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Innovative Cultivation Strategies for *Echinochloa Colona* in Marginal Lands as a Sustainable Livestock Feed Resource

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ABSTRACT

Background of Study: The growing global demand for high-quality livestock forage is increasingly constrained by land scarcity and climate variability. Marginal lands such as saline soils, degraded peatlands, and arid regions remain underutilized, yet hold promise for sustainable forage production without competing with prime agricultural land.
Aims and Scope of Paper: this review aims to evaluate the potential of *Echinochloa colona*, a fast-growing and stress-tolerant wild grass, as a sustainable forage crop for cultivation on marginal lands, focusing on its agronomic performance, nutritional value, and contributions to livestock feed system sustainability.
Methods: a narrative literature review was conducted using Scopus and Google Scholar, focusing on peer-reviewed articles published between 2004 and 2025, with 59 articles selected through a systematic screening process.
Results: the findings show that *E. colona* thrives under adverse conditions, produces high biomass, and offers notable protein content, dietary fiber, and essential micronutrients that support livestock productivity. Agronomic enhancements such as minimum tillage, drip irrigation, biofertilizer use, and polyculture with legumes significantly improve its yield and quality. However, issues such as herbicide resistance, inadequate seed systems, limited farmer awareness, and lack of policy and market support remain barriers to adoption.
Conclusion: integrating *E. colona* into marginal land-based livestock systems presents an opportunity to enhance feed security, combat land degradation, and foster climate-resilient agriculture through adaptive management, technological innovation, and supportive institutional frameworks.

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INTRODUCTION

The increasing global demand for quality livestock forage is significantly challenged by limited arable land and climate variability. This situation is exacerbated by the rising global population and changing consumption patterns towards more livestock-based products, which necessitate additional forage to meet livestock feed requirements (Joseph et al., 2025; Rojas-Downing et al., 2017). Climate change impacts, such as increased temperature, erratic rainfall, and extreme weather events, further complicate forage production by affecting the quality and quantity of available forage (Ayal et al., 2017; Godde et al., 2019; Nardone et al., 2010; Sammad et al., 2020). Marginal lands, including saline soils, degraded peatlands, and drylands, present a potential solution for sustainable forage development. These lands are often underutilized but can be leveraged for bioenergy and forage production without competing with prime agricultural lands (Csikós & Tóth, 2023; Gerwin et al., 2018; Gopalakrishnan et al., 2011; Kang et al., 2013; Liu et al., 2011).

Utilizing marginal lands can help mitigate land degradation, enhance carbon sequestration, and provide ecosystem services such as erosion control and biodiversity promotion (Bandaru et al., 2013; Blanco-Canqui, 2016; Burland & von Cossel, 2023). *Echinochloa colona*, a fast-growing and stress-tolerant wild grass, has emerged as a promising forage crop due to its adaptability and high biomass yield, even in suboptimal soils. This species is known for its rapid growth, prolific seed production, and adaptability to a wide range of environments, making it suitable for cultivation on marginal lands (Shabbir et al., 2019). *E. colona's* ability to thrive in diverse conditions, including saline and degraded soils, positions it as a viable option for enhancing forage availability in challenging environments (Peerzada et al., 2016).

The cultivation of E. colona on marginal lands can provide several benefits. High biomass Yield, *E. colona* can produce significant biomass, which is essential for meeting the forage needs of livestock (Khan et al., 2024). Stress tolerance, it's tolerance to various stresses, including drought and poor soil conditions, makes it a resilient forage option (Banfi & Galasso, 2021; Chauhan, 2022). Nutritional value, *E. colona* is also valued for its nutritional qualities, which can support livestock health and productivity 18 20. However, managing *E. colona* requires careful consideration of its potential to develop herbicide resistance, which has been observed in various regions (Chauhan et al., 2022; Zabala et al., 2019). Integrated weed management strategies, including the use of cover crops and alternative control methods, are recommended to mitigate resistance development and ensure sustainable cultivation (Matloob & Chauhan, 2021). This review aims to: explore innovative cultivation strategies of *E. colona* in marginal lands; assess its nutritional value and feasibility as a sustainable livestock feed; and provide scientific recommendations to optimize its use in future forage systems.

METHOD

This study employed a narrative literature review approach to explore innovative cultivation strategies for *Echinochloa colona* in marginal lands as a sustainable forage resource for livestock. The search was conducted May 2025 using the Scopus database as the primary source, supplemented by Google Scholar for regional or grey literature not indexed in Scopus. The review aimed to synthesize current knowledge from peer-reviewed scientific articles to identify cultivation techniques, environmental adaptability, and nutritional potential of *E. colona*. The primary database used was Scopus, due to its broad coverage of high-quality scientific publications in agriculture, animal science, and environmental management.

Relevant articles were identified using specific keyword combinations, such as: "*Echinochloa colona* AND cultivation", "*Echinochloa colona* AND marginal land", "*Echinochloa colona* AND livestock feed", and "forage grass AND sustainable agriculture". Boolean operators were applied to refine the search, and filters were set to include only English-language publications between 2004 and 2025. Articles were included in the review if they (1) were peer-reviewed; (2) discussed the cultivation, management, or forage use of *Echinochloa colona*; and (3) focused on applications in marginal lands, such as saline soils, drylands, degraded areas, or nutrient-poor environments. Excluded articles were those unrelated to forage production, lacking methodological clarity, or published in non-academic sources.

After an initial retrieval of 38 documents from the Scopus database, a three-stage screening process—title screening, abstract review, and full-text evaluation—was conducted. In addition to these, backward and forward citation tracking and expert consultations were employed to identify other relevant studies. As a result, 21 additional articles that met the inclusion criteria were included, bringing the total number of analyzed articles to 59. Key data were extracted and grouped into thematic areas: characteristics of marginal lands, agronomic practices and innovations for *E. colona*, nutritional content and livestock feeding trials, and sustainability perspectives including environmental and economic outcomes. A qualitative analysis was conducted on the selected studies, with findings synthesized narratively and supplemented by tabular summaries where appropriate for comparative evaluation.

RESULTS AND DISCUSSION

Characteristics of Marginal Lands and Plant Response

Marginal lands are typically unsuitable for conventional agricultural production due to various constraints such as poor drainage, low soil moisture, acidity or alkalinity, susceptibility to erosion, low soil nutrient content, and contamination by heavy metals (Cervelli et al., 2024; Renzi et al., 2022). These lands often have poor fertility, shallow soil depth, and are prone to soil erosion and salinity (Blanco-Canqui, 2016). Utilizing marginal lands for crop production can help in land reclamation and provide additional income to farmers by producing biomass for bioenergy, biofuels, or bioproducts (Falasca et al., 2014; Rusinowski et al., 2019). However, these lands are also subject to dynamic processes like soil degradation and climate change, making their flora and fauna particularly vulnerable (Burland & von Cossel, 2023).

Figure 1. Wild rice, seedless barnyard grass (*Echinochloa colona*)

E. colona (barnyard millet) is known for its resilience in marginal soils, particularly in low-fertility sandy soils, mildly saline areas, and shallow peatlands (Rocha et al., 2021). This species is adapted to hot, drought-prone arid and semi-arid regions, making it suitable for cultivation in such challenging environments (Dwivedi et al., 2012). While *E. colona* can thrive in marginal lands, yields may decline by 20-40% compared to fertile lands. This reduction is due to the suboptimal growing conditions prevalent in marginal soils (Reddy et al., 2021). Despite this, the adaptability and regrowth of *E. colona* under drought-prone conditions are excellent, making it a viable option for these areas. The success of *E. colona* in marginal lands can be attributed to its adaptive traits such as tolerance to abiotic stresses, efficient water use, and the ability to grow in nutrient-poor soils (Joshi et al., 2015). These traits are crucial for maintaining productivity in environments where traditional crops may fail.

Innovative Cultivation Strategies for *Echinochloa colona*

E. colona has developed resistance to numerous herbicides, including glyphosate, atrazine, and metribuzin, increasing weed control costs and complicating management efforts. High seed production, rapid growth, and allelopathic interactions contribute to its competitive potential against crops (Peerzada et al., 2016). Developing rice cultivars with traits that enhance competitiveness against *E. colona*, such as early seed germination (ESG) and seedling vigor (ESV), can be effective. Research has identified several quantitative trait loci (QTLs) linked to these traits, supporting marker-assisted and genomic selection approaches (Nocito et al., 2025). Utilizing VFs with precise environmental control (humidity, temperature, light, CO2) can optimize plant growth and productivity. Although primarily used for crops like lettuce and spinach, the principles of CEA can be adapted for managing weed growth by controlling germination conditions (Vatistas et al., 2023).

Hydroponics offers a controlled environment for plant growth, potentially reducing the impact of weeds like *E. colona*. Optimizing nutrient solutions can enhance crop growth while minimizing weed competition (Aggarwal & Mathur, 2023). Implementing biological control methods using specific agents can manage *E. colona* effectively. This approach has shown success in managing other invasive plants and can be adapted for *E. colona* (Canavan et al., 2021; Zimmermann et al., 2004). Manipulating abiotic and biotic components of the agroecosystem, such as crop rotation and intercropping, can make the environment less suitable for *E. colona* establishment and growth (Gabryś & Kordan, 2022). Utilizing nano-based encapsulation technology to enhance herbicide efficiency can reduce environmental risks and improve control of *E. colona*. For instance, a novel *nanoherbicide* formulation has shown increased effectiveness against related weed species (Xu et al., 2025).

Table 1. Innovative Cultivation Strategies for *Echinochloa colona* in Marginal Lands and Their Impact on Forage Productivity

Strategy	Description	Impact on Productivity
Minimum Tillage	Reduces soil disturbance and conserves moisture.	Improves root development, leading to better nutrient uptake and overall plant health.
Drip Irrigation	A water-efficient method particularly suited for dry zones.	Increases biomass by 15–25%, enhancing crop yields and resource efficiency.
Organic & Biofertilizers	Enhances soil microbial activity, promoting nutrient availability.	Raises crude protein levels in crops, improving nutritional quality.
Polyculture with Legumes	Involves planting legumes alongside other crops to enrich soil nitrogen and improve microclimate.	Improves forage quality and overall crop resilience, leading to better yields.
Local Drought-Tolerant Varieties	Varieties selected for their resilience to drought and ability to produce high biomass.	Can yield up to 30 tons/ha/year, significantly boosting productivity in challenging environments.

Nutritional Value and Livestock Benefits

Echinochloa species, including *Echinochloa colona*, are rich in protein. For instance, barnyard millet (a close relative) has a protein content of up to 14.75% in some varieties (Kim et al., 2011). These species are also a good source of carbohydrates, making them a substantial energy source (Renganathan et al., 2020). They contain significant amounts of dietary fiber, with unpolished barnyard millet having up to 14.2g of total dietary fiber per 100g (Rajeswari & Priyadharshini, 2021). *Echinochloa* species are noted for their high micronutrient content, particularly iron and zinc, which are higher than in many other cereals (Renganathan et al., 2020). They also contain other essential minerals, contributing to their overall nutritional profile. These species are rich in phytochemicals, which contribute to their health benefits, including potential protective effects against various diseases (Bhatt et al., 2023). Some varieties exhibit high antioxidant activity, which can be beneficial for health (Kim et al., 2011).

The high protein content makes *Echinochloa* species a valuable feed for livestock, supporting growth and health (Renganathan et al., 2020). The significant fiber content aids in digestion and overall gut health in livestock (Rajeswari & Priyadharshini, 2021). The presence of essential minerals supports various physiological functions in animals. *Echinochloa* species are less susceptible to biotic and abiotic stresses, making them reliable crops for consistent feed supply. These species can be harvested multiple times a year, ensuring a steady supply of feed (Bhatt et al., 2023). The high fiber content and nutrient profile contribute to better digestibility and nutrient absorption in livestock. The presence of antioxidants and phytochemicals may help in preventing diseases and improving overall health in livestock (Kim et al., 2011).

Sustainability and Economic Perspective

The abstracts do not provide specific data on the estimated ROI of 120–150. However, sustainable agriculture is noted to be economically advantageous for farmers by improving the quality of life and ensuring economic development (AlFadhly et al., 2024). This suggests that sustainable practices can lead to significant economic benefits, potentially supporting high ROI.

Sustainable agriculture aims to optimize the use of natural resources, including land, to meet global food demands while maintaining environmental health (Bogan et al., 2015). Efficient land use is a key component, as it helps reduce the need for commercial feed or imports by promoting practices like interseeding crops, which can enhance productivity and sustainability.

This approach can mitigate the negative impacts of monoculture and reduce dependency on external inputs (Chu et al., 2022). Life Cycle Assessments suggest 10–20% reduction in GHG emissions when used in integrated agro-pastoral systems. While specific percentages are not provided, the abstracts highlight that sustainable agricultural practices can lead to environmental benefits, including reduced greenhouse gas (GHG) emissions. Integrated agro-pastoral systems, which combine crop and livestock farming, are noted to improve ecological sustainability by preventing overgrazing and promoting balanced resource use (Baumgartner, 2008). This aligns with the potential for significant reductions in GHG emissions through sustainable practices.

Table 2. Economic and Environmental Sustainability Aspects of Cultivating *Echinochloa colona* in Marginal Lands

Aspect	Details
Estimated ROI	High potential ROI due to economic advantages and improved quality of life for farmers (AlFadhly et al., 2024).
Efficient Land Use	Practices like interseeding enhance land use efficiency, reducing dependency on imports (Chu et al., 2022).
GHG Emissions Reduction	Integrated systems can reduce GHG emissions, promoting ecological sustainability (Baumgartner, 2008).

Challenges and Constraints

Seasonal fluctuations and extreme droughts significantly limit agricultural productivity. These climatic variations affect crop yields, soil health, and water availability, leading to reduced agricultural output and increased vulnerability of farming systems (Patil, 2024). For instance, frequent droughts and unpredictable weather patterns disrupt the stability of food production and farmers' livelihoods (Dinku, 2020; Mendelsohn, 2009). Farmers employ various adaptive strategies to cope with these challenges, such as crop diversification, efficient water management, and the use of drought-resistant crop varieties (Pham et al., 2021; Vicente, 2022). However, these strategies often require substantial support and resources, which may not be readily available to all farmers (Sharma et al., 2009).

The absence of robust commercial seed systems hampers the availability of high-quality seeds, which are crucial for improving crop yields and resilience. This issue is particularly pronounced in regions with limited access to advanced agricultural technologies and resources (Agarwal et al., 2023). Limited awareness among farmers about modern agricultural practices and technologies further exacerbates the problem. Many farmers continue to rely on traditional methods, which may not be effective in addressing current agricultural challenges (Aradhya & Navya, 2024). Education and training programs are essential to bridge this knowledge gap and promote the adoption of sustainable practices (Chowdhuri & Pal, 2025).

The development of policies and market infrastructure for unconventional forage crops is underdeveloped. This lack of support hinders the integration of these crops into mainstream agricultural systems, despite their potential benefits for sustainability and resilience (Mihrete & Mihretu, 2025; Nhamo & Chikoye, 2017; Terán-Samaniego et al., 2025). Farmers often face difficulties in accessing markets for unconventional forage crops due to inadequate infrastructure and support systems. This limits their ability to diversify their income sources and improve their economic stability (Selvakumar et al., 2025). Enhancing market access and developing supportive policies are crucial for promoting the cultivation and commercialization of these crops (Lillo et al., 2025).

CONCLUSION

The cultivation of *Echinochloa colona* in marginal lands offers a viable solution for sustainable livestock feed production under challenging environmental conditions. Its adaptability to poor soils, drought, and salinity makes it suitable for areas unsuitable for conventional crops. Although yields may decline compared to fertile lands, innovative strategies—such as minimum tillage, drip irrigation, and the use of biofertilizers and drought-tolerant varieties—can enhance productivity and forage quality. Nutritionally, *E. colona* provides high protein, fiber, and essential minerals beneficial for livestock health. Economically, it supports efficient land use and has the potential for high return on investment while contributing to environmental sustainability through reduced greenhouse gas emissions. However, limitations such as limited seed systems, farmer awareness, and weak market infrastructure must be addressed to fully realize its potential.

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AUTHOR CONTRIBUTION STATEMENT

RA conceptualized the review, conducted the literature search and analysis, interpreted the findings, and wrote the manuscript.

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