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Short review on Role of Agroforestry in ecosystem services and carbon sequestration

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Abstract:

In the era of climate change, trees play a vital role in bolstering the resilience of agriculture by providing crucial benefits such as carbon sequestration, livelihood improvement, and enhanced food security. This review explores the multifaceted roles of agroforestry in providing essential ecosystem services and contributing significantly to carbon sequestration. In terms of ecosystem services, agroforestry promotes biodiversity conservation by creating diverse habitats and food resources. It plays a vital role in soil conservation and fertility enhancement through reduced erosion, improved soil structure, and organic matter enrichment. Furthermore, agroforestry systems contribute to effective water management, microclimate regulation, and pollination services, positively impacting overall agricultural productivity. On the carbon sequestration front, agroforestry serves as a potent carbon sink, storing carbon both above and below ground. Long-term carbon locking is facilitated through the incorporation of long-lived tree species and the sustainable utilization of harvested wood. Therefore, agroforestry systems provide ‘win-win’ opportunity to bridge-up the adaptation and mitigation strategies help to reduce the impact of climate change.

Keywords: Carbon sequestration, livelihood, adaptation, climate-smart agriculture

Introduction

In India, agroforestry has evolved from a conservation-focused approach to a production-oriented system, notably seen in the rise of industrial agroforestry. This shift involves incorporating short rotation tree species, such as Poplar and Eucalyptus, widely across the country. The Forest Survey of India's 2011 estimates reveal a substantial presence of plywood and veneer making units, with over 3,400 such units producing 15.6 million cubic meters of finished products. The Northern India Plywood Manufacturers Association boasts over 1,900 members, reflecting the success of agroforestry, particularly in states like Uttar Pradesh, Punjab, Haryana, and Uttarakhand. The cultivation of fast-growing tree species has proven beneficial for both farming sustainability and community income. Challenges, however, persist in estimating carbon sequestration benefits due to small land holdings and methodological difficulties, despite the introduction of international mechanisms like CDM, REDD+, GCF, and CER to incentivize plantation owners.

The Indian government, recognizing the need to address environmental degradation and enhance livelihoods, introduced the National Agroforestry Policy 2014 (NAP 2014) to promote tree cultivation on farms. The Sub Mission on Agroforestry was subsequently launched in various states to achieve a one-third tree cover through agroforestry. Additionally, international agreements on climate change necessitate a 35% reduction in carbon footprint by 2030, making agroforestry a crucial strategy to meet these targets. Accurate estimation of agroforestry areas and carbon sequestration potential is essential, despite existing challenges. Currently, unlike forest cover and cultivated areas, precise figures for agroforestry are unavailable.

Environmental Services of Agroforestry

Agroforestry not only provides vital environmental services but also enhances the adaptability and resilience of farming systems in the face of climate challenges. The intentional integration of trees into agricultural landscapes is a strategic response to the need for sustainable and climate-resilient food production. As governments and international bodies increasingly recognize the importance of such practices, agroforestry emerges as a crucial component in the global effort to address environmental degradation, improve livelihoods, and achieve climate targets. With ongoing research and implementation, agroforestry stands poised to contribute significantly to a more sustainable and resilient agricultural future.

Agroforestry as livelihood options

Agroforestry is positioned as a crucial livelihood option, particularly in regions dominated by smallholder farmers with limited land. The adoption of a farming systems approach proves effective in disseminating agricultural technologies. Crop diversification within these systems is essential to meet diverse demands while maintaining soil fertility. In areas where a majority of farmers operate on small plots, holistic approaches show promise in significantly increasing net returns and household consumption. Low-cost interventions, including improved varieties, nutrient management, and agroforestry, enhance profitability and generate additional employment. The integration of bio-intensive cropping methods is vital for the long-term sustainability of smallholder systems, addressing food, fodder, fiber, fuel, and fertility requirements. Agroforestry emerges as a key component in enhancing economic viability and overall livelihoods for smallholder farmers, contributing to resilience and prosperity in evolving agricultural landscapes.

Carbon sequestration potential of agroforestry

Agroforestry emerges as a potent climate change mitigation strategy, surpassing other options due to its diverse benefits. Besides carbon sequestration, it addresses food security, land tenure, income generation, biodiversity, watershed management, and soil conservation. Singh and Pandey (2011) highlight its appeal for carbon sequestration, as it intensifies land use, reduces reliance on destructive practices, and provides sustainable wood substitutes. Agroforestry's dual benefits, improving livestock diets and sequestering carbon, make it unique.

The potential to remove CO_2 from the atmosphere lies in agroforestry's carbon uptake and emission reduction. Harvesting trees, with non-destructive wood use, locks sequestered carbon. Studies confirm its effectiveness in increasing carbon stocks. Tropical agroforestry sequesters 12-228 Mg ha^{-1}, averaging 95 Mg ha^{-1} (Pandey, 2007). Globally, agroforestry could store 1.1-1.2 Pg C over 50 years (Albrecht and Kandji, 2003), reinforcing its role in global carbon sequestration efforts. The intricate connection between agroforestry, environmental sustainability, and carbon sequestration establishes it as a vital solution for sustainable land use and climate change mitigation.

Table 1. Carbon sequestration potential (Mg C ha^{-1}yr^{-1}) of various agroforestry systems in India

Location	Agroforestry System	Tree species	No. of tree per hectare	Age (year)	CSP (Mg C ha^{-1}yr^{-1})	References
Jhansi, Uttar Pradesh	Agrisilviculture	*A. pendula*	1666	5.3	0.43	Rai *et al.,* 2002
Uttarakhand	Agrisilviculture	*D. hamiltonii*	1000	7	15.91	Kaushal *et al.,* 2014
Himachal Pradesh	Agrihorticulture	Fruit trees	69	-	12.15	Goswami *et al.,* 2013
Khammam, Andhra Pradesh	Agrisilviculture	*L. leucocephala*	4444	4	14.42	Prasad *et al.,* 2012
			10000	4	15.51	
Dehradun, Uttarakhand	Silviculture	*E. tereticornis*	2500	3.5	4.40	Dhyani *et al.,* 1996
			2777*	2.5	5.90	
Kurukkhetra, Haryana	Silvipasture	*A. nilotica*	1250	7	2.81	Kaur *et al.,* 2002
		D. sissoo	1250	7	5.37	
		P. juliflora	1250	7	6.50	
Chandigarh	Agrisilviculture	*L. leucocephala*	10666	6	10.48	Mittal and Singh, 1989
Tripura	Silviculture	*T. grandis*	444	20	3.32	Negi *et al.,* 1990
		G. arborea	452	20	3.95	
Tarai Region Uttarakhand	Silviculture	*T. grandis*	570	10	3.74	Negi *et al.,* 1995
			500	20	2.25	
			494	30	2.87	

Jhansi, Uttar Pradesh	Agrisilviculture	*A. procera*	312	7	3.70	Ramnewaj *et al.*, 2008

In agroforestry systems, carbon sequestration is a dynamic process with distinct phases: an initial establishment phase where some systems emit greenhouse gases, followed by rapid accumulation and maturation periods leading to substantial carbon storage in trees and soil. However, at the end of the rotation period, during tree harvest and land reversion to cropping, some stored carbon may be released. Effective sequestration requires a positive net carbon balance over time. Perennial agroforestry systems, like perennial-crop combinations and windbreaks, offer realistic opportunities for carbon storage, especially if the wood is transformed into long-lasting products. The decomposition rate for wood products in the tropics is suggested to be between 1-2%. Alternatively, wood can be used as fuel, impacting carbon returns. While carbon sequestration significance may vary, utilizing wood for fuel from arable or grazed lands presents opportunities for CO_2 mitigation by protecting forests, conserving soil productivity, and reducing fossil energy consumption. Understanding these secondary effects requires further research to comprehensively evaluate agroforestry's role in CO_2 mitigation.

Conclusion

carbon sequestration has become a critical international policy concern within the context of climate change, recognized as a major regulating ecosystem service. Agroforestry emerges as a viable option for carbon sequestration, providing an opportunity to integrate trees into farmlands, either alone or in association with crops. Increasing the forest area is challenging without expanding tree cover outside traditional forest lands, making agroforestry systems crucial in this regard. These options not only contribute to carbon sequestration but also offer a means to diversify production systems and enhance the sustainability of smallholder farming. Agroforestry research is inherently site-specific, resulting in technology variations across different agro-climatic zones. For instance, poplar and eucalyptus-based agroforestry models are popular in the Indo-Gangetic plains, while alder-large cardamom-based models show promise in the North Eastern Hill region. Despite regional variations, all agroforestry systems have significant carbon sequestration potential across diverse agro-ecological zones in India, offering a valuable contribution to mitigating the adverse effects of climate change.

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