Buzhdygan, 2021).

Introduced invasive weeds are a severe problem in grasslands globally. These species can have undesirable economic effects by reducing crop yields or the quality of grazing areas. And also, they can have poor ecological impacts include reducing biodiversity, endangering rare communities and impacting natural processes like nitrogen cycling (Goslee *et al*., 2001). Similar to the worldwide issue of invasive weeds in grasslands, invasive weeds in rangelands result in substantial economic losses ($2 billion yearly) and ecological effects, such as reducing biodiversity and habitat quality (DiTomaso, 2000). Invasive plants have severe economic and ecological impacts on grasslands, including reducing habitat quality and changing the ecological processes. Using integrated solutions based on ecological principles and addressing underlying issues are necessary for effective management (Masters and Sheley, 2001).

Methodology

Articles were searched in Google Scholar , using the terms "allelopathic" or' 'allelopathy" in combination with the terms "grassland" or "pasture" and "weeds" or "weed grasses". These terms had to appear in article title, abstract or key words. The search resulted many articles, among them considered some articles for the analysis. After that, using those articles the review was written to collect the relevant information for future research in this field.

Allelopathic compounds found in grasses

The variety of secondary metabolites generated by plants is extensive, with chemical structures varying from simple hydrocarbons to complex polycyclic aromatics (Weston and Duke, 2003). Different grass species have different chemicals and those chemicals have specific roles (Table 2). Allelochemicals can exert their effects if they are released into the environment at sufficient concentrations (Reigosa *et al*., 1999). Plants generally increase their production of allelochemicals when subjected to stress. The synthesis of these compounds can be affected by a variety of biotic and abiotic factors, including the quality and quantity of light, nutrient deficiencies, water scarcity, extreme temperature conditions, the application of herbicides and pesticides, the presence of plant diseases, as well as the age and genetic makeup of the plant (Serajchi, 2017). Allelochemicals exhibit various mechanisms of actions like their influence on cellular structure, cell division, cell elongation, cell wall integrity, ultrastructural components, growth regulators (primarily as inhibitors), membrane permeability, nutrient absorption, stomatal opening, as well as photosynthesis and respiration processes (Reigosa *et al*., 1999). Some grass species produce allelopathic substances such as phenolics, flavonoids, and terpenoids, which inhibit the growth of rival plant species and affect soil chemistry as well as microbial

Table 2: *Allelopathic compounds identified in various grass species and their inhibitory functions.*

Grass Species	Chemicals	Function	References
1.*Phalaris arundinacea*	Linolenic acid, linoleic acid, palmitic acid	Inhibits seed germination and root growth of other plants	(Tomes, 2013)
2.*Vulpia* spp. (annual grasses)	Phenolic acids (unspecified)	Synergistic inhibition of crop and pasture establishment	(Pratley,1996)
3.*Festulolium* spp. (Hybrid Forage)	Caffeic acid, syringic acid, vanillic acid, p-coumaric acid, ferulic acid, apigenin, chlorogenic acid, 4-hydroxybenzoic acid, gallic acid	Inhibit weed germination and growth via phenolic compounds	(Motalebnejad *et al.*, 2023)
4. *Sorghastrum nutans*	Root leachates (phenolics)	Inhibits shoot growth of milkweed	(Parker, 2000)
5.*Caucasian bluestem*	Root leachates (unspecified)	Can enhance or inhibit growth of certain native forbs	(Parker, 2000)
6. *Paspalum notatum*	Phenolic compounds	Suppresses growth of neighboring plants via root exudates	(Martin and Smith, 1994)
7.*Imperata cylindrica*	Phenolic acids, flavonoids, terpenoids	Suppresses native plant germination and growth; reduces biodiversity	(Martin and Smith, 1994)
8.*Setaria viridis*	Phenolic acids	Inhibits seedling growth of other plants	(Martin and Smith, 1994)
9.*Echinochloa crus-galli*	Phenolic acids, flavonoids	Inhibits seed germination of other species	(Martin and Smith, 1994)
10.*Setaria pumila*	Phenolic acids	Suppresses germination of competing species	(Martin and Smith, 1994)
11.*Setaria faberi*	Phenolic acids	Suppresses germination of crops and grasses	(Martin and Smith, 1994)
12.*Digitaria sanguinalis*	Phenolic acids	Inhibits seedling growth of other grasses	(Martin and Smith, 1994)
13.*Sorghum halepense*	Dhurrin (cyanogenic glycoside)	Toxic to grazers; inhibits neighbor plant growth	(Martin and Smith, 1994)
14.*Dactylis glomerata*	Phenolic acids	Minimal inhibition of other species	(Martin and Smith, 1994)
15.*Brachiaria brizantha*	Lactic acid, phenolic acids, flavonoids	Weed suppression, radicle elongation block	(Kobayashi and Kato-Noguchi, 2015)
16. *Galinsoga parviflora*	1,4-Cyclohexanedicarboxylic acid, Succinic acid	Inhibitory effects on the seed germination and seedling growth of other plants	(Cheng *et al.*, 2025)
17. *Cenchrus ciliaris*	alkaloids, coumarins, and saponins	Toxic effects on the growth and germination	(Jabeen *et al.*, 2023)
18. *Polypogon monspeliansis*	flavonoids, phenols, coumarins,	Inhibit growth and germination	(Jabeen *et al.*, 2023)
19. Dicanthium annulatum	alkaloids, flavonoids, phenols, coumarins, and saponins	Toxic effects on the growth and germination	(Jabeen *et al.*, 2023)
20. *Urochloa decumbens*	DHMP, gallic acid	Inhibits root growth and induces autotoxicity	(Oliveira *et al.*, 2016)

interactions (Hierro and Callaway, 2021).

Impact of allelopathy in grasslands

Grassland productivity and biodiversity are strongly shaped by allelopathy, as the allelochemicals released by grasses influence plant competition by either inhibiting or promoting the growth of surrounding species (Gxasheka *et al.*, 2025). Grasslands provide excellent real-world systems for studying allelopathy due to their plant diversity, frequent disturbances, and importance in agriculture and conservation. Furthermore, allelopathy is shaped by various factors, including environmental conditions, characteristics of plant species, interactions with microorganisms, and the spatial and temporal dynamics within ecosystems (Silva *et al.*, 2017).

Allelopathy plays a significant role in influencing plant competition and the composition of species within grassland ecosystems. Specific grass species release allelochemicals that can adversely affect the germination and growth of neighboring plants. For instance, phenolic acids are known to hinder both root and shoot development, while flavonoids and terpenoids can influence seed germination and overall plant metabolism (Serajchi, 2017). Allelopathy influences plant competition by inhibiting the germination and growth of adjacent plants, as well as modifying soil microbial communities, which results in a decline of beneficial microbes (Oduor *et al*., 2020). Soil microorganisms could play a role in enhancing the biotic resistance of indigenous plant communities to invasive species, particularly within the framework of the diversity- invisibility relationship (Kulmatiski *et al*., 2008). Experiments on soil sterilization indicated that invasive plant species exhibited enhanced growth in sterilized soil, implying that microbial interactions may contribute to resistance against invasion (Eisenhauer *et al*., 2012).

Allelochemicals have the potential to affect soil microbial communities, resulting in a rise in pathogenic fungi that adversely impact grasses, while simultaneously diminishing the presence of Arbuscular mycorrhizal fungi (AMF), which typically support native grass species (Oduor *et al*., 2024). Allelopathic substances modify the composition of soil microbial communities, frequently resulting in a decline of beneficial microorganisms and a rise in pathogenic fungi. This alteration can create nutrient imbalances, rendering the soil less conducive to the growth of various plant species. Furthermore, the occurrence of allelochemicals in root exudates, leaf litter, and decaying plant matter can exert enduring impacts on soil health (Latif *et al*., 2017., Khang *et al*., 2023). Allelochemicals alter soil properties, reducing nutrient availability for non - dominant species. Inhibitory effects on beneficial soil microbes impact nitrogen fixation and plant-microbe interactions (Serajchi, 2017).

Allelopathy reduces species richness by promoting specific competitive grass species while suppressing others. Certain invasive grasses, exhibiting strong allelopathic properties can dominate essential resources such as nutrients, water, and light, resulting in a decrease in native species populations. This phenomenon is associated with a decline in forage quality and a reduction in habitat diversity for herbivorous animals (Gxasheka *et al*., 2025). Some primary allelochemicals responsible for inhibiting neighboring plants (Li and Zhao, 2025) identified that there are seven allelochemicals in *Stellera chamaejasme* roots. They are Umbelliferone, Chamechromone, Daphnoretin, Isoneochamaejasmin A, Neochamaejasmin B, Dihydrodaphnodorin B and 7-methoxylneochaejasmin. Among them Umbelliferone is the primary allelochemical responsible for inhibiting neighboring plants (Li and Zhao, 2025). Native grasses generally exhibit less potent allelopathic effects, which promotes greater biodiversity. In contrast, invasive grasses, such as *Imperata cylindrica*, produce more powerful allelochemicals that diminish diversity (Serajchi, 2017).

Allelopathy in plant invasion

When considering the allelopathy in plant invasion, allelopathic interactions are crucial in determining how well native plant communities can withstand invasive species (Oduor *et al*., 2024). Allelopathy is recognized as a major mechanism that contributes to plant invasiveness by enhancing the competitive ability of invasive species against native flora. According to Hierro *et al*., (2005) the "novel weapon hypothesis" suggests that invasive plants often release allelochemicals unfamiliar to native communities, giving them a significant advantage in suppressing local species and establishing dominance. Notably, invasive species such as *Centaurea diffusa* (diffuse knapweed), *Mikania micrantha*, and *Solidago canadensis* (Canada goldenrod) have demonstrated strong allelopathic effects, inhibiting the germination and growth of native plants through chemical release into the soil (Bao-Ming *et al*., 2017). These allelochemicals, including phenolics, flavonoids, and sesquiterpenoids, disrupt vital soil microbial communities and plant-mycorrhizal associations, further weakening native plant resilience (Ismail and Mah, 1993). In some cases, allelopathy interacts synergistically with other invasive strategies, such as resource competition and pathogen accumulation, intensifying the impact of invaders (Bao-Ming *et al*., 2017), highlights that environmental factors like soil nutrient levels and microbial activity can influence the strength of allelopathic interactions.

Grassland management

Grassland management refers to a collection of methods used to preserve, improve, or restore the biodiversity, productivity, and ecological health of grassland ecosystems, especially in order to sustain ecosystem services, promote livestock production, and protect species. Due to the high productivity and richness of these systems, as well as their susceptibility to deterioration from invading species, overgrazing, and changed disturbance regimes, grassland management is particularly important in tropical regions (Buisson *et al*., 2019; Xu *et al*., 2023; Boval *et al*., 2017). There are many key grassland management practices. Rotational and well-timed grazing promotes forage species regrowth, avoids overgrazing, and maintains pasture productivity. In order to give grasses time to recover, livestock are frequently moved between paddocks, and grazing is scheduled to occur during the best times for grass recovery (Boval *et al*., 2017). Prescribed burning is used to prevent the spread of woody plants, preserve species diversity, and replicate natural disturbance processes. Long-term fire exclusion can reduce biodiversity and raise the risk of wildfires (Buisson *et al*., 2021). Soil fertility and pasture resilience are improved by practices including legume planting, periodic cultivation, and the introduction of drought-resistant species. Restoring grasslands and preventing weed invasion can also be accomplished with mechanical treatments like light discing and mowing (Pathak *et al*., 2004). Reintroducing native grasses, managing invasive species, and occasionally removing topsoil in severely deteriorated regions are the main goals of restoration projects. Restoring ecological resilience and function is the goal of these interventions (Buisson *et al*., 2021). Animal husbandry and grassland management are closely related because pasture productivity and health have a direct impact on livestock performance and local livelihoods (Boval *et al*., 2017).

Among the many ecosystem services that grasslands offer carbon sequestration, water management, and biodiversity habitat. When considering the effects of allelopathy in grassland management (Xu *et al*., 2023) communicated that allelopathic weeds and grasses have the ability to inhibit the growth of other plant species, which can lower biodiversity and, in certain situations, hasten the deterioration of grasslands, particularly when overgrazing is occurring (Xu *et al*., 2023). Allelopathic mechanisms are being investigated more and more as natural weed control methods that may reduce the need for chemical pesticides and encourage more environmentally friendly management techniques (Khamare *et al*., 2022; Cheng and Cheng, 2015). Allelopathic interactions between grasses and other plant species must be taken into consideration while managing grasslands in tropical environments. This entails choosing suitable species for restoration, controlling grazing intensity to reduce allelopathic weed spread, and incorporating allelopathic knowledge into more comprehensive ecosystem management and restoration plans (Xu *et al*., 2023; Khamare *et al*., 2022; Cheng and Cheng, 2015). Grassland management refers a collection of methods used to preserve, improve, or restore the biodiversity, productivity, and ecological health of grassland ecosystems, especially in order to sustain ecosystem services, promote livestock production, and protect species. Due to the high productivity and richness of these systems, as well as their susceptibility to deterioration from invading species, overgrazing, and changed disturbance regimes, grassland management is particularly important in tropical regions (Buisson *et al*., 2019; Xu *et al*., 2023; Boval *et al*., 2017). Soil fertility and pasture resilience are improved by practices including legume planting, periodic cultivation, and the introduction of drought-resistant species. Restoring grasslands and preventing weed invasion can also be accomplished with mechanical treatments like light discing and mowing (Pathak *et al*., 2004). Reintroducing native grasses, managing invasive species, and occasionally removing topsoil in severely deteriorated regions are the main goals of restoration projects. Restoring ecological resilience and function is the goal of these interventions (Buisson *et al*., 2021). Animal husbandry and grassland management are closely related because pasture productivity and health have a direct impact on livestock performance and local livelihoods (Boval *et al*., 2017).

In grassland ecosystems, allelopathy is important for helping plant invasions by chemically suppressing neighboring forage species. (Liu *et al*., 2025). Certain tropical grasses and legumes exhibit allelopathic potential, affecting seed sprout and radicle elongation of pasture weeds. This is relevant to grazing animals as it might change what kinds of plants are present in the pasture. (Souza Filho *et al*., 1997). Allelochemicals can interfere with plant establishment and growth potentially reducing he availability and nutritional value of forage for grazing animals (Xu *et al*., 2023). Allelopathic native invasive species degrade alpine meadows and reduce the quantity and quality of feed by affecting the pastoral livelihoods on China's

Qinghai–Xizang Plateau, underscoring the necessity for allelopathy-based management techniques (Liu *et al*., 2025).

Conclusions and Recommendations

Allelopathy is a double edged ecological mechanism in grassland ecosystems. While it offers a sustainable, natural alternative to chemical weed control, it can also contribute to biodiversity loss specially when driven by invasive species. In tropical grasslands, where ecological balance is fragile, understanding and managing allelopathic interactions is essential for maintaining productivity, preserving native species, and achieving long-term sustainability. Maintaining ecosystem health and productivity requires incorporating knowledge of allelopathic mechanisms into grassland management techniques like species selection, fire regimes, controlled grazing, and soil restoration. Additionally, using allelopathy as a greener substitute for chemical pesticides creates new opportunities for ecosystem restoration and sustainable agriculture, particularly in the delicate tropical grasslands. For grassland conservation and management, allelopathy thus presents both a challenge and an opportunity that calls for careful research and implementation in upcoming ecological and agricultural planning.

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Novelty Statement

While allelopathy has been extensively reviewed in agricultural weed management, this review is written to specifically synthesize allelopathic interactions within the context of tropical grassland management, linking grass-derived allelochemicals to grazing systems, invasive species dynamics, and restoration practices.

Author's Contribution

M.N.A. Perera: Developing ideas, formal analysis, collected and analyzed relevant data, compiled relevant literature, Writing original draft preparation.
P.C.D. Perera: Conceptualization the review topic, methodology, supervision, investigation, writing original draft preparation.
M. A. Khan: Critically refined, edited, and improved the manuscript's scientific coherence and language.

Generative AI and AI-assisted technology statement
The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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