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Research Article

Agroforestry for Soil Fertility, Climate Resilience and Livelihoods in Sub-Saharan Africa: Fertiliser Trees, Alley Cropping, Farmer-Managed Natural Regeneration and Evergreen Agriculture

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Abstract

Soil fertility decline is the silent crisis of smallholder farming in sub-Saharan Africa (SSA). Continuous cropping without nutrient replenishment, erosion, and low use of inorganic fertiliser have left many soils low in organic matter, nitrogen, and phosphorus, with maize yields often below 2 tonnes per hectare (Sanchez, 2002; FAO, 2023). Agroforestry, the deliberate integration of trees with crops and livestock on the same land, offers a low-cost, locally available way to restore fertility, sequester carbon, buffer climate shocks, and diversify income (Garrity et al., 2010; Sileshi et al., 2014). This article synthesises peer-reviewed evidence published between 2000 and 2025 on agroforestry in SSA, with emphasis on fertiliser trees, alley cropping, farmer-managed natural regeneration (FMNR), and evergreen agriculture. Evidence shows that alley cropping with Gliricidia sepium and systematic planting of Faidherbia albida increased maize yields by 0.7 to 2.5 Mg ha-1 over no-input controls, an 89 to 318 percent increase across Africa (Sileshi et al., 2014). A meta-analysis of Faidherbia found significant increases in soil organic carbon by 46 percent, total nitrogen by 50 percent, phosphorus by 21 percent, potassium by 32 percent, and maize yield by 150 percent (Sileshi et al., 2020). In Zambia, maize under Faidherbia canopy averaged 4.7 tonnes per hectare compared with 1.9 tonnes outside the canopy, and in Malawi maize yields increased by 100 to 400 percent under Faidherbia (FAO, 2011; Garrity et al., 2010). The article reviews mechanisms, species choice, management, carbon and climate benefits, economics, gender, tenure, and adoption, and it proposes a practical, farmer-centred agroforestry design for smallholders. The central argument is that trees should not be seen as competing with crops for land, but as the cheapest fertiliser factory, shade, windbreak, fodder, fruit, and timber source that a smallholder can own, provided species, spacing, tenure, and management are chosen to fit the farm.

Keywords: agroforestry; Faidherbia albida; Gliricidia sepium; soil fertility; evergreen agriculture; farmer-managed natural regeneration; sub-Saharan Africa

1. Introduction

A smallholder who plants maize on the same field year after year without adding nutrients is mining the soil. Each harvest removes nitrogen, phosphorus, potassium, and organic matter, and if those nutrients are not replaced, yields fall, soils harden, and crops become more vulnerable to drought and pests (Sanchez, 2002). Inorganic fertiliser can replace nutrients, but it is often expensive, unavailable at planting time, or used at low rates because of cash constraints and risk. Organic manure can help, but livestock numbers are often too low to produce enough manure for all fields. Agroforestry offers a third path: grow the fertiliser on the farm, in the form of trees that fix nitrogen, recycle nutrients from deep soil, add leaf litter, and improve soil structure.

Agroforestry is not new. Farmers in SSA have long kept trees on farms for fruit, timber, shade, medicine, and fodder, and have protected useful species in fields and fallows (Garrity et al., 2010). What is new is the systematisation: planting fertiliser trees at known spacing, pruning them at known times, and combining them with crops, livestock, and conservation practices in a design that is intended to be productive, not merely traditional. Evergreen agriculture, a term coined by the World Agroforestry Centre, describes intensive farming that integrates trees with annual crops to

maintain green cover year-round, even in the dry season (Garrity et al., 2010).

This article asks three questions. First, how does agroforestry improve soil fertility, water, and microclimate, and how large are the yield effects? Second, which species and systems work best for which farms, soils, and climates? Third, why do some farmers adopt agroforestry while others do not, and what support makes adoption more likely and more durable? The synthesis concentrates on maize-based systems, where evidence is strongest, while drawing on sorghum, millet, cocoa, coffee, and vegetable systems where relevant.

2. How Trees Improve Soil, Water and Microclimate

Trees improve soil through five mechanisms. First, nitrogen-fixing leguminous trees, such as Faidherbia albida, Gliricidia sepium, Sesbania sesban, and Leucaena leucocephala, fix atmospheric nitrogen through symbiosis with rhizobia, adding 34 to 83 kg of nitrogen per hectare per year from Faidherbia leaf fall alone in some studies (Sileshi et al., 2014; Garrity et al., 2010). Second, deep roots capture nutrients from below the crop root zone and return them to the surface as leaf litter, a process called nutrient pumping. Third, leaf litter and prunings add organic matter, improving soil structure, water-holding capacity, and microbial activity. Fourth, tree roots and canopy reduce erosion by wind and water, and improve infiltration. Fifth, trees support mycorrhizal fungi and soil fauna that help crops access phosphorus and other nutrients.

Water and microclimate effects are equally important. Trees provide shade, reducing soil temperature and evaporation, and act as windbreaks, reducing crop water loss and physical damage. In the Sahel, farmer-managed natural regeneration has been shown to reduce wind erosion, improve infiltration, and increase soil moisture, allowing crops to survive dry spells that would otherwise cause failure (Reij et al., 2009). Faidherbia is unusual because it sheds its nitrogen-rich leaves in the early rainy season, when crops are planted, and regrows leaves in the dry season, when crops are dormant, so it fertilises crops without shading them at the critical growth period (Garrity et al., 2010; Sileshi et al., 2014).

Carbon sequestration is a co-benefit, not the main reason farmers plant trees. Agroforestry systems sequester carbon in biomass and soil, and they can reduce pressure on forests by providing fuelwood and timber on-farm. Carbon payments can supplement income, but they should not be the sole incentive, because payments are often small, delayed, and complex to access for smallholders. The primary incentive should be yield, income, and resilience, with carbon as a bonus.

3. Fertiliser Trees and Alley Cropping: Evidence on Yields

Fertiliser trees are the most studied agroforestry practice in SSA. Sileshi et al. (2014) reviewed alley cropping with Gliricidia and systematic planting of Faidherbia and found that maize yields increased by 0.7 to 2.5 Mg ha-1 over no-input controls, a 89 to 318 percent increase across Africa. The gains were largest where soil fertility was low, where fertiliser use was low, and where trees were well-managed, pruned, and protected from grazing. In Zambia, maize under Faidherbia canopy averaged 4.7 tonnes per hectare compared with 1.9 tonnes outside the canopy, and in Malawi maize yields increased by 100 to 400 percent under Faidherbia (FAO, 2011; Garrity et al., 2010). A meta-analysis of Faidherbia by Sileshi et al. (2020) found significant increases in soil organic carbon by 46 percent, total nitrogen by 50 percent, phosphorus by 21 percent, potassium by 32 percent, and maize yield by 150 percent and sorghum yield by a similar magnitude.

Alley cropping, where crops are grown between hedgerows of Gliricidia, Leucaena, or Sesbania, works through regular pruning. Prunings are applied as mulch or incorporated into soil, providing nitrogen and organic matter, while hedgerows reduce erosion on slopes. Alley cropping requires labour for pruning, protection from livestock, and management to avoid competition for water and light. It works best on soils with moderate fertility, with rainfall above 800 mm, and where labour is available at pruning time. On very dry soils, competition can outweigh benefits, so spacing should be wider and pruning more frequent.

Improved fallows, where fertiliser trees are planted on land resting from crops for one to three years, are another option. Sesbania, Tephrosia, and Gliricidia fallows can restore fertility, suppress Striga, and provide fuelwood, after which the land is returned to crops. Fallows require land to spare, which many smallholders do not have, so they are more suitable for farmers with larger holdings or for community land. In Malawi and Zambia, improved fallows have been adopted by farmers who can afford to rest land, and they have been shown to increase subsequent maize yields by 50 to 100 percent compared with continuous cropping without inputs.

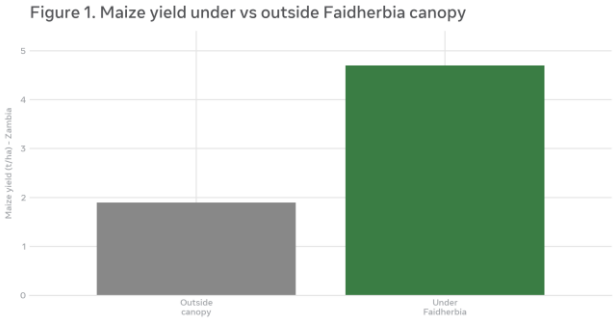


Figure 1. Maize yield under versus outside Faidherbia canopy in Zambia, as reported by FAO (2011). Yields were higher under the canopy (4.7 t/ha) than outside the canopy (1.9 t/ha), especially where soil fertility was low.

4. Farmer-Managed Natural Regeneration and Evergreen Agriculture

Farmer-managed natural regeneration (FMNR) is one of the most successful, low-cost restoration approaches in SSA. Instead of planting new trees, farmers protect and manage living stumps, roots, and seedlings already in their fields, pruning them to a few stems, protecting them from grazing and fire, and allowing them to regrow (Reij et al., 2009). In Niger, FMNR has restored millions of hectares of degraded land, with farmers protecting species such as Faidherbia, Piliostigma, and Guiera in their fields. FMNR costs little, uses local knowledge, and can be scaled quickly because it does not require nurseries, transport, or planting. It is especially valuable in the Sahel, where rainfall is low and tree planting survival is often poor.

Evergreen agriculture integrates FMNR, fertiliser trees, and conservation agriculture into a year-round green cover system. In Zambia and Malawi, evergreen agriculture, based on Faidherbia and other trees, has been reported to double

or triple maize yields for smallholders, with farmers in Malawi increasing yields by up to 280 percent under Faidherbia canopy (Garrity et al., 2010). The system also provides firewood, fodder, and fruit, reducing the need to cut forests. Evergreen agriculture is not a single technology, but a principle: keep the land covered with useful trees and crops year-round, so that soil is protected, nutrients are recycled, and income is diversified.

Cocoa and coffee agroforestry are important in West and East Africa. Shade trees in cocoa and coffee systems, such as Gliricidia, Albizia, and fruit trees, can improve soil, reduce temperature stress, provide habitat for pollinators, and diversify income with fruit, timber, and honey. Shade must be managed: too much shade reduces cocoa and coffee yield, while too little shade increases heat stress and pest pressure. Research in Ghana and Côte d'Ivoire has shown that moderate shade, 30 to 40 percent, can maintain cocoa yield while improving resilience and income diversity.

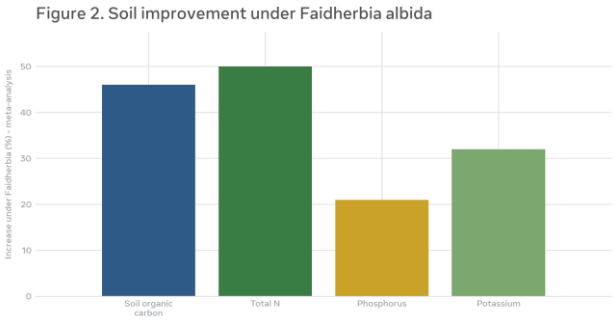


Figure 2. Soil improvement under Faidherbia albida, from meta-analysis by Sileshi et al. (2020). Increases in soil organic carbon (+46%), total nitrogen (+50%), phosphorus (+21%) and potassium (+32%) explain much of the yield benefit.

Table 1. Common agroforestry practices in SSA and their management.

Practice	How it works	Best for	Key management
Faidherbia parkland	Trees scattered in fields	Maize, sorghum, millet	Protect trees, allow leaf fall
Alley cropping	Crops between hedgerows	Maize, moderate rainfall	Prune regularly, mulch
Improved fallow	Trees on resting land 1–3 yr	Degraded land, larger farms	Protect from grazing
FMNR	Manage regrowth from stumps	Sahel, degraded land	Prune, protect from fire
Cocoa / coffee shade	Shade trees in plantation	Cocoa, coffee	Manage shade 30–40%

5. Species Choice, Spacing and Management

Species choice should be based on climate, soil, farm size, and farmer goals, not on a single recommended species. Faidherbia is ideal for maize in semi-arid to sub-humid areas with low soil fertility, because of its reverse phenology and nitrogen fixation. Gliricidia is ideal for alley cropping and fodder in humid and sub-humid areas, because it coppices well and produces high-quality leaf. Sesbania is ideal for short fallows and for waterlogged soils. Leucaena is ideal for fodder and fuelwood but can become invasive if not managed. Fruit trees, such as mango, avocado, and citrus, provide income and nutrition but require more water and protection.

Spacing and management determine whether trees help or hinder crops. Faidherbia should be planted at 10 by 10 metres or wider, to allow light and machinery, with pruning to maintain a single stem. Gliricidia hedgerows should be spaced 4 to 6 metres apart, pruned 2 to 3 times per season to 0.5 metres height, with prunings applied as mulch. Trees should not be planted too close to crops, should not be allowed to shade crops at critical stages, and should be protected from livestock, fire, and termites, especially in the first two years. Farmers should keep records of planting date, species, spacing, pruning, and yield, to learn what works on their farm.

6. Economics, Gender, Tenure and Adoption

Economics must be explicit. Trees take time to produce benefits: Faidherbia may take 5 to 10 years to reach full effect, while Gliricidia can produce benefits in 1 to 2 years. This time lag is a major barrier, because farmers who need food and income now may not invest in a benefit that arrives in five years. Programmes should therefore combine fast-benefit species, such as Gliricidia and Sesbania, with long-term species, such as Faidherbia, and should provide interim benefits, such as fodder, fuelwood, and fruit, to sustain motivation. Carbon payments, if available, should be seen as a bonus, not the main incentive.

Tenure is decisive. Farmers who do not have secure rights to land and trees are unlikely to plant trees that will benefit a landlord or a future owner (Garrity et al., 2010; Reij et al., 2009). In many SSA countries, tree tenure is separate from land tenure, and farmers may need permission to plant, prune, or harvest trees. Reform that gives farmers clear rights to trees they plant or protect, including rights to harvest and sell, is one of the most powerful policies for agroforestry adoption. Community by-laws that protect FMNR trees from grazing and fire, and that recognise farmer rights, have been shown to be effective in Niger and Malawi.

Gender and adoption are central. Women often manage home gardens, fuelwood, and fruit, yet they may not control decisions about planting trees on family land, and they may face taboos against planting certain species. A study in Legambo, Ethiopia, found that gender and livestock ownership significantly promoted agroforestry adoption, while smaller land sizes and younger age posed challenges. In East Wollega, Ethiopia, female-headed households had a 9.2 percentage-point lower probability of integrated conservation agriculture-agroforestry adoption, potentially reflecting differences in extension access. Programmes that channel seedlings, training, and credit through women's groups, and that ensure women have rights to trees and income, are more likely to reach those who actually manage trees and to sustain adoption.

Table 2. Barriers to agroforestry adoption and what helps overcome them.

Barrier	Why it matters	What helps
Time lag	Trees take years to benefit	Combine fast + long-term species, interim fodder / fruit
Tenure insecurity	No incentive to plant if no rights	Clear tree tenure, community by-laws
Labour for pruning	Pruning takes time	Train, use group labour, choose low-labour species
Grazing / fire	Livestock and fire kill seedlings	Protect, fence, community rules
Seedling access	No nursery, poor quality	Community nurseries, FMNR, quality seed

7. Research and Policy Priorities

Several gaps remain. First, long-term, multi-location trials that measure not only yield but also soil, water, carbon, income, and nutrition over 10 years or more are still scarce, because most trials last only 2 to 3 years. Second, research on tree-crop competition, on optimal spacing and pruning for different soils and climates, should be prioritised. Third, economics research should measure the full value of trees, including fodder, fuelwood, fruit, timber, and carbon, not only crop yield. Fourth, research on gender, tenure, and governance should be embedded in agroforestry trials, not treated as separate.

Policy should align incentives with long-term soil health. Public investment should support community nurseries, FMNR, and extension, with clear tree tenure reform. Seed systems for agroforestry species should be improved, with quality seed, germplasm, and nurseries available at planting time. Carbon and payment-for-ecosystem-services schemes should be simplified, with transparent, timely payments to farmers. Regional coordination on restoration, on the Great Green Wall, and on climate adaptation can ensure that agroforestry is not a project, but a permanent part of farming systems (FAO, 2023; Reij et al., 2009).

8. Conclusion

Agroforestry offers a practical, low-cost, and locally available way to restore soil fertility, buffer climate shocks, and diversify income in SSA. Fertiliser trees can increase maize yields by 89 to 318 percent over no-input controls, Faidherbia can increase soil organic carbon by 46 percent and maize yield by 150 percent, and FMNR can restore millions of hectares at low cost (Sileshi et al., 2014; Sileshi et al., 2020; Reij et al., 2009). The challenge is not a lack of technology; it is the challenge of making seedlings, knowledge, tenure, and markets available to millions of smallholders, especially women and youth who manage trees. If that is achieved, agroforestry can turn trees from a perceived competitor with crops into the cheapest fertiliser, shade, fodder, and timber source a farmer can own, and can make evergreen agriculture the norm, not the exception, in SSA.

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Conflict of Interest

The authors declare no conflict of interest.

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