Agroforestry lit review (Draft)

Introduction

Climate change and loss of biodiversity seriously affects the well-being of humans and life on earth, including significant impact on food production and the agricultural system, which requires solutions that work well and are cost-effective. This review covers the literature on the effects of climate change on agriculture, food production, and farmers to explain the case for fighting climate change by increasing tree cover through agroforestry, which is a nature-based solution that integrates trees and shrubs into agricultural land, creating systems that enhance both ecological and economic resilience. This method not only combats land degradation but also restores soil health by improving nutrient cycling and increasing organic matter content, which is crucial in countries like India where significant portions of agricultural land suffers from degradation. Agroforestry effectively addresses multiple environmental challenges by not only enhancing biodiversity but also playing a significant role in carbon sequestration to mitigate climate change impacts. The increase in biodiversity by creating vital habitats for different plants and animals also supports ecosystem services such as pollination and soil health. Agroforestry is a crucial tool to fight climate change by sequestering carbon and revitalize degraded land which leads to better crop yields and higher incomes for farmers.

Climate change's impact on farmer yields

Climate change is increasingly disrupting agricultural productivity, particularly in regions reliant on rain-fed farming, by shifting temperatures and rainfall patterns, which in turn reduce crop yields and threaten food security (Castle et al., 2021). Farmers face growing challenges in resource management due to erratic weather, with rising temperatures, droughts, and floods negatively impacting soil moisture and crop growth. This is particularly severe in low- and middle-income countries, where agriculture is a key livelihood source, and farmers have limited resources to adapt (Castle et al., 2021).

In India, the impact of climate change on staple crops like rice and wheat is especially concerning. Together, these crops occupy nearly half of the country's arable land, with rice grown on 31% and wheat on 20%. Climate models project that between 2010 and 2039, yields of these crops could decline by 4.5–9%, and by 2070–2099, they may drop by at least 25%, unless adaptation strategies are implemented (Guiteras, 2009). This would pose a significant threat to food security and farmer incomes. Additionally, with over 60% of India's cultivated land reliant on rain-fed systems, erratic rainfall patterns further exacerbate the vulnerability of agriculture, emphasizing the need for water-saving techniques and stable irrigation systems (Srinivasrao et al., 2015).

Extreme weather events result in annual crop losses, which equate to about 0.25% of India's GDP (MoEF, 2010). Beyond economic losses, the social impact is severe. As Carleton (2017) notes, growing debt burdens caused by yield reductions have led to a rise in farmer suicides. Furthermore, the agricultural sector is undergoing a demographic shift, with fewer cultivators and more agricultural laborers—a trend Gupta (2016) attributes to the increasing pressures on farming. This highlights the urgent need for more sustainable and resilient farming practices to secure livelihoods and food production.

Farmers struggling with soil degradation and reasons for degradation

Soil health is essential for sustainable agriculture, yet many farmers face challenges like erosion, nutrient loss, and compaction, often driven by conventional farming, deforestation, and climate change (Tomar et al., 2021; Fahad et al., 2022). These issues pose significant risks to agricultural productivity and global food security (Fahad et al., 2022).

The Green Revolution, initiated by the Indian government in the 1960s, improved food security but also contributed to widespread land degradation. The heavy use of chemical fertilizers, pesticides, and high-yield seeds led to soil exhaustion, nutrient depletion, and biodiversity loss (Singh, 2000). Water-intensive crops in unsuitable regions further exacerbated groundwater depletion and salinization. Long-term effects include soil erosion and reduced fertility, particularly due to monoculture and unsustainable farming practices (Pingali, 2012).

Deforestation and unsustainable agriculture further accelerate soil degradation by exposing soil to erosion and disrupting nutrient cycles (Fahad et al., 2022). Climate change compounds these issues by intensifying extreme weather events and altering rainfall patterns, worsening soil health.

Globally, 24% of the world's land is experiencing degradation, affecting 1.5 billion people (IPBES, 2018). In India, 29% of the country's land—about 96.4 million hectares—suffers from degradation due to deforestation, overgrazing, and unsustainable agricultural practices (ISRO, 2016). This threatens agricultural productivity, food security, and biodiversity.

Soil degradation results in lower crop yields, reduced farm income, and increased restoration costs, making sustainable practices like agroforestry essential for restoring soil health and ensuring agricultural sustainability (Tomar et al., 2021; Fahad et al., 2022).

Biodiverse agroforestry as a solution

Biodiverse agroforestry, which integrates diverse trees, shrubs, crops, and livestock, fosters sustainable agriculture by enhancing soil health, pest control, and ecosystem services. This approach reduces dependency on chemical inputs through natural pest management supported by plant diversity (Salve et al., 2022; Singh et al., 2021).

Agroforestry systems also increase yields and resource efficiency through intercropping and natural processes like nutrient cycling and carbon sequestration (Satish et al., 2024). Trees improve soil structure, reduce erosion, and boost water retention, all of which support crop growth (Sekhar et al., 2024). These systems also regulate water cycles and sequester carbon, mitigating climate change and stabilizing microclimates, providing resilience against weather extremes (Tschora & Cherubini, 2020; Schoeneberger, 2008).

Agroforestry has the potential to restore degraded lands and improve agricultural productivity. An estimated 1 billion hectares of global agricultural land could benefit from agroforestry, representing 43% of all agricultural land worldwide (Zomer et al., 2009). In India, the National Agroforestry Policy 2014 highlights the potential to rehabilitate 25 million hectares of degraded land through agroforestry, with the practice expandable to 65% of India's agricultural land, improving soil health and farmer incomes.

Agroforestry not only enhances soil health and agricultural resilience but also supports biodiversity, conserves water, and offers farmers diversified income sources through timber and other products (Fahad et al., 2022). This makes agroforestry a sustainable and economically viable strategy for climate adaptation and land restoration (Mondal et al., 2023).

In summary, biodiverse agroforestry offers a sustainable solution by enhancing soil health, improving climate adaptation, and providing ecosystem services. Its adoption is crucial to addressing global challenges like food security, climate change, and environmental degradation.

Agroforestry's impact on farmer incomes

Agroforestry significantly increases farmer incomes by diversifying revenue streams and improving crop yields. Studies show that integrating trees into agricultural systems can boost yields by 20% to 50%, thanks to improved soil health, better water retention, and microclimate regulation (Pretty et al., 2018). Systems like alley cropping and silvopasture enhance nutrient cycling and reduce erosion, leading to higher productivity.

Agroforestry also diversifies income sources by providing timber, fruits, and non-timber products, reducing farmers' reliance on single crops and improving resilience (Pancholi et al., 2023). For example, in Madagascar, agroforestry systems that incorporate crops like vanilla and cocoa contribute significantly to exports (Andriatsitohaina et al., 2024). Studies estimate that agroforestry can boost farmer incomes by 30% to 60% through these diversified products and improved yields (Mbow et al., 2014).

In Jharkhand, India, mango plantations supported by the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) have notably increased farmer incomes through crop diversification and higher yields, providing long-term economic benefits for rural communities (Dreze & Nair, 2023).

This practice improves food security by diversifying both income and food sources, making farmers more resilient to market fluctuations and crop failures (Castle et al., 2021). It also contributes to rural development by empowering smallholders, fostering community initiatives, and building local skills (Satish et al., 2024; Singh et al., 2021).

Agroforestry's impact on reversing soil degradation

Agroforestry offers a highly effective solution to soil degradation by improving soil health and increasing ecosystem resilience (Salve et al., 2022; Fahad et al., 2022). The integration of trees stabilizes soil, reduces erosion, and enhances nutrient cycling, significantly increasing organic matter, which boosts soil fertility and water retention (Sekhar et al., 2024; Tomar et al., 2021; Wato & Amare, 2020). Trees contribute to nutrient cycling by capturing nutrients like nitrogen and phosphorus, gradually releasing them into the soil, reducing the need for external inputs (Fahad et al., 2022; Sekhar et al., 2024).

Additionally, organic matter from tree litter improves soil structure, water retention, and fertility (Sekhar et al., 2024; Tomar et al., 2021). Research demonstrates that agroforestry can reduce soil erosion by up to 50%, increase soil organic carbon by 21%, and boost nitrogen and phosphorus availability by 46% and 11%, respectively, while also improving soil pH by 2% (Muchai et al., 2020). These improvements not only enhance soil health but also contribute to long-term agricultural productivity and sustainability.

Agroforestry systems are especially effective in increasing soil organic carbon, improving soil structure, and boosting water retention, making them vital for enhancing resilience to climate change. As these systems maintain healthy soils essential for crop growth, they help mitigate climate change impacts by creating more resilient farming systems. By ensuring long-term productivity, agroforestry supports both environmental sustainability and the economic well-being of farming communities, providing a sustainable foundation for future generations to combat food insecurity and soil degradation challenges (Salve et al., 2022; Fahad et al., 2022).

The capacity of restored soils to store more water

Soil moisture retention is significantly improved through agroforestry, which enhances water availability for crops and promotes overall ecosystem health. Integrating trees into agricultural landscapes increases soil water storage by improving infiltration rates and reducing surface runoff. Deep-rooted trees create porous soils, allowing rainwater to penetrate effectively, reducing both erosion and waterlogging risks (Sekhar et al., 2024; Muchai et al., 2020).

These systems also support groundwater recharge, vital for regions facing water scarcity (Kuyah et al., 2019). The increased soil moisture boosts drought resilience, helping crops during dry periods and enhancing food security in vulnerable areas (Sekhar et al., 2024). Studies show that water infiltration rates in agroforestry systems are about 75% higher compared to monocultures, thanks to organic inputs like leaf litter that improve soil structure and water-holding capacity (Muchai et al., 2020).

Agroforestry and moderate tree cover's impact on replenishing the water table

Agroforestry supports water resources by enhancing groundwater recharge and improving water quality (Castle et al., 2021; Kuyah et al., 2019). Trees in these systems increase water percolation, reduce surface runoff, and aid in water table replenishment (Kuyah et al., 2019). Their roots stabilize the soil, improving structure and aiding in water retention and erosion control (Castle et al., 2021). Moderate tree cover balances the hydrological cycle by intercepting rainfall, reducing runoff, and creating microclimates that minimize evaporation (Satish et al., 2024).

Additionally, agroforestry improves water quality by reducing sedimentation and nutrient runoff, while stabilizing soil and absorbing excess nutrients (Castle et al., 2021; Kuyah et al., 2019). Practices such as contour planting and cover cropping further enhance these effects (Morya et al., 2023). Together, these benefits make agroforestry a valuable strategy for replenishing water tables, improving water quality, and fostering agricultural sustainability (Kuyah et al., 2019; Feliciano et al., 2017).

The additional benefits of drip irrigation

Drip irrigation, a water-efficient technique, significantly enhances agroforestry systems by delivering water directly to plant roots, reducing waste and conserving water resources, particularly in arid regions (Satish et al., 2024). By minimizing evaporation and runoff, drip irrigation greatly improves water use efficiency, ensuring crops receive consistent moisture while reducing weed growth and disease risks (Satish et al., 2024). This also helps lower herbicide use and prevents fungal infections, contributing to healthier crops and reducing input costs. Moreover, drip irrigation boosts crop productivity by improving nutrient uptake and enhancing soil aeration, leading to more vigorous plant growth (Satish et al., 2024).

Another advantage of this system is its ability to apply fertilizers with precision, which reduces leaching and minimizes environmental impacts (Satish et al., 2024). When combined with agroforestry, drip irrigation provides additional synergies, such as enhanced soil moisture retention, microclimate regulation through tree shade, and better resource optimization, all of which support biodiversity, soil health, and water quality (Satish et al., 2024).

In Maharashtra, research highlights that drip irrigation results in substantial water and energy savings, with farmers saving ₹1.1 lakh per hectare for sugarcane and ₹69.9 thousand per hectare for banana (Gorain et al., 2018). These savings in both water and electricity contribute significantly to cost reductions, while social benefits, such as off-farm employment, enhance the overall economic impact. However, social costs include government subsidies and investments in well construction. Despite these costs, the benefit-cost ratio of drip irrigation over 10 years was found to be 2.08 at a 10% discount rate (Gorain et al., 2018).

By optimizing water use and boosting productivity, drip irrigation supports both ecological sustainability and economic resilience, making it a critical component of sustainable agroforestry systems (Satish et al., 2024).

The importance of cash transfers and subsidies in helping farmers transition to agroforestry and sustainable environmental practices

The transition to agroforestry often requires significant investments and changes in farming practices, posing considerable challenges for smallholder farmers in low-income regions (Castle et al., 2021; Wato & Amare, 2020). Estimates from F4F's work indicate that the cost to transition ranges from $1800 to $2000 per hectare or $1.5 to $2 per tree. Similarly, in the Brazilian Amazon, costs have been estimated between $1500 and $2000 per hectare. While passive reforestation or assisted natural regeneration (helping the forest grow back in areas where it already existed) is significantly cheaper, transitioning to agroforestry on agricultural lands is expensive given the extent of soil degradation on these lands.

Cash transfers are a key tool in supporting farmers through this transition by reducing financial barriers and promoting long-term investments. Agroforestry practices, which improve soil health and carbon sequestration, often come with upfront costs for seedlings, labor, and maintenance, making adoption difficult for resource-constrained farmers. Jayachandran et al. (2017) found that cash transfers help offset these costs and provide short-term income security, encouraging the adoption of sustainable land-use practices. Financial support has been shown to significantly increase participation rates in agroforestry programs, leading to better environmental outcomes and enhanced rural livelihoods.

In addition to supporting agroforestry, cash transfers play a crucial role in reducing deforestation by offering financial support to rural communities, enabling them to adopt sustainable practices (Hance, 2017). The lack of funds often serves as a major barrier to implementing solutions that could reduce deforestation rates. Financial incentives help mitigate the economic pressures faced by communities, leading to more sustainable land use and conservation efforts.

A regression discontinuity analysis of Mexico's National Program demonstrates the potential of cash transfers to balance ecological goals with socioeconomic benefits. The program showed that financial support not only reduced deforestation but also improved social outcomes, providing long-term benefits for local communities (Alix-Garcia et al., 2019).

By linking financial support to sustainable practices, policymakers can encourage the planting of tree species that improve ecosystem services, such as nitrogen-fixers or drought-tolerant varieties (Castle et al., 2021). Cash transfers also act as a safety net against climate risks, enabling farmers to invest in climate-resilient agroforestry systems, which are essential in regions facing increasingly unpredictable weather patterns (Gifawesen et al., 2020; Sekhar et al., 2024).

However, financial support alone is not sufficient. Training programs are essential for equipping farmers with the knowledge needed for successful agroforestry, such as tree selection, planting techniques, and product marketing (Satish et al., 2024; Verma et al., 2016). Furthermore, effective policy frameworks should address issues such as land tenure, market development, and equitable access to resources, ensuring long-term success in agroforestry adoption (Castle et al., 2021; Wato & Amare, 2020).

In summary, cash transfers, subsidies, education, and supportive policies are vital to fostering the adoption of agroforestry. This approach not only enhances environmental sustainability but also promotes rural development, providing smallholder farmers with the tools and financial support necessary to thrive in the face of climate challenges (Castle et al., 2021; Wato & Amare, 2020).

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