Millet-Based Agroforestry Systems for Mitigating Climate Change, Achieving Nutritional Security and Sustaining Soil Health

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ABSTRACT

Climate change, declining soil fertility, water scarcity and malnutrition are interconnected challenges confronting modern agriculture. Millet-based agroforestry systems offer a promising nature-based approach that can address these challenges simultaneously by combining nutrient-dense, climate-resilient cereal crops with trees. Millets are characterized by short duration, relatively low water requirements and tolerance to heat and moisture stress. Their cultivation can contribute to climate-change mitigation through biomass production, carbon fixation, root-derived carbon inputs and the return of crop residues to the soil. When integrated with trees, these benefits are strengthened because carbon is stored in both above- and below-ground biomass and in soil organic carbon pools. Agroforestry systems can also improve nutrient cycling, reduce erosion and enhance soil biological activity. From a nutritional perspective, millets are rich sources of dietary fibre, minerals, vitamins, essential amino acids and bioactive compounds, making them valuable for dietary diversification and nutritional security. Thus, millet-based agroforestry represents more than an alternative cropping system: it is a strategy for building resilient farms,

healthier diets and more sustainable soils.

INTRODUCTION:

Agriculture is increasingly being challenged by rising temperatures, irregular rainfall, prolonged droughts, soil degradation and the growing demand for nutritious food. Conventional cereal-based agriculture, particularly where it depends heavily on irrigation and external inputs, can become increasingly vulnerable under these conditions. Climate variability is already affecting crop productivity through changes in temperature regimes, rainfall distribution, water availability and the frequency of extreme weather events. At the same time, intensive cultivation, declining soil organic matter, erosion and nutrient depletion are threatening the long-term productive capacity of agricultural land. There is therefore an urgent need for agricultural systems that can produce food while conserving natural resources and strengthening the capacity of farming systems to withstand climatic stresses.

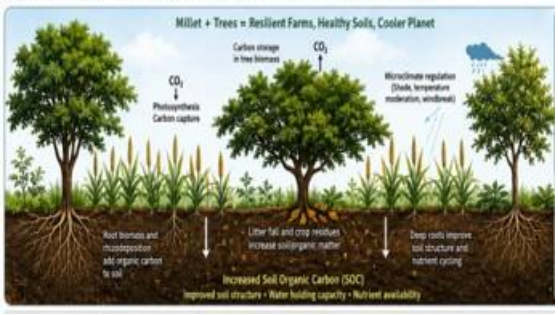
Millets have emerged as particularly relevant crops in this context. These small-seeded cereals include finger millet, foxtail millet, pearl millet, barnyard millet, and kodo millet. Historically cultivated in dryland and marginal environments, millets possess considerable tolerance to heat and moisture stress and can produce grain under conditions where some conventional cereals face greater production risks. Their nutritional richness has also resulted in increasing recognition of millets as "nutri-cereals" rather than merely traditional or coarse grains (Kumar *et al*., 2018). Their relatively low water requirement, short growing duration and adaptability to diverse agro-ecological conditions make them particularly relevant to climate-smart agricultural strategies. However, the significance of millets extends beyond their ability to survive under stressful environments. As annual crops, millets capture atmospheric carbon dioxide through photosynthesis and transform it into plant biomass. Although the long-term carbon-storage capacity of annual millet crops is naturally lower than that of perennial woody vegetation, their contribution becomes more meaningful when they are integrated with trees in agroforestry systems. In such systems, carbon can be distributed among several pools, including tree biomass, crop biomass, roots, litter and soil organic carbon.

The greatest opportunity, therefore, lies not simply in growing millets as sole crops but in integrating them into agroforestry systems. Agroforestry combines trees with agricultural crops on the same land, allowing farmers to obtain food while simultaneously benefiting from biomass production, nutrient cycling, microclimate regulation, biodiversity and carbon storage. Agroforestry research has demonstrated considerable potential for increasing soil organic carbon and strengthening carbon-storage capacity in agricultural landscapes (Pan *et al*., 2025). Thus, millet-based agroforestry represents a multifunctional approach to sustainable agriculture rather than simply an alternative method of cereal production. It links carbon sequestration with food production, nutritional quality with livelihood diversification, and crop productivity with soil conservation. Such multifunctionality is particularly valuable for small and marginal farmers, where land, water and financial resources are often limited and where agricultural resilience is closely linked with household livelihood security.

1. Millet-Based Agroforestry for Climate-Change Mitigation

Millets as carbon-capturing crops: The carbon advantage becomes substantially greater when millets are grown with trees. Agroforestry therefore creates multiple carbon pools-above-ground tree biomass, below-ground biomass, crop biomass and soil organic carbon. Earlier synthesis of agroforestry research showed substantial carbon sequestration in both biomass and soil, demonstrating the potential of tree-based systems as climate-mitigation strategies.

Figure 1. Millet-based agroforestry system for climate change mitigation and soil sustainability.



Building soil organic carbon: One of the most important climate benefits of millet-based agroforestry is its potential to increase soil organic carbon (SOC). Tree litter, crop residues, root turnover and rhizodeposition provide continuous sources of organic material.

Carbon storage beyond the millet crop: This complementarity is one of the major strengths of agroforestry. Trees and crops can exploit different soil layers and resources, while the system maintains productive land use. Studies have shown that agroforestry can increase carbon sequestration compared with conventional agricultural systems and simultaneously provide soil and ecosystem benefits (Pan *et al*., 2025).

2. Millets for Nutritional Security: Small Grains with Big Nutritional Value

A powerhouse of nutrients: Millets are rich in dietary fibre, protein, minerals, vitamins and bioactive compounds. Depending on the species and variety, they can provide important amounts of iron, calcium, phosphorus, magnesium, zinc. Recent reviews describe millets as nutrient-dense foods with significant potential for addressing dietary deficiencies and improving food and nutritional security (Sadh *et al*., 2024).

Easily incorporated into diverse diets: Another strength of millets is their versatility. They can be consumed as porridge, roti, bread, dosa, fermented foods, snacks, malted products and other traditional or modern foods. Their gluten-free nature also makes them useful ingredients in gluten-free food formulations (Sadh *et al*., 2024).

From food security to nutritional security: Millet-based agroforestry diversify farm production while providing nutrient-rich grains. The tree component can additionally provide fruits, fodder, fuelwood, leaf biomass and other products depending on the species selected. Such diversification can reduce dependence on a single crop and strengthen household food and livelihood security.

3. Millet-Based Agroforestry for Soil Sustainability

Less water, greater resilience: Millets are particularly valuable because many species are adapted to relatively dry environments and can maintain production under moisture-limited conditions. Their comparatively short duration and physiological adaptations allow them to fit well into rainfed and water-constrained production systems.

Protecting and enriching the soil: Soil sustainability depends on maintaining organic matter, nutrient availability, soil structure, biological activity and protection against erosion. Millet-based agroforestry can address several of these components simultaneously.

Why Millet-Based Agroforestry is a Climate-Smart Choice

Challenge	Contribution of millet	Contribution of trees	Combined benefit
Climate change	Stress tolerance and short duration	Long-term biomass and carbon storage	Climate-resilient production
Carbon emissions	Biomass and residue-derived carbon	Woody biomass and soil C inputs	Greater carbon-storage potential
Nutritional insecurity	Nutrient-rich grain	Fruits/fodder and diversified products	Dietary and livelihood diversification

The Way Forward

- The expansion of millet-based agroforestry should be supported by location-specific research rather than a one-size-fits-all approach.
- Tree canopy density, root competition, shading, litter quality, water availability, soil type and crop duration must be considered when designing combinations.
- Greater attention should also be given to farmer-preferred tree-millet combinations, improved millet varieties, residue management, soil-carbon monitoring, water-use efficiency and value addition.
- Agroforestry planning should therefore move from simply asking *"Which millet should be grown?"* to asking "Which millet-tree combination can provide the best balance of food, income, carbon, water and soil benefits at a particular location?"

CONCLUSION

Millet-based agroforestry systems offer an opportunity to rethink the relationship between food production and environmental sustainability. Millets are not merely traditional grains; they are climate-resilient, nutrient-dense crops capable of contributing to food production under increasingly challenging environmental conditions. When combined with trees, their contribution becomes even broader. Millet biomass and residues can contribute to soil carbon inputs, while trees provide a longer-term carbon reservoir through woody biomass, roots and litter. The future of agriculture will not be defined simply by how much food we produce, but by how efficiently we produce nutritious food while conserving water, rebuilding soils and reducing atmospheric carbon. Millet-based agroforestry sits at this intersection. It connects the grain in our food bowl with the carbon in our soil and the resilience of our farms. With appropriate tree selection, scientific management, supportive policies and stronger markets, millet-based agroforestry can become an important pathway towards climate mitigation, nutritional security and long-term soil sustainability.

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