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Agroecological agroforestry system designed for more efficient use of Irrigation water by family farmers

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Abstract

One of the main challenges faced by family farmers, especially those settled through agrarian reform programs, is the limited availability of water for food production. Crop diversification and intercropping are traditional practices in family farming, while agroforestry systems have emerged as one of the most promising production strategies for improving food sovereignty and security, generating income for family farmers, simultaneously preserving biodiversity and natural resources. This study aimed to design an agroecological agroforestry system that reduces water use while optimizing irrigation management by family farmers. This design was developed collaboratively by the agroecology team of Embrapa Meio Ambiente, the Non-Governmental Organization Mutirão Agroflorestal, and family farmers from the Sepé Tiraju Agrarian Reform Settlement (Serrana and Serra Azul, São Paulo state, Brazil) within the framework of the Public Policy of the Sustainable Rural Development Program of the São Paulo State Secretariat for the Environment. Thirty-five agroforestry systems, covering 25.4 hectares, were implemented in the Sepé Tiaraju Settlement in 2014. Unlike conventional agroforestry designs, in which economically productive trees (including fruit and timber species) and native trees from different ecological groups for biomass production are planted within the same row, the proposed system arranges these species in alternating rows, spaced 5 m apart, with 4 m between trees within each row. Because irrigation is restricted to the economically productive tree rows, while native species rely on their greater adaptation to low soil moisture conditions, the system reduced water consumption by 50% and irrigation infrastructure costs by 37.6%. In addition, the arrangement facilitates sequential pruning of the native tree rows, streamlining biomass production for mulching the economically productive tree rows, thereby improving soil moisture conservation, suppressing spontaneous vegetation, reducing erosion, enhancing nutrient cycling, and decreasing reliance on external inputs. These characteristics contribute to greater system self-sufficiency and demonstrate the potential of this agroforestry design as a practical strategy for improving the sustainability of family farming under water-limited conditions.

Keywords: Agroforestry, agroecology, water economy, arrangement

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Introduction

One of the main challenges faced by family farmers, particularly agrarian reform settlers, is the limited availability of water for food production. Many family farmers in Brazil, Latin America, and the Caribbean lack adequate conditions in terms of water availability for agriculture production, whether due to socioeconomic constraints, such as the lack of irrigation equipment, limited water availability or lack of access to water resources, and/or adverse climatic conditions, such as naturally low rainfall in a given region (Castro, 2024).

Crop diversification, or intercropping, is a traditional practice in family farming, and agroforestry systems (AFS) have emerged as one of the most promising production strategies for improving food sovereignty and food security, generating income for this category of farmers, and, at the same time, preserving biodiversity and natural resources. AFS have the potential to promote greater water-use efficiency by creating a microclimate capable of maintaining air and soil temperature and moisture conditions favorable to plant growth and development (Queiroga et al., 2023; Voltolini et al., 2018). They may also represent na alternative for minimizing conflicts arising from competing water demands in regions facing water scarcity (Guerra, 2014).

Despite this potential of AFS, more efficient water use in the irrigation of these systems is crucial. According to Han et al (2021), there are few studies and limited information on the use and management of irrigation systems in AFS that can provide basis for technical recommendations to family farmers aimed at achieving more efficient water use.

Efficient use of water can be achieved through existing irrigation infrastructure, in terms of cropping practices, irrigation management, techniques that increase water-use efficiency, and improvements in the ration between the amount of water effectively used by crops and the amount withdrawn from the water source (Coelho et al., 2005). According to Marouelli et al. (2008), only through the adoption of appropriate irrigation management is it possible to reduce water use by up to 30%.

In this context, this study aimed to design an agroecological agroforestry system through a participatory process with family farmers to reduce water waste and optimize irrigation water management.

Material and Methods

The research was conducted at the Sepé Tiaraju Agrarian Reform Settlement, located in the municipalities of Serrana and Serra Azul, São Paulo State, Brazil (Figure 1). The settlement was officially established in 2004 as the first settlement under the Sustainable Development Project (SDP) modality in the state. It comprises 80 families and covers a total area of 814 hectares.

According to the Köppen climate classification, the region has an Aw climate (tropical climate with a dry winter) or a transitional climate toward Cwa type (highland tropical climate), with two well-defined seasons: a hot, rainy summer (from October to March) and a mild, dry winter (from April to September). Mean annual precipitation ranges from 1,300 to 1,500 mm, concentrated in the summer months, which requires water management planning for the periods of water deficit.

The predominant soils in the region are Latossols, which are deep and well-drained but naturally acidic, requiring organic matter management. Patched of acrisols also occur in areas with steeper slopes. The settlement is located in a transition zone between the Atlantic Forest and Cerrado biomes and is situated in a region historically dominated by intensive sugarcane monoculture.

The methodology adopted in this study was based on Minayo (2014) and Geilfus (2002), who adopted participatory tools that favor an environment of dialogue and encourage participants to voice their opinions. Two AFS planning workshops were conducted with 35 family-farming households that had benefited from the public policy of the Sustainable Rural Development Program (PDRS), implemented by the Sao Paulo State Secretariat for the Environment and partner institutions, such as Embrapa Environment. This public policy supported the establishment of 600

hectares of AFS in 2014 through 21 projects in different regions of the state. One of these projects was carried out at the Sepé Tiaraju Settlement, where 35 AFS were established, ranging from 0.5 to 1.0 hectares, totaling 25.4 hectares (Santos el al., 2018).

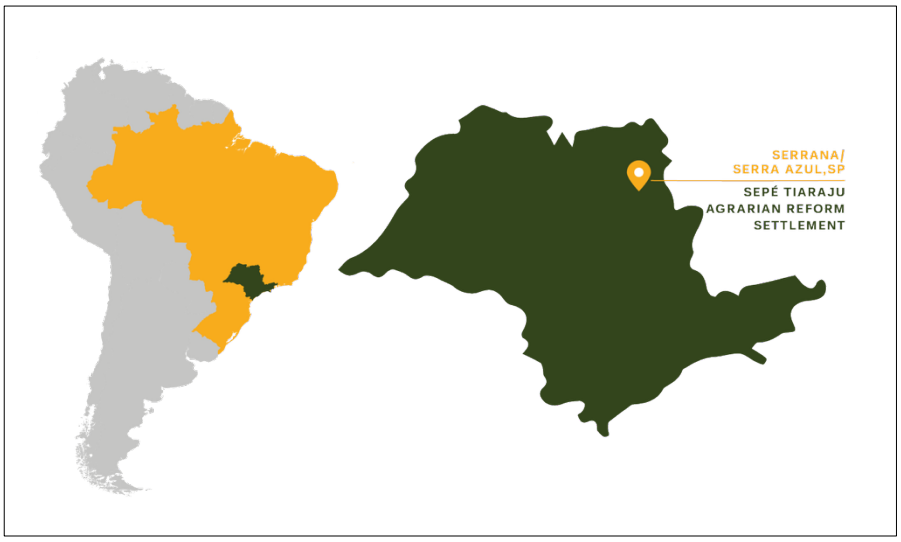


Figure 1: Location of the Sepé Tiaraju Agrarian Reform Settlement, São Paulo State, Brazil.

During the workshops, two alternative agroforestry system (AFS) designs were presented, along with their respective advantages and disadvantages regarding management operations and irrigation water use. This information provided a basis for family farmers to select the designs to be implemented.

Results and Discussion

The agroforestry system (AFS) design selected by family farmers in the Sepé Tiaraju Settlement was designed by the Agroecology team at Embrapa Environment and the Non-Governmental Organization Mutirão Agroflorestal, differing from the conventional, more widespread and adopted design by featuring tree rows for economic production with irrigated fruit and timber species, intercropped with rows of native trees for biomass production without irrigation. Due to being more rustic and resistant to low soil moisture conditions, native species exhibit satisfactory growth and development under rainfed conditions. Spacing between economic production rows and biomass production rows is 4 to 5 m, and within-row tree spacing is 4 m, interspersed with banana plants every 2 m between trees (Figure 2).

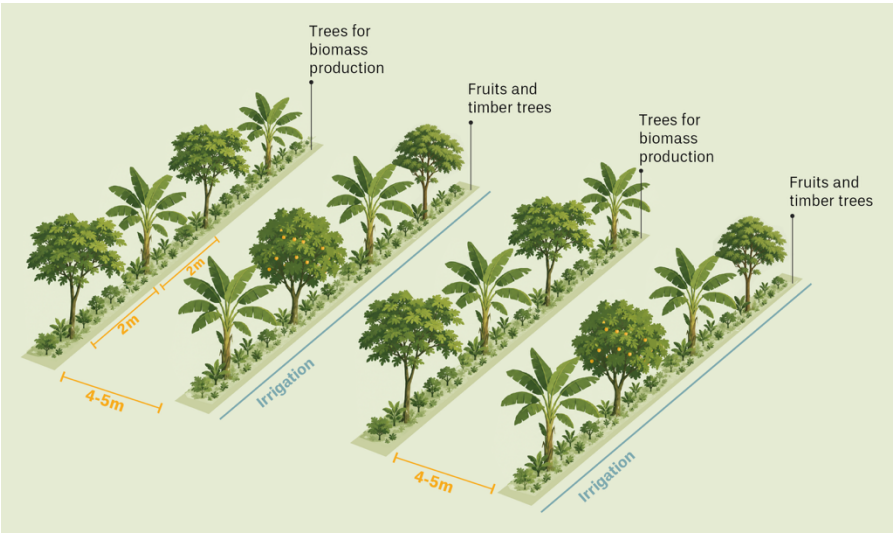


Figure 2. Illustrative diagram of an agroforestry system designed for more efficient water use.

In the conventional AFS design, all rows contain economic production species intercropped with biomass production species and irrigation. The adoption of this new design, in which only tree rows for economic production are irrigated, demonstrated the advantage of reducing by 50% the volume of water required to meet the demands of arboreal species intended for economic production when compared to the conventional design. This reduction percentage can be even greater by selecting economic production species with similar water requirements within the same row, enabling reductions in irrigation frequency and/or irrigation runtime for rows with species of lower water demand.

Table 1 presents the materials required for the installation of a gravity-fed drip irrigation system in AFS with a conventional design and in AFS with the new design, along with their respective costs. The new design showed the advantage of reducing by 37.6% the cost of materials required for its implementation relative to the conventional design.

Another operational advantage of this innovative design is the optimization of labor during pruning operations of biomass-producing tree species, which are conducted sequentially along the same row and eliminate the need for damage-prevention measures around economic tree species. Conversely, a trade-off of the innovative design is the additional labor required to transport pruned green manure and mulch material from the biomass rows to the economic production rows.

Pruning of native species aims to generate organic biomass for soil cover (mulching) along economic production rows. This practice enhances soil moisture conservation, minimizes labor and operational costs associated with weed control, supplies nutrients to cash crops, and decreases family farmers' reliance on off-farm external inputs, in accordance with agroecological principles.

Table 1: Material and implementation costs of a gravity-fed drip irrigation system in agroforestry systems (AFS) under conventional and innovative designs utilized by family farmers in the Sepé Tiaraju Agrarian Reform Settlement, São Paulo State, Brazil.

System componentes	Unit	Conventional AFS Cost (€)	Innovative AFS Cost (€)	Cost difference (€)	Relative reduction (%)
Mainline	m	24.61	24.61	0.00	0.0%
Drip tape	m	165.35	94.49	-70.86	-42.9%
Connectors	units	5.16	2.95	-2.21	-42.9%
End caps	units	7.75	4.43	-3.32	-42.9%
Total implementation cost	—	202.75	126.48	-76.27	-37.6%

Note: Original values in Brazilian Reais (BRL) were converted to Euros (EUR) at an exchange rate of €1.00 = R$ 5.08. For international reference and economic comparison, on October 30, 2026..

Conclusions and Outlook

This innovative agroforestry system (AFS) design demonstrated technical and economic viability by reducing water consumption, lowering material costs for drip irrigation system implementation, optimizing pruning management for biomass production, promoting reduced reliance on external inputs, and increasing profitability for family farmers. It represents a practical and sustainable solution for family farming to mitigate the impacts of water scarcity and climate change on food production.

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