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Evaluating Impact of Agricultural Land Use on CO_2 Sequestration and Oxygen Release: A Case Study in Aranyik Subdistrict, Thailand

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Abstract: *This study investigates the impact of various agricultural land use practices on CO_2 sequestration and oxygen release in Aranyik Subdistrict, Mueang District, Phitsanulok Province, Thailand. The region, characterized by lowland plains and a network of canals, supports diverse agricultural activities, with rice paddies dominating the landscape. Our analysis revealed significant variability in biomass distribution and carbon sequestration potential across different land use types. Eucalyptus plantations demonstrated the highest CO_2 sequestration and oxygen release rates, highlighting their role in climate change mitigation. However, the ecological implications of such monocultures, including water consumption and soil health, warrant careful consideration. In contrast, other land use types, such as mixed grasslands, lime orchards, and rice fields, exhibited lower sequestration rates but are crucial for maintaining biodiversity and supporting sustainable land management. This study underscores the importance of integrated land use strategies that balance carbon storage with ecological health, providing valuable insights for regional land use policy and climate change mitigation efforts. Further research should explore temporal land use changes and their broader environmental impacts to enhance the sustainability of agricultural practices in the region.*

Keywords: carbon sequestration, landuse land cover, oxygen release

INTRODUCTION

Human-induced climate change, primarily fueled by the sharp rise in greenhouse gas emissions, especially carbon dioxide (CO_2), poses a significant threat to both global ecosystems and human societies (Intergovernmental Panel on Climate Change [IPCC], 2021). The ongoing increase in global average temperatures has triggered a chain reaction of environmental changes, including rising sea levels, more

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frequent and severe extreme weather events, and significant disruptions to agriculture and biodiversity. Within this escalating climate emergency, carbon sequestration has gained prominence as a crucial mitigation strategy, providing a means to slow the accumulation of CO_2 in the atmosphere. Carbon sequestration, which involves capturing atmospheric carbon dioxide and storing it in long-term reservoirs, is a key element of managing the global carbon cycle (Lal, 2008). Its role in mitigating climate change is critical; by removing CO_2 from the atmosphere and storing it in terrestrial, oceanic, or geological sinks, carbon sequestration can potentially slow or even reverse the buildup of greenhouse gases, thereby reducing the severity of global warming.The way land is used significantly influences carbon sequestration processes. The variety of terrestrial ecosystems—including forests, grasslands, farmlands, wetlands, and urban areas—differs greatly in their capacity to sequester carbon (Pan et al., 2011). Human activities that alter land cover and land use directly impact the global carbon cycle, affecting both carbon emissions and the rates of sequestration. Understanding and strategically managing these land use dynamics is essential in the fight against climate change. Changes in land use can have complex and often nonlinear effects on carbon sequestration. For example, converting primary forests into agricultural land typically leads to large carbon emissions by reducing both above-ground biomass and soil organic carbon stores (Don et al., 2011). On the other hand, reforestation or adopting sustainable agricultural practices, like conservation tillage or agroforestry, can enhance carbon storage in terrestrial ecosystems (Smith et al., 2008). While urbanization is usually linked with higher carbon emissions, it can also contribute to carbon sequestration through careful urban planning, the integration of green spaces, and the use of materials that sequester carbon (Churkina et al., 2020).

The effectiveness of carbon sequestration varies significantly across different plant species and types. Trees, known for their large biomass and long-life spans, are generally considered effective carbon sinks. A mature tree can sequester several tons of CO_2 over its lifetime, with sequestration rates depending on the species, age, and environmental conditions (Nowak & Crane, 2002). However, carbon sequestration potential is not limited to trees. Grasslands, for instance, store a significant amount of carbon underground in their extensive root systems and in soil organic matter (Conant et al., 2017). Similarly, certain crops and agricultural practices can contribute significantly to soil carbon storage, improving both climate mitigation potential and soil health (Paustian et al., 2016). The effectiveness of plants in sequestering carbon depends on a complex set of factors, including growth rate, lifespan, and what happens to the carbon once the plant dies. While fast-growing species may absorb carbon quickly, the long-term benefits can be limited if the carbon is quickly released back into the atmosphere through decomposition or burning (Körner, 2017). Therefore, understanding the carbon sequestration potential of different plant types and ecosystems is crucial for developing effective and sustainable land use strategies to address climate change.

The Plant Genetic Conservation Project under the Royal Initiative of Her Royal Highness Princess Maha Chakri Sirindhorn, established in 1993, aims to raise awareness and promote the preservation of Thailand's plant genetics. Building on the visionary foresight of His Majesty King Bhumibol Adulyadej, who emphasized the conservation of native plant species in 1960, the project focuses on protecting endangered plant genetics, cultivating species in suitable environments, and developing a

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comprehensive, accessible plant genetic information system. By engaging the public and conducting modern botanical research, the initiative seeks to ensure that Thailand's diverse plant species are conserved and utilized sustainably, preserving their invaluable contributions to human needs and the nation's cultural heritage.

The researchers are particularly focused on exploring the carbon sequestration potential in Aranyik Subdistrict, Mueang Phitsanulok District, Phitsanulok Province, specifically within areas managed by local administrative organizations participating in the Local Resource Base initiative. This study aims to deepen knowledge and provide insights relevant to the researchers' academic field. The data gathered will shed light on the area's capacity to sequester carbon and offer government agencies a strong basis for making policy decisions at the provincial level, especially in formulating strategies to promote plant cultivation. Such strategies would help local farmers make the best use of their land while conserving resources and maintaining forest ecosystems sustainably.

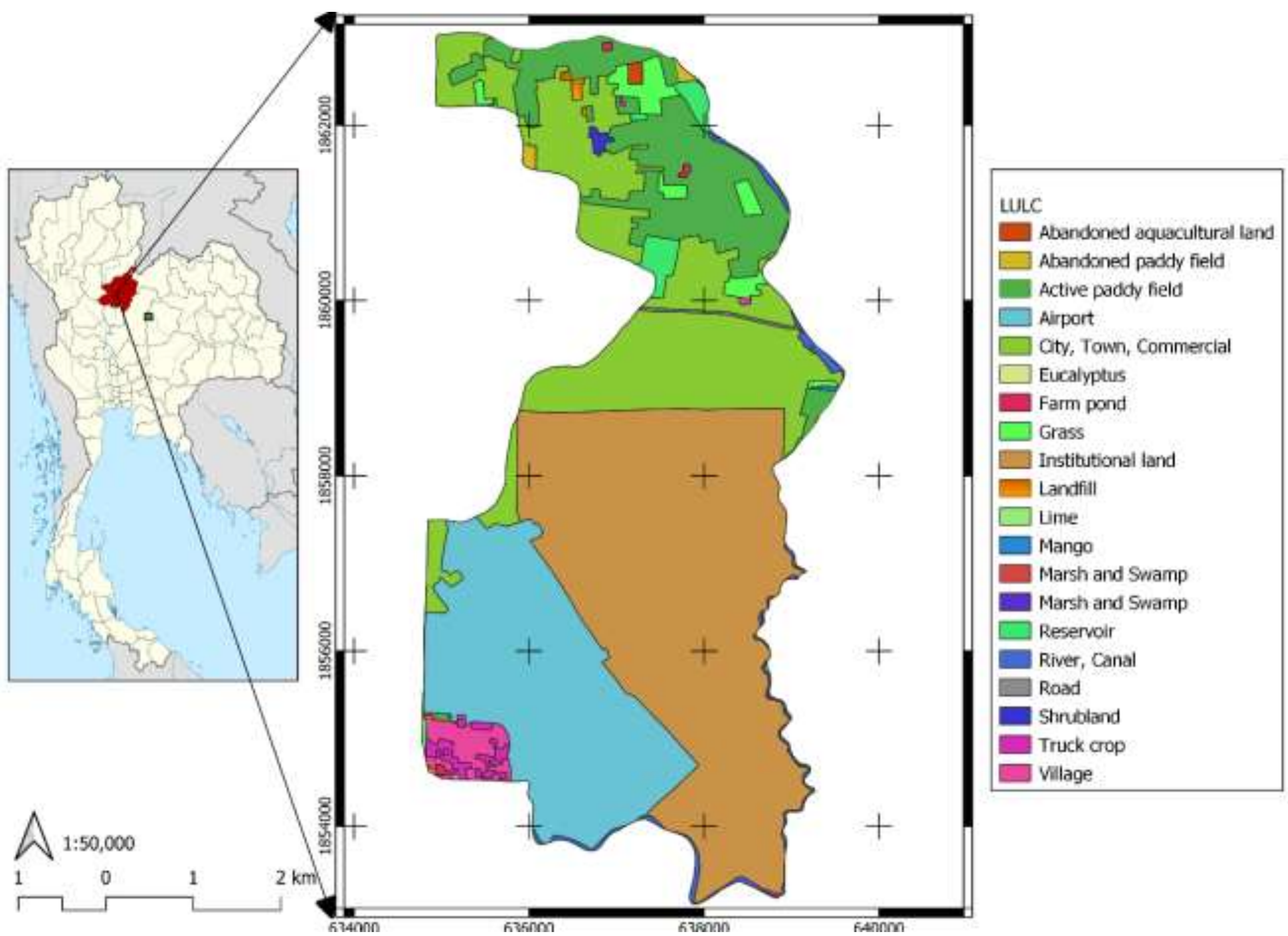

Figure 1 LULC of study area

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METHODOLOGY

Study Area

This research, conducted in Aranyik Subdistrict, Mueang District, Phitsanulok Province, spans a total area of 8,432 hectares, and is embedded within the framework of the Plant Genetic Conservation Project under the royal patronage of Her Royal Highness Princess Maha Chakri Sirindhorn. The study's primary aim is to evaluate carbon sequestration across different components of the ecosystem, including above-ground biomass, root systems, and understory vegetation, within the jurisdiction of the local administrative body in Aranyik. The choice of this area is particularly relevant due to its association with a royal conservation initiative, offering a distinctive backdrop for investigating carbon dynamics in a managed landscape. By analyzing various aspects of the ecosystem, the research adopts a holistic approach to accurately measure carbon stocks and their distribution across different land use and land cover types (LULC). This localized investigation not only contributes to the understanding of carbon sequestration patterns in similar ecological settings but also provides critical insights that can inform conservation strategies and climate change mitigation efforts at the sub-district level. The LULC data for this study was sourced from Thailand's Land Development Department in 2023.

Field Sampling

Field sampling was conducted in March 2023, utilizing a systematic sampling approach to evaluate carbon sequestration throughout the study area, adhering to established protocols outlined by Pearson et al. (2007). The methods employed included the following:

1) Tree Sampling: Fourteen 40x40 meter quadrats were randomly established across the study area. Within each quadrat, all tree species were identified and measured. For each tree, data were collected on diameter at breast height (DBH) measured at 1.3 meters above ground level, total height, and crown diameter, following the guidelines provided by MacDicken (1997).
2) Rice, Crop, Understory, and Litter Sampling: to estimate carbon storage in understory biomass and forest floor litter, twenty-four 1x1 meter subplots were randomly distributed within the larger quadrats. This approach was guided by the methodology established by Ravindranath and Ostwald (2008). In these subplots, samples of understory vegetation and surface litter were systematically collected, allowing for a comprehensive assessment of the carbon content present in these specific components of the ecosystem.
3) Biomass Processing

   Rice, Crop, Understory, and Litter samples were dried in an oven at 80°C for 48 hours, or until reaching a constant weight, following standard procedures (Nelson & Sommers, 1996). The dry weight of the biomass (DW) was then measured to quantify the biomass amount using gravimetric methos.

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Data Analysis

1) **Allometric for biomass and carbon stock estimation**

Biomass components, including stem biomass (WS), branch biomass (WB), and leaf biomass (WL), were estimated using species-specific allometric equations (see Table 1) tailored to different land use types, in accordance with the methodology proposed by Chave et al. (2014). The aboveground biomass (AGB) was computed as the aggregate of these components (AGB = WS + WB + WL). Belowground biomass (RB), which predominantly consists of root biomass, was estimated using the established equation provided by Cairns et al. (1997)

Table 1 Allometric equation of tree

Landuse	Species	Stem (WS)	Branch (WB)	Leaf (WL)	Root (RB)	ref
Mango orchard	*Mangifera indica*	$0.0396 (DBH^2h)^{0.9326}$	$0.3349 (DBH^2h)^{0.50995}$	$0.913 (DBH^2h)^{0.22404}$	EXP {-1.0587 + 0.8836 x ln(GB)}	Ogawa et al. (1965)
Lemon garden	*Citrus limon*	$0.2903(DBH^2h)0.9815$	$0.11920WS^{1.059}$	$0.09146 (WS+WB)^{0.7266}$		Yamakura et al. (1986)
Eucalyptus garden	*Eucalyptus* spp.	$0.0305 (DBH^2h)^{0.9862}$	$0.0008 (DBH^2h)^{1.2698}$	$0.0003 (DBH^2h)^{1.1666}$		Treepatanasuwan et al. (2008)
Neem Garden	*Azadirachta indica*	$0.0410 (DBH^2h)^{0.9148}$	$0.0018 (DBH^2h)^{1.1037}$	$0.0023 (DBH^2h)^{0.9388}$		Viriyabuncha et al. (2004)
Pradu plantation	*Pterocarpus macrocarpus*	$0.0396 (DBH^2h)^{0.9326}$	$0.006003 (DBH^2h)^{1.027}$	$[(28/WS+WB) +0.025]^{-1}$		Ogawa et al. (1965)
Belowground biomass						Cairns et al.(1997)

Then, the carbon stocks for various biomass components were calculated using the following equations: Carbon stocks (ton C ha^{-1}) = Biomass (ton C ha^{-1}) x CF Where CF is the carbon fraction of dry matter, assumed to be 0.47 IPCC (2006) guidelines.

2) **Carbon Sequestration and Oxygen Release Estimation**

The quantification of CO_2 sequestration (ton CO_2 ha^{-1}) and O_2 release (ton O_2 ha^{-1}) was conducted utilizing the molecular weight ratios of CO_2 to C (44/12) and O_2 to C (32/12), respectively, in accordance with the methodology delineated by IPCC (2003). The calculations were performed as follows: CO_2 sequestration (ton CO_2 ha^{-1}) was derived by multiplying the carbon stock (ton C ha^{-1}) by 44/12, while O2 release (ton O_2 ha^{-1}) was obtained by multiplying the carbon stock (ton C ha^{-1}) by 32/12.

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RESULTS

Land use distribution

An analysis of land use patterns in Aranyik Subdistrict, Mueang District, Phitsanulok Province, reveals that the area is characterized by lowland plains intersected by canals that delineate boundaries with adjacent subdistricts. This topographical configuration renders the region particularly suitable for agricultural activities. The total agricultural activities area under consideration encompasses approximately 2,867.15 hectares (about 34% of total), which is distributed across eight distinct land use categories. The land use types identified in the study area, listed in descending order of area coverage, are as shown in **Figure 2**

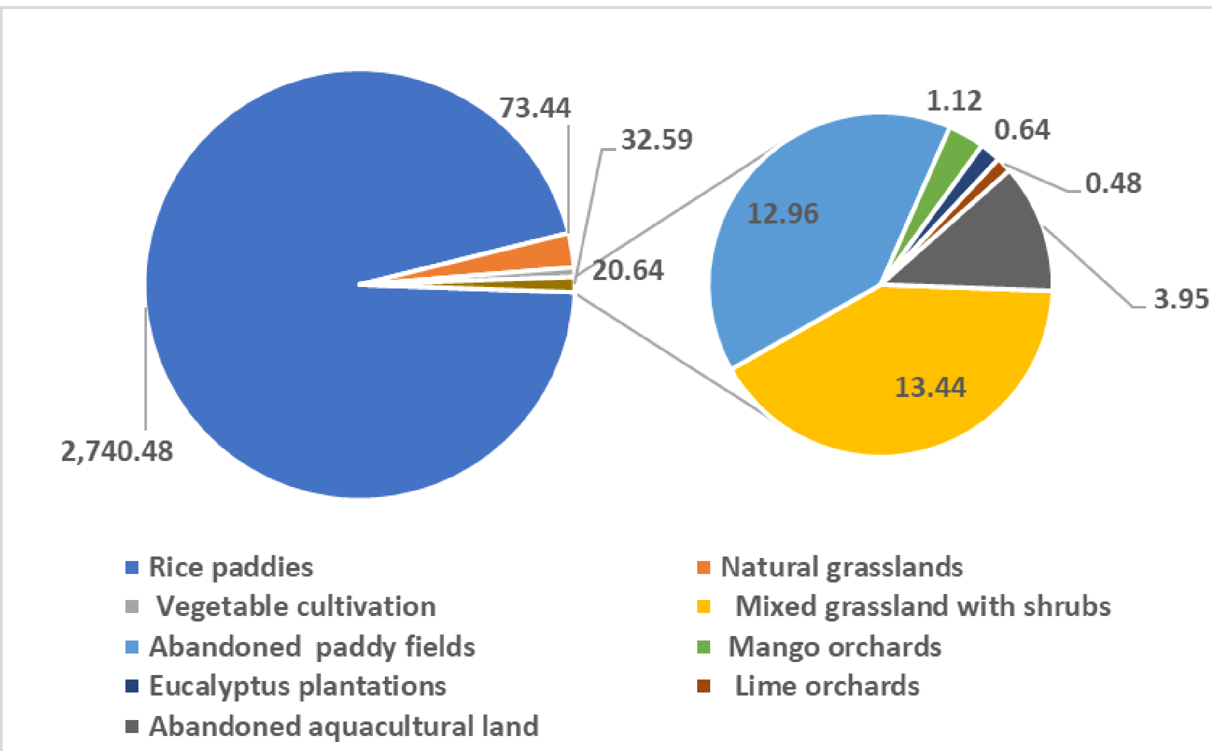

Figure 2 the spatial distribution of LULC in Aranyik

This land use distribution reflects the predominance of rice cultivation in the subdistrict, which accounts for approximately 95.6% of the total agricultural activities area. The significant presence of rice paddies underscores the region's agricultural importance and its potential contribution to local and national food security. The presence of natural grasslands and mixed grassland areas suggests the existence of uncultivated or less intensively managed zones, which may serve ecological functions or represent potential areas for future agricultural expansion. The relatively small areas dedicated to fruit orchards

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(mango and lime) and eucalyptus plantations indicate a degree of agricultural diversification, albeit on a limited scale. It is noteworthy that the data presents a snapshot of land use at a specific point in time. Further research could explore temporal changes in land use patterns, the socio-economic factors influencing land use decisions, and the environmental implications of the current land use distribution in Aranyik Subdistrict.

Biomass estimation

Table 2 showed the analysis of biomass in the study area revealed an average biomass approximately 264.76 Ton ha^{-1}. Above-ground biomass was the most substantial component, averaging 224.63 Ton ha^{-1}, followed by stem biomass at 152.55 Ton ha^{-1}, branch biomass at 59.85 Ton ha^{-1}, root biomass at 37.99 Ton ha^{-1}, leaf biomass at 8.75 Ton ha^{-1}, and understory vegetation and surface litter at 4.77 Ton ha^{-1}. The total biomass for the entire study area was calculated at 8,567.84 tons. Most of this biomass, 6,312.06 tons, was attributed to understory vegetation and surface litter (active rice paddies), while above-ground biomass contributed 1,655.24 tons. The distribution of biomass among other components included 1,137.30 tons in stems, 416.35 tons in branches, 294.99 tons in roots, and 87.68 tons in leaves.

The study also assessed biomass distribution according to land use types within Aranyik Subdistrict. The average biomass was highest in eucalyptus plantations, with 2,010.75 Ton ha^{-1}, followed by mixed grasslands/shrublands, lime, mango, natural grasslands, rice paddies, abandoned fields, and vegetable gardens, with biomass values of 49.26, 43.32, 5.56, 3.00, 2.83, 2.30, and 1.03 Ton ha^{-1}, respectively. In terms of accumulation biomass by land use, rice paddies accounted for the highest biomass at 6,312.06 tons, followed by eucalyptus (1,286.88 tons), mixed grasslands/shrublands (662.03 tons), natural grasslands (207.83 tons), abandoned fields (50.80 tons), vegetable gardens (21.22 tons), lime (7.72 tons), and mango (6.23 tons).

Table 2 Biomass of each agricultural activities area

LULC		Biomass per area (Ton ha^{-1})				Accumulation biomass (Ton)			
		UL	**AGB**	**RB**	**total**	**UL**	**AGB**	**RB**	**total**
1	Natural grasslands	2.83	-	-	2.83	207.83	-	-	207.83
2	Mixed grassland with shrubs	1.58	39.77	7.91	49.26	21.22	534.48	106.33	662.03
3	Active paddies	2.30	-	-	2.30	6,312.06	-	-	6,312.06
4	Abandoned fields	3.00	-	-	3.00	50.80	-	-	50.80
5	Vegetation cultivation	1.03	-	-	1.03	21.22	-	-	21.22

LULC		Biomass per area (Ton ha^{-1})				Accumulation biomass (Ton)			
		UL	AGB	RB	total	UL	AGB	RB	total
6	Lime	1.12	34.48	7.71	43.32	0.54	16.55	3.70	20.79
7	Mango	1.28	3.38	0.90	5.56	1.43	3.79	1.01	6.23
8	Eucalyptus	3.92	1,719.41	287.42	2,010.75	2.51	1,100.42	183.95	1,286.88
Average		2.13	224.63	37.99	264.76	827.20	206.91	36.87	1,070.98

* UL is Rice, Crop, Understory, and Litter biomass, AGB is Aboveground biomass, RB is underground biomass

CO_2 Sequestration and Oxygen Release estimation

The study on CO_2 sequestration across different land use types in Aranyik was shown in table 3, revealed an average CO_2 sequestration rate of 970.78 ton CO_2 ha^{-1} which highlights the potential of these lands to contribute to climate change mitigation through carbon storage. The highest sequestration was observed in eucalyptus plantations, with a rate of 7,372.76 ton CO_2 ha^{-1}, followed by mixed grassland/woodland, lime orchards, mango orchards, natural grasslands, rice fields, fallow land, and vegetable plots, with sequestration rates of 180.61, 158.83, 20.39, 11.02, 10.38, 8.45, and 3.77 ton CO_2 ha^{-1}, respectively.

The highest sequestration rate was observed in eucalyptus plantations, with an impressive 7,372.76 ton CO_2 ha^{-1}. This substantial sequestration capacity underscores the role of fast-growing, high-biomass species like eucalyptus in carbon capture, particularly in managed forestry operations. However, the ecological implications of eucalyptus monocultures, such as water consumption and soil health, must be considered in conjunction with their carbon sequestration benefits.

In contrast, other land use types, such as mixed grassland/woodland and lime orchards, exhibited much lower sequestration rates, at 180.61 and 158.83 ton CO_2 ha^{-1}, respectively. These findings suggest that while these ecosystems sequester less carbon per hectare than eucalyptus plantations, they still play a critical role in the broader landscape's carbon budget. The relatively low sequestration rates observed in mango orchards, natural grasslands, rice fields, fallow land, and vegetable plots further emphasize the diversity in carbon storage potential across different land uses.

. Oxygen release, an essential byproduct of photosynthesis, was also assessed, with an average release rate of 706.02 ton O_2 ha^{-1}, with the largest portion coming from eucalyptus plantations of 5,362.01 ton O_2 ha^{-1}, followed by mixed grassland/woodland, lime orchards, mango orchards, natural grasslands, rice fields, fallow land, and vegetable plots, with sequestration rates of 131.35, 115.51, 14.83, 8.01, 7.55, 6.14, 2.74 ton O_2 ha^{-1}, respectively. Similar to CO_2 sequestration, eucalyptus plantations dominated oxygen release, contributing 5,362.01 tons of O_2 per hectare. This highlights the dual role of such

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plantations in both sequestering carbon and releasing oxygen, further emphasizing their importance in the global carbon cycle.

The findings from this study provide a nuanced understanding of how different land use practices contribute to CO_2 sequestration and oxygen release. While eucalyptus plantations offer the highest carbon sequestration and oxygen release rates, the ecological and environmental trade-offs must be carefully managed. Meanwhile, the lower sequestration and oxygen release rates in other land use types point to the need for integrated land management strategies that maximize carbon storage while maintaining biodiversity and ecosystem health. These insights are crucial for informing land use policies and conservation strategies in the region, particularly in the context of climate change mitigation efforts.

Table 3 CO_2 sequestration and O_2 release of each agricultural activities area

	LULC	CO_2 sequestration (ton CO_2 ha^{-1})	O_2 release (ton O_2 ha^{-1})
1	Natural grasslands	10.38	7.55
2	Mixed grassland with shrubs	180.61	131.35
3	Active paddies	8.45	6.14
4	Abandoned fields	11.02	8.01
5	Vegetation cultivation	3.77	2.74
6	Lime	158.83	115.51
7	Mango	20.39	14.83
8	Eucalyptus	7,372.76	5,362.01
Average		970.78	706.02
Summation		7,766.20	5,648.15

DISCUSSION

The study on carbon sequestration and oxygen release in Aranyik Subdistrict contributes to a growing body of literature that examines the role of various land use types in climate change mitigation. The findings align with other research that underscores the significant carbon sequestration potential of eucalyptus plantations, a feature well-documented in studies focusing on fast-growing species in managed forestry systems. For instance, Walsh et al. (2008) demonstrated that eucalyptus species are among the most efficient in carbon uptake due to their rapid growth and high biomass productivity, making them a cornerstone of afforestation and reforestation strategies aimed at enhancing carbon sinks.

In comparison to other ecosystems, the lower carbon sequestration rates observed in mixed grasslands and orchards in Aranyik Subdistrict mirror findings from other regions. Grasslands, although less effective per unit area in carbon sequestration compared to forested systems, play a critical role in carbon storage, particularly in their soil carbon content. The study by Conant et al. (2017) further supports this by emphasizing the importance of grasslands in long-term carbon storage through soil organic carbon, even if their above-ground biomass is comparatively modest.

In addition to carbon sequestration, the study also explored oxygen release, another critical ecological function. Eucalyptus plantations again stood out for their significant contribution to oxygen release, further emphasizing their dual role in the global carbon and oxygen cycles. However, the environmental implications of relying heavily on such plantations, including potential impacts on biodiversity, need careful consideration.

Overall, the findings from this study underscore the need for integrated land management strategies that balance carbon sequestration with other ecological functions. While certain land uses like eucalyptus plantations offer high carbon storage potential, the broader landscape's health and sustainability depend on a diverse mix of land uses that support both carbon storage and ecological diversity. These insights are essential for informing land use policies and conservation strategies, particularly in the context of addressing climate change. The findings from Aranyik Subdistrict align with broader trends observed in ecological research, where different land use types contribute variably to carbon sequestration and oxygen release. While eucalyptus plantations demonstrate high potential in these areas, the ecological trade-offs must be carefully weighed. The comparative lower sequestration and oxygen release in other land use types underscore the need for diverse and integrated land management practices that optimize carbon storage while maintaining ecological health and sustainability. Future land use policies should consider these multi-faceted roles to effectively balance climate mitigation efforts with ecological conservation.

CONCLUSION

The comprehensive analysis of land use patterns in Aranyik Subdistrict highlights the area's predominant reliance on rice cultivation, which significantly contributes to both local agricultural productivity and national food security. The distribution of biomass across various land use types underscores the critical role of eucalyptus plantations in carbon sequestration and oxygen release, positioning them as pivotal elements in climate change mitigation strategies. However, the study also reveals the necessity of balancing these benefits with the potential ecological drawbacks associated with monoculture practices, such as increased water consumption and potential soil degradation. Furthermore, the presence of mixed grasslands and less intensively managed areas indicates opportunities for enhancing biodiversity and ecosystem resilience through diversified land management approaches. These findings advocate for integrated land use policies that not only maximize carbon storage and oxygen production but also promote sustainable agricultural practices and ecological health, thereby ensuring long-term environmental and socio-economic sustainability in the region.

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