



Integrating Conservation Agriculture and Agroforestry for Climate-Resilient and Sustainable Food Systems

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Agroforestry includes the amalgamation of trees with other agricultural operations like livestock or crop production or managing a woodlot for a diversity of special forest products while ensuring production of crops underneath the trees before the tree canopy is fully closed. The integration fosters symbiotic biological relationships that yield numerous advantages, such as a more resilient and multifaceted income stream, enhanced ecological productivity, superior water infiltration, and enriched living spaces for both people and local fauna. Farmers primarily implement agroforestry to achieve financial security and environmental sustainability. By integrating trees with crops or livestock, they can generate diverse outputs such as fuel, fodder, and mulch while improving the overall health and management of their land. Concurrently, trees provide shelter for livestock and habitats for wildlife while actively preventing soil erosion. Additionally, legumes enhance soil fertility by fixing atmospheric nitrogen (Mutua et al., 2014).

While agroforestry supports long-term productivity, it can cause immediate yield declines in semi-arid regions. The competition for sunlight occurs above ground among the stems of trees and crops, while competition for moisture and nutrients takes place below ground (Rao et al., 1997; Ong et al., 1991; Radersma and Ong, 2004). Recent research suggests that root pruning is an effective management strategy to mitigate belowground competition for water and nutrients in semi-arid agroforestry (Bayala et al., 2015; Muthuri et al., 2005). Beyond pruning, improved nutrient management and water conservation can minimize competition and boost crop yields within agroforestry systems (Guto et al., 2012; Hulugalle and Ndi, 1993).

Conservation agriculture (CA) is a resource-efficient production system based on three integrated pillars: (1) minimum mechanical soil disturbance (i.e., zero/reduced tillage); (2) permanent organic soil cover (minimum 30% crop residue); and (3) crop diversification (crop rotations including a minimum of 3 different crops), in particular including legumes (www.fao.org/ag/ca). Adopting these practices reduces production cost by 2000-3000 ha⁻¹ while boosting yields by 4-10% and enabling earlier sowing. It enhances soil health, resource use efficiency, and carbon sequestration, which builds climate resilience and cuts greenhouse gas emissions. Furthermore, maintaining surface residues suppresses weeds like *Phalaris minor*, prevents the pollution caused by crop burning, and moderates soil temperature, creating a more sustainable and diversified farming system (Bhan and Behera, 2014).

CA and agroforestry share key features like increased ground cover and use of legumes. Both systems benefit from minimal soil disturbance, and their integration creates a synergy that significantly boosts soil health and overall crop yields (Kassam et al., 2009). Integrating CA with agroforestry is a sustainable strategy for producing food, fuel, fodder, and fiber while generating income from intercropped trees. This combining effectively restores depleted soils and enhances overall land productivity (Garrity et al., 2010).

Climate Change Mitigation and Adaptation in Agroforestry

Table 1. Climate change mitigation and adaptation in agroforestry

Major Climate Change Function	Agroforestry Functions Supporting Climate Change Mitigation & Adaptation
Adaptation	Alters microclimate to reduce the impact of extreme weather events on crops; minimizes livestock stress; increases habitat diversity, supporting beneficial organisms; enhances structural and functional diversity; creates diversified production systems; and reduces risks under unpredictable climate conditions.
Facilitating Species Movement	Supports plant species migration through strategic planting choices.
Mitigation and Reducing Greenhouse Gas Emissions	Carbon sequestration lowers fossil fuel consumption, reduces farmstead heating and cooling needs, decreases N ₂ O emissions, reduces synthetic N fertilizer use, enhances forage quality, and lowers CH ₄ emissions from livestock.

(Source: Pancholi *et al.*, 2023)

Conservation Agriculture (CA) with Agroforestry (AF)

Integrating trees into conservation agriculture significantly boosts climate resilience and carbon sequestration. While standard CA systems typically capture 0.2 to 0.4 t C ha⁻¹ yr⁻¹ the addition of agroforestry increases this to 2 to 4 t C ha⁻¹ yr⁻¹ a tenfold improvement. By using "fertilizer trees" like *Faidherbia* or *Gliricidia*, these systems accumulate carbon both above and below ground while providing superior protection against drought (Makumba *et al.* 2006). Integrating *Faidherbia albida* into farming systems serves as a prime example of effective conservation agroforestry, demonstrating how timber and crops can be grown together to outperform monocultures. This species is unique for its "reverse phenology," where it loses its leaves during the growing season and maintains a full canopy during the dry winter months. Integrating *Faidherbia* into CA frameworks enhances yields and diminishes the need for supplemental fertilization (Garrity *et al.*, 2010). Deep-rooted tree species contribute to soil fertility by translocating nutrients from lower horizons back to the surface (Ram *et al.*, 2017). Notably, the expression of reverse phenology as the shedding of foliage during the growing season is contingent upon adequate subsoil moisture and the avoidance of excessive pruning.

According to estimates by Ram *et al.* (2017), leguminous trees in agroforestry systems contribute an average of 18.7 kg of litter per hectare annually. Given a mean density of 12.44 trees per hectare, the litterfall results in a total nitrogen (N) input of 0.055 Tg through litterfall across India's agroforestry landscapes. Furthermore, biological nitrogen fixation (BNF) from an average of 1.5 trees per hectare, fixing approximately 11.18 kg N ha⁻¹ yr⁻¹ accounts for an additional 0.195 Tg of N annually across 17.45 million hectares. These biomass and nutrient contributions offer significant advantages for conservation agriculture (CA) frameworks. However, adoption of these systems is typically highest in regions characterized by severe soil degradation, erosion, and a high demand for fuelwood and fodder.

Agreement of CA and AF

Agroforestry is, of course, a multifaceted concept, but at heart it integrates trees into farmland and rangeland, and in so doing, diversifies and sustains production for increased benefits for farmers and the environment (Elevitch, 2004).

Conclusions

The integration of conservation agriculture and agroforestry offers a sustainable and climate-resilient approach to modern agriculture by improving productivity, resource-use efficiency, and environmental stability. Agroforestry enhances biodiversity, nutrient cycling, soil

fertility, water infiltration, and livelihood diversification, while CA promotes minimum soil disturbance, residue retention, and crop diversification for improved soil health and reduced production costs. The combined application of CA and AF creates strong synergies that significantly enhance carbon sequestration, climate change mitigation, and adaptation capacity. Tree-based conservation systems restore degraded soils, improve resilience against drought, reduce greenhouse gas emissions, and contribute to sustainable food, fodder, fuel, and fiber production. Species such as *Faidherbia albida* and other leguminous trees further support these systems through biological nitrogen fixation and nutrient recycling. Overall, integrating agroforestry with conservation agriculture represents an ecologically sound and economically viable strategy for achieving long-term agricultural sustainability, environmental conservation, and climate resilience.

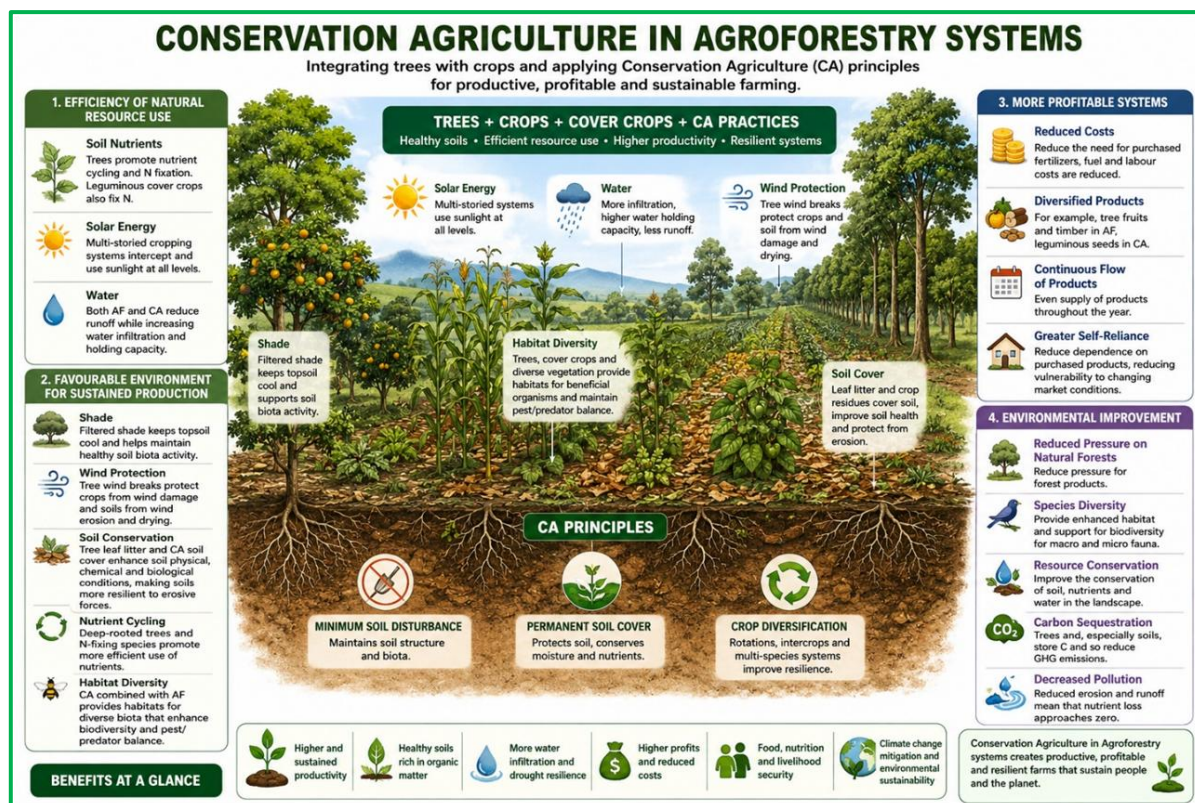


Fig. 1. Benefits, compatibility and complementarity of AF and CA system

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