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Medicinal and Aromatic Plants as Nature Based Solutions for Degraded Land Management

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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Abstract

Land degradation presents a formidable global challenge, severely impacting ecosystem stability, agricultural productivity, and biodiversity. Traditional restoration methods often prove resource-intensive and economically unviable, thus highlighting the urgent need for innovative, nature-based solutions. This comprehensive review investigates the multifaceted potential of medicinal and aromatic plants (MAPs) as an integrated and sustainable strategy for the restoration of degraded lands. MAPs exhibit remarkable adaptive traits, including inherent tolerance to significant abiotic stresses such as drought, salinity, and heavy metal contamination; which allows them to flourish in marginal environments where conventional crops typically fail. Their crucial ecological functions encompass soil stabilization, effective erosion control, significant carbon sequestration, and efficient phytoremediation, all of which are vital for rejuvenating soil health and restoring essential ecosystem services. Furthermore, MAPs actively foster beneficial soil microbial

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communities through intricate rhizosphere interactions, thereby enhancing nutrient cycling and promoting long-term soil productivity. Economically, the cultivation of MAPs offers substantial opportunities through the production of high-value essential oils, the creation of diverse value-added by-products, and the provision of carbon sequestration incentives. These economic benefits render restoration efforts financially viable and highly attractive to a broad range of stakeholders. However, achieving successful large-scale adoption necessitates addressing critical challenges related to appropriate species selection, the conservation of genetic resources, market volatility, and the establishment of robust, supportive policy frameworks. This review conclusively demonstrates that integrating MAPs into land management systems establishes a synergistic model that concurrently achieves profound ecological restoration and significantly improves rural livelihoods, thereby offering a sustainable and economically sound pathway towards effectively combating land degradation while simultaneously supporting global biodiversity and human communities.

Keywords: Restoration; phytoremediation; biodiversity; sustainability; sequestration; livelihoods; resilience.

1. Introduction: The Convergence of Land Degradation and Plant-Based Solutions

Land degradation ranks among the most urgent environmental issues of the twenty-first century, endangering food security, biodiversity, and ecosystem services worldwide. Unsustainable land management approaches, industrial growth, urban expansion, and contamination have severely endangered land resources, making large areas of fertile land either marginal or completely unproductive (Gupta *et al.*, 2021). The United Nations has announced 2021–2030 as the "Decade on Ecosystem Restoration," highlighting the critical need to restore degraded environments globally (Tomar et al., 2025). In light of this context, traditional methods for restoring degraded lands—covering physical, chemical, and biological techniques—have often been costly and tend to be unsustainable without the integration of sophisticated technology (Tomar *et al.*, 2025).

This scenario has sparked a quest for environmentally based, economically sustainable alternatives. Medicinal and aromatic plants (MAPs) have surfaced as an intriguing nature-based approach, providing a distinctive blend of ecological restoration capabilities, economic benefits, and resilience to stress. In contrast to traditional crops that require rich soils and substantial resources, numerous aromatic species are suited to the severe environmental conditions typical of degraded landscapes (Gupta *et al.,* 2021). The theoretical question that drives this review goes beyond whether MAPs can thrive on degraded lands; it examines why and through which mechanisms these plants concurrently rehabilitate degraded soils while producing economic benefits—a dual role that contests the traditional belief in trade-offs between land restoration and productive application.

This article compiles the existing understanding of using medicinal and aromatic plants for the conservation of degraded lands, exploring the ecological processes that support their healing abilities, their potential for phytoremediation, economic viability, and the policy structures required for expanding these approaches.

2. Methodology

This review synthesizes existing knowledge and research on the application of medicinal and aromatic plants (MAPs) for degraded land management. The approach involved a thorough and systematic examination of peer-reviewed literature, including research articles, comprehensive reviews, and technical reports, primarily focusing on the ecological, economic, and social aspects of MAP-based restoration. Key themes explored include MAPs' adaptive traits and stress tolerance mechanisms (Yadav et al., 2024), their pivotal roles in soil stabilization and erosion control (Tomar et al., 2025), carbon sequestration potential (Khan and Verma, 2020; Yadav et al., 2023), and their efficacy in phytoremediation of contaminated soils (Ait Elallem et al., 2021; Kumar et al., 2021). The analysis also delved into the crucial function of soil microbiomes in MAP-facilitated restoration processes (Wang et al., 2022; Zhao et al., 2025). The economic viability was rigorously assessed by considering income generation from essential oil production, the valorization of waste into value-added by-products, and the financial incentives associated with carbon sequestration (Yadav et al., 2023). Furthermore, the review critically examined conservation issues, sustainability concerns, including threats to wild MAP populations and overexploitation (Ahmad et al., 2023; Brinckmann et al., 2022), and the necessary regulatory structures and organizational assistance for successful large-scale implementation (Tomar et al., 2025; Licata et al., 2022). The synthesis aimed to identify the current state of understanding, highlight significant knowledge gaps, and propose concrete future research directions to advance the integration of MAPs into sustainable land management practices globally.

3. Theoretical Basis: What Makes Aromatic Plants Suitable for Degraded Lands?

- **The Environmental Justification**

The core ecological reason for using aromatic plants on degraded lands is based on their developed mechanisms for tolerating stress. Medicinal and aromatic plants have been acknowledged since antiquity for their ability to produce secondary metabolites—terpenoids, phenolic compounds, and alkaloids—that perform protective roles against environmental stressors (Yadav *et al.,* 2024). The same metabolic pathways responsible for generating commercially valuable essential oils also provide resilience against abiotic stresses such as heavy metal contamination, salinity, and drought (Emami Bistgani *et al.,* 2024).

The idea of ruderal species—nature's robust pioneers that flourish in disturbed, low-stress environments via quick growth and extensive dispersal—offers an ecological basis for comprehending why some MAPs are especially adapted to degraded landscapes. Various aromatic grasses, especially *Chrysopogon zizanioides, Cymbopogon flexuosus*, and *Cymbopogon martini*, have been found to be highly effective for the restoration of arid lands, mining-damaged regions, and soils contaminated with metals and pesticides (Yadav *et al*., 2023).

- **Principles of Restoration Ecology**

The difference between ecological restoration—returning to a past reference state—and rehabilitation—enhancing site function—is essential for establishing project objectives when using MAPs on degraded lands 8. Most MAP-focused approaches are more aligned with rehabilitation, seeking to enhance soil function and ecosystem services instead of restoring conditions prior to disturbance. Effective restoration relies on leveraging natural processes like ecological succession, facilitation, and nutrient cycling, with aromatic plants acting as facilitator species that kickstart these processes on otherwise unproductive substrates.

The rhizosphere—the soil area directly around plant roots—plays a key role in the healing process. Roots of plants act as dynamic environmental engineers, releasing substances that modify local soil chemistry, access vital nutrients, and attract advantageous microbial populations (Wang *et al.,* 2022). Aromatic plants enhance microbial breakdown of organic matter and promote nutrient cycling through root exudates, gradually benefiting soil health.

4. Processes for Restoring Degraded Land

- **Soil Stabilization and Erosion Management**

A key way aromatic plants rehabilitate degraded soils is by stabilizing the soil physically. Rapidly growing, non-consumable plants with extensive root networks help stabilize soil and mitigate erosion, providing both cost-effective and ecologically responsible solutions (Tomar *et al*., 2025). The comprehensive analysis by Tomar *et al*. (2025) showed that fragrant plants can decrease soil erosion and runoff by 30%–54% and 60%–80%, correspondingly. These numbers indicate significant enhancements in hydrological performance, especially important for sloped terrains in the Himalayan area and other erosion-susceptible environments.

The agroforestry method, which integrates aromatic grasses with tree species, has been studied as a comprehensive system for rehabilitating degraded land. Tomar *et al.* (2023) assessed the growth of lemongrass *(Cymbopogon flexuosus)* and java grass *(Cymbopogon winterianus)* cultivated alongside mulberry trees (*Morus alba*) on degraded land in the north-western Himalayan foothills, showing enhancements in plant yields and soil conditions over a three-year period. These polyculture systems utilize complementary root structures and nutrient cycling processes to improve overall ecosystem performance.

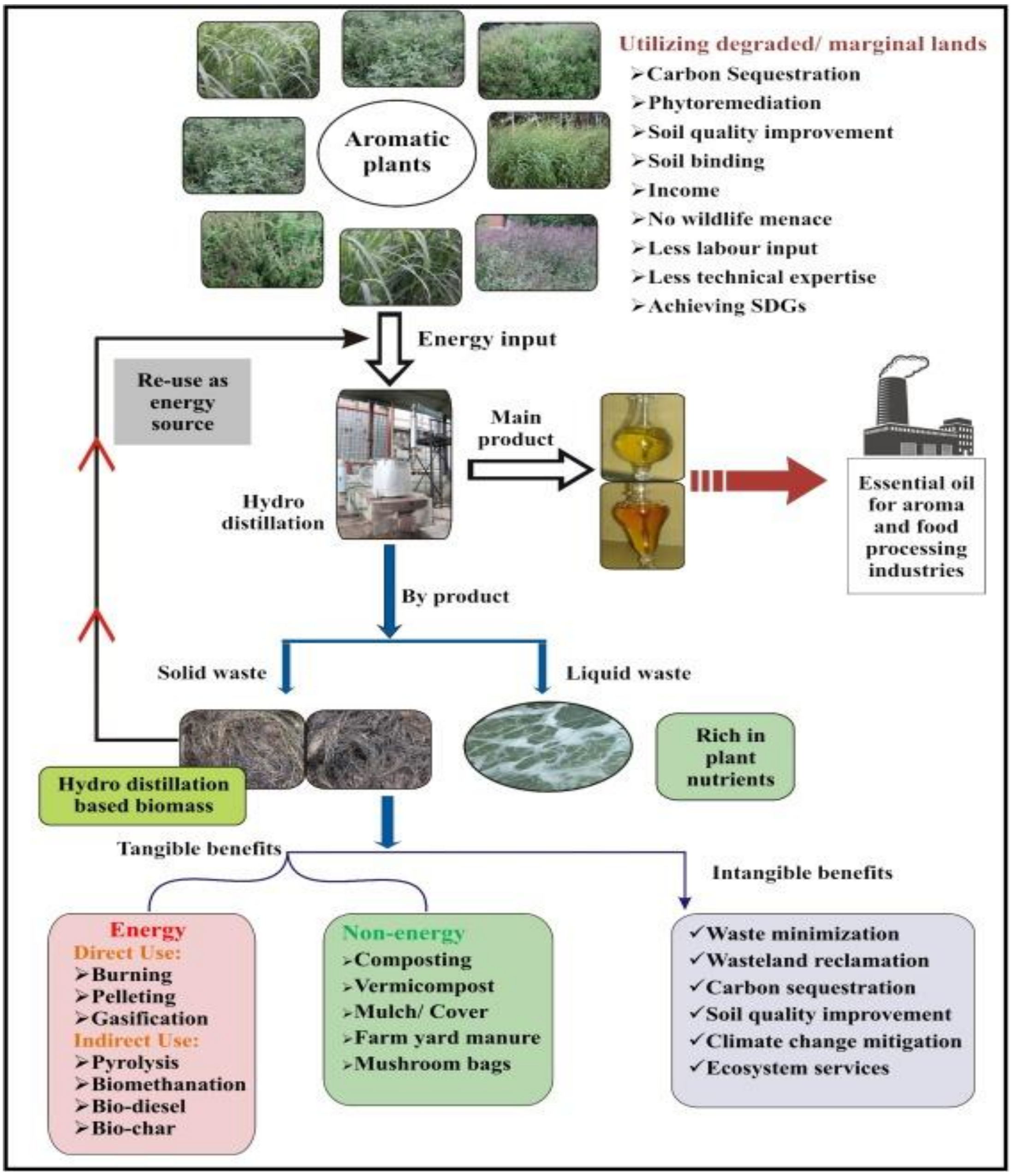

Fig. 1. Aromatic plants for sustainable utilization of degraded land
Source: Gupta et al. (2021)

Table 1. Comparative Table of MAP Species and Their Restoration Capacities

Species	Degradation Type	Key Mechanism	Reported Benefit
Vetiveria zizanioides	Eroded/mining land	Deep root stabilization	Runoff reduction 60–80%
Cymbopogon **spp**	Marginal/arid soils	Carbon sequestration	5.38–15.2 t C ha^{-1}
Mentha arvensis	Heavy metal contaminated	Phytoextraction	Non-food crop safe harvesting
Ocimum basilicum	Saline degraded soils	Salinity tolerance	Soil organic carbon improvement
Pelargonium **spp.**	Mining waste	Metal stabilization	Economically viable essential oil

Source: Tomar et al. (2025)

Description: This table synthesizes data from reviews showing that aromatic plants can reduce soil loss by 30–54% and runoff by 60–80%, while sequestering 5.38 to 15.2 t ha^{-1} of carbon

- **Carbon Capture and Storage**

Carbon sequestration for climate change mitigation is another essential ecosystem service offered by cultivating aromatic plants on degraded land. The ongoing increase in atmospheric CO_2 levels requires methods to replenish the diminished soil carbon reserves, and aromatic plants present a practical solution (Khan and Verma, 2020). Tomar *et al.* (2025) indicated that aromatic plants show promise for improving carbon sequestration, ranging from 5.38 to 15.2 t / ha.

Yadav *et al*. (2023) presented detailed economic evaluations of carbon dynamics linked to the cultivation of aromatic grasses on degraded lands. Based on the reported degraded land in India (38,600 ha), they estimated that cultivating aromatic plants for carbon sequestration could cost between 16 and 45 million USD. Additionally, transforming the distilled waste produced during essential oil extraction into compost, vermicompost, and biochar could sequester around 0.02 × 105 to 335 × 105t of carbon, worth about 0.2–1913 million USD. This waste recovery method significantly enhances the carbon capture capacity of the aromatic plant supply chain.

- **Phytoremediation of Polluted Soils**

The ability of medicinal and aromatic plants to facilitate phytoremediation is a notably encouraging approach for rehabilitating chemically degraded soils. Heavy metal contamination presents a serious risk to farming output and human well-being, and traditional remediation methods are too costly for widespread use (Kumar *et al.,* 2021). Fragrant and therapeutic plants provide a sustainable solution for phytoremediation since the heavy metals they absorb do not integrate into the food chain during essential oil extraction, contrary to food crops (Lone and Gaffar, 2021).

Ait Elallem *et al*. (2021) demonstrated the advantages of utilizing aromatic and medicinal plants for the rehabilitation and revegetation of chemically degraded soils, specifically in mined areas, recognizing various species as efficient "nurse plants" that aid in overall ecosystem restoration 14. It is advised to choose native plant species for phytoremediation to prevent ecological risks tied to the introduction of non-native species (Nedjimi, 2020). *Peganum harmala*, for example, has shown tolerance to heavy metals during germination, indicating its potential use in restoring polluted drylands.

- **Mitigation of Non-Biological Stresses**

In addition to heavy metals, aromatic plants show the ability to withstand and alleviate various abiotic stresses such as salinity and drought. The analysis by Tomar et al. (2025) verifies that aromatic plants can effectively reduce abiotic stresses such as heavy metal pollution, saline conditions, and drought. Drought, especially, presents a considerable obstacle limiting the productivity of medicinal and aromatic plants by hindering essential processes such as photosynthesis and respiration (Emami Bistgani *et al.,* 2024). The adaptive strategies these plants have developed—including osmotic adjustment, generation of antioxidants, and altered root structures—allow numerous species to sustain productivity in water-scarce environments.

Yadav *et al.* (2024) examined the effects of abiotic stresses and tolerance strategies in MAPs, highlighting that grasping these mechanisms is crucial for choosing suitable species for particular degraded land situations. The ability to withstand diverse environmental conditions allows multiple MAPs to be used as indigenous plants in various degraded regions.

5. The Function of Soil Microbiomes in MAP-Facilitated Restoration

The relationship between aromatic plants and soil microbial communities signifies a new area in comprehending restoration processes. Helpful microorganisms aid in soil restoration and enhancement of medicinal plant quality through various mechanisms such as nutrient mobilization, pathogen control, and decomposition of organic matter (Wang *et al.,* 2022). Zhao *et al.* (2025) examined ecological restoration methods through soil microbiomics, highlighting microbial community engineering as an emerging approach for addressing soil contamination and improving ecological decline.

The rhizosphere priming effect—where root exudates enhance microbial breakdown of soil organic matter—is especially important for MAP-based restoration, since aromatic plants usually generate plentiful root exudates high in terpenes and other secondary metabolites. These compounds can specifically attract advantageous microbial groups, fostering positive feedback cycles between plant growth and enhancements in soil health.

6. Economic Feasibility and Technological Economics

A key characteristic of MAP-based land restoration is its ability to achieve economic self-sustainability. In contrast to solely ecological restoration efforts that need ongoing external financial support, cultivating aromatic plants produces income from essential oil manufacturing, thus motivating ongoing land management (Khan and Verma, 2020). The projected profitability of cultivating aromatic grasses and the related carbon sequestration in marginal or degraded lands may amount to 22–629 million USD considering the degraded land available in India (Yadav *et al.,* 2023).

The essential oil market drives the need for fragrant crops in various sectors such as aroma, food, cosmetics, perfumery, and toiletries (Gupta *et al.,* 2021). India, being the top exporter of essential oils, can gain significantly by directing production to degraded lands instead of vying with food crops for productive agricultural land (Khan and Verma, 2020). *Cymbopogon martini* (palmarosa) has been recognized as a promising aromatic crop for industrial use, encompassing applications in pharmaceuticals, cosmeceuticals, food additives, and agriculture (Sen *et al.,* 2023).

The waste valorization aspect enhances economic value. While distilling aromatic plants, considerable amounts of solid and liquid waste (hydrosol) are produced. This waste contains high levels of carbon and nutrients, which can be transformed into value-added products such as compost, vermicompost, and biochar (Yadav *et al*., 2023). Utilizing hydrosol and smoke water produced during distillation has the potential to sequester around 0.014 to 7,403 t of carbon, with an estimated expense ranging from 0.001 to 0.42 million USD. This circular economy model converts waste into extra income and ecological advantages.

7. Conservation Issues and Sustainability Worries

- **Dangers to Resources of Medicinal and Aromatic Plants**

In promoting MAP cultivation on degraded lands, acknowledging the conservation challenges confronting wild MAP populations is crucial. The loss of medicinal plant resources worldwide is largely driven by habitat degradation and destruction. The surge in population and changes in climate have increasingly threatened these valuable plant resources (Shafi *et al.,* 2021). Brinckmann *et al.* (2022) presented a fresh global assessment of MAP species in commercial farming and their conservation status, emphasizing the necessity to transition from wild harvesting to organized cultivation.

International coordination is essential for conserving and sustainably utilizing MAP genetic resources. Barata *et al*. (2016) highlighted that as the demand for medicinal and aromatic plants grows, fresh income opportunities arise for rural communities, yet this needs to be balanced with the conservation of genetic resources. Growing MAPs on degraded lands presents a possible solution to this conflict—by creating new farming zones on non-agricultural land, the strain on wild populations can be alleviated while also meeting restoration goals.

- **Species at Risk and Excessive Exploitation**

Numerous important MAP species face threats from overharvesting, unsuitable collection methods, and habitat destruction (Ahmad *et al*., 2023). Conservation initiatives in areas like Nepal (Sharma *et al.,* 2004) and Uttarakhand, India (Naithani, 2022) have created in-situ conservation locations, but these are inadequate considering the magnitude of the threat. The Ladakh Changthang region alone contains 95 species of medicinal significance, with twenty species listed as threatened in the area (Paul *et al.,* 2021).

The combined strategy of growing MAPs on degraded lands and preserving wild populations in protected areas exemplifies a cooperative approach. Shukla *et al*. (2025) examined how the cultivation of medicinal and aromatic plants can contribute to sustainable development when paired with effective conservation strategies, highlighting that numerous MAP species can withstand different degrees of soil degradation.

8. Regulatory Structures and Organizational Assistance

Incorporating aromatic plants into national land management strategies necessitates favourable policy frameworks. Tomar *et al*. (2025) emphasized the significance of policy frameworks, scientific studies, and community participation in advancing the use of aromatic plants for ecological restoration, especially regarding India's pledges under the Paris Agreement to attain land degradation neutrality by 2030. Decision support systems aimed at combating land degradation should recognize synergies between restoration objectives and productive utilization, adhering to trends where enhancement of land quality yields both ecological and financial benefits (Willemen *et al*., 2018).

The multifunctionality criterion—where agricultural systems offer production, environmental, and social results at the same time—offers a basis for assessing MAP-based restoration. Licata *et al*. (2022) explored medicinal and aromatic plants within agricultural research by focusing on multifunctionality and sustainability, highlighting major transformations in agriculture concerning energy needs and modern technologies in the last twenty years.

9. Choosing Species and Considering Site-Specific Factors

Table 2. Economics of aromatic plants that are grown on degraded lands of India

S. no.	Crop	Scientific name	Cost of cultivation (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	References
1	Lemon grass	*Cymbopogon citratus*	22,500	42,000	19,500	Hanumanthappa
2	Java grass	*Cymbopogon winterianus*	19,500	33,750	14,250	et al. (2018)
3	Palma rosa	*Cymbopogon martinii*	22,500	40,500	18,000	
4	Lemon grass	*Cymbopogon citratus*	27,041	64,927	37,887	Tomar and
5	Java grass	*Cymbopogon winterianus*	24,961	49,941	24,980	Singh (2012)
6	Palma rosa	*Cymbopogon martinii*	24,144	53,829	29,685	
7	Lemon grass	*Cymbopogon citratus*	24,500	82,500	58,250	Kumar et al. (2014)
8	Mentha	*Mentha arvensis*	20,500	36,000	15,500	Singh and Jha (2008)
9	Basil	*Ociumum basilicum*	11,500	20,000	8500	Mittal and Singh
10	Jamarosa	*Cymbopogon nardus*	25,000	50,375	25,375	et al. (2007)
11	Mentha	*Mentha arvensis*	23,489	76,739	53,250	Tomar and
12	Basil	*Ociumum basilicum*	18,106	58,200	40,094	Singh (2012)
13	Vetiver	*Vetiver zizanioides*	55,517	229,450	153,933	

Source: Tomar et al. (2025)

Successful implementation of MAPs for restoring degraded land necessitates thoughtful species selection tailored to the specific site conditions. Among the most thoroughly researched species, vetiver (*Chrysopogon zizanioides*) shows remarkable ability for soil stabilization owing to its large, deep root structure. Lemongrass (*Cymbopogon flexuosus)* and palmarosa (*Cymbopogon martini)* exhibit strong stress resilience alongside significant economic worth (Yadav *et al*., 2023). Maiti and Kumar (2016) illustrated the application of *Cymbopogon citratus* and *Chrysopogon zizanioides* alongside organic fertilizers for the phytostabilization of polluted soils in energy plantations.

Nevertheless, as Yadav *et al*. (2023) warned, additional databases are required to enhance data on the productivity and selectivity of specific aromatic plants across various soil and agro-climatic zones. Grasping the significance of ruderal species and their contribution to the rehabilitation of degraded areas offers further insight for species choice, as plants demonstrating the ruderal strategy spectrum—quick colonization, stress resilience, and promoting succession—are especially suitable for early restoration stages (Ranđelović and Jovanović, 2023).

10. Directions for Future Research

Multiple important knowledge gaps require focus. The understanding of how particular aromatic plant species engage with soil microbiomes to promote restoration processes is still lacking. Although the basic concept of rhizosphere engineering is understood, the unique effects of different species and their time-related changes on degraded substrates need thorough exploration.

Secondly, it is essential to conduct long-term monitoring studies to evaluate the sustainability of MAP-based restoration over multi-year periods. Many current studies present findings over a span of three to five years (Tomar *et al*., 2023), yet the path of ecosystem recovery—whether it attains self-sustaining conditions or necessitates ongoing management—still remains unclear.

Third, the economic modeling of MAP-oriented restoration requires improvement. Present profitability estimates (Yadav *et al.,* 2023) depend on extrapolating from restricted datasets and fail to sufficiently consider market fluctuations in essential oil prices, transaction costs for small-scale farmers, or the economic assessment of ecosystem services beyond carbon.

Fourth, the scaling hurdle—transitioning from effective plot-level demonstrations to broader landscape-level application—necessitates institutional advancements such as supply chain enhancement, quality certification processes, and alignment with current land-use planning systems.

11. Final Thoughts

The use of medicinal and aromatic plants for the conservation of degraded land signifies a shift in perspective, moving from seeing restoration and productive use as opposing goals to acknowledging their possible synergy. The reviewed evidence shows that certain aromatic plant species can effectively stabilize soils, sequester carbon, remediate pollutants, and produce economic benefits—an integrated ability seldom equaled by other restoration methods.

The theoretical contribution of this work challenges the traditional belief that degraded lands must be either left unused or restored through expensive external efforts before they can be productive. Rather, the MAP-based method utilizes the developed stress resilience of specific plant lineages to trigger restoration activities that are self-sustaining via economic motivation. This exemplifies a nature-based solution in every aspect—collaborating with, instead of opposing, ecological processes to fulfill both conservation and development goals.

Nonetheless, achieving this potential on a large scale demands tackling substantial knowledge deficiencies related to species-site compatibility, long-term ecological pathways, and the institutional structures necessary for broad acceptance. Incorporating aromatic plants into land management strategies, as recommended for attaining land degradation neutrality under the Paris Agreement (Tomar *et al.,* 2025), requires synchronized efforts involving scientific research, policy formulation, and community involvement.

12. Conclusion

This review underscores the profound scientific significance of integrating Medicinal and Aromatic Plants (MAPs) into degraded land management strategies, challenging the conventional dichotomy between ecological restoration and productive land use. Scientifically, MAPs represent a sophisticated, nature-based solution rooted in their unique physiological and biochemical adaptations. Their inherent resilience to severe abiotic stresses, such as drought, salinity, and heavy metal contamination, is not merely an ecological advantage but a testament to complex evolutionary pathways that enable survival and thriving in marginal environments. This adaptive capacity allows MAPs to initiate and drive ecological succession on otherwise barren or contaminated substrates, a process often unattainable by conventional crops.

Furthermore, the scientific contribution extends to understanding the intricate mechanisms through which MAPs restore ecosystem functions. Their deep and extensive root systems provide critical soil stabilization and erosion control, demonstrably reducing soil loss and runoff by significant percentages. Beyond physical stabilization, MAPs actively participate in biogeochemical cycles, notably through substantial carbon sequestration in both biomass and soil, offering a vital natural climate solution. Their phytoremediation capabilities, particularly in sequestering heavy metals without entering the food chain, highlight a crucial scientific pathway for detoxifying chemically degraded soils. Perhaps most scientifically compelling is the role of MAPs in shaping and enhancing soil microbiomes. Through the release of specific root exudates, MAPs engage in a "rhizosphere priming effect," actively recruiting beneficial microbial communities that facilitate nutrient cycling, organic matter decomposition, and overall soil health improvement. This intricate plant-microbe interaction represents a frontier in restoration ecology, offering insights into self-sustaining ecosystem recovery.

Economically, the dual benefit of ecological restoration coupled with the production of high-value essential oils and other by-products provides a self-financing model that fundamentally alters the economic landscape of restoration projects. This economic viability is a critical scientific breakthrough, demonstrating that environmental conservation can be intrinsically linked with sustainable rural livelihoods, thereby fostering long-term commitment and success. While challenges remain in species-site compatibility, long-term ecological monitoring, and robust economic modeling, the scientific evidence overwhelmingly supports MAPs as a powerful, synergistic, and sustainable pathway toward achieving global land degradation neutrality and enhancing biodiversity, offering a compelling paradigm shift in environmental management.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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