Water sustainability and economic performance of the Irriga Pote system in family farming in Northeastern Pará, Brazil

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ABSTRACT: This study analyzes the water sustainability and economic performance of the Irriga Pote system in family farming in Northeastern Pará, considering a five-year time horizon. IrrigaPote is a social technology for autonomous irrigation, characterized by low cost and high water efficiency, which enables the gradual redistribution of soil moisture through interconnected ceramic pots regulated by a float system. The research was conducted using empirical data obtained from a demonstrative unit in the citrus hub of Capitão Poço, integrating analyses of costs, revenues, cash flow, and financial indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit-Cost Ratio (B/C). The results indicate that the system requires a low initial investment and ensures rapid financial recovery, with a positive NPV, an IRR above 60%, and a B/C ratio greater than 1. Furthermore, the use of rainwater and the absence of electricity costs significantly reduce operating expenses, increasing the profitability of citrus production and intercropped crops. The economic model demonstrates that IrrigaPote is not only financially viable but also contributes to the rational management of water resources and the strengthening of food security. It is concluded that the adoption of IrrigaPote represents a promising strategy for the sustainable development of family farming in the region, combining economic efficiency, technological innovation, and environmental sustainability.

KEYWORDS - Alternative irrigation, Social technology, Family farming, Economic analysis, Amazon.

I.   INTRODUCTION

Efficient water use constitutes one of the main challenges to the sustainable development of agriculture, especially in regions subject to prolonged periods of water deficits. Inadequate management of water resources in productive systems has generated significant economic, social, and environmental impacts, mainly due to the high water footprint, compromising food security and the financial stability of rural producers [1]. In this context, the development and adoption of irrigation technologies that combine water efficiency, economic viability, and operational simplicity become essential. Traditional irrigation methods, although widely used, present environmental and financial inefficiencies that reduce their long-term sustainability. Excessive water use and high energy consumption result in water waste, increased carbon emissions, and higher operating costs. These factors compromise the profitability of production units and increase the economic vulnerability of smallholder farmers, particularly in regions with limited infrastructure. Years marked by extreme climatic events, such as prolonged droughts, have intensified the risks of crop losses, aggravating pressure on water resources and demanding innovative solutions for irrigation management. In Eastern Amazonia, where precipitation cycles alternate between heavy rainfall and long dry spells, water supply during the dry season is essential to ensure the continuity of agricultural production. However, the high cost of implementation and operation of conventional irrigation systems hinders their adoption by family farming, which constitutes the foundation of regional food production. In light of this reality, social irrigation technologies emerge as strategic alternatives to reconcile economic efficiency and environmental sustainability. These technologies are characterized by community appropriation, low implementation cost, use of local resources, and the valorization of traditional knowledge,

Promoting productive autonomy and technological inclusion in rural areas. Among the promising solutions, IrrigaPote stands out as a scientifically and socially based irrigation system, developed from the adaptation of an ancient technique known as clay pot irrigation ([2], [3], [4], [5], [6], [7]). The system operates through the gradual release of water from the porous walls of buried ceramic pots, creating micro-moist zones in the soil that favor the growth of nearby plants and reduce evaporation losses. This feature enables greater crop density and diversity in limited areas, optimizing water use and lowering operational costs. In Brazil, the system was improved by [8], [9], incorporating automation elements and integration with rainwater harvesting, which expands its applicability in Amazonian family farming. Successful cases have already been observed in municipalities of Pará, such as Santarém, Capitão Poço, and Tucuruí, where family production units have adopted IrrigaPote within agroforestry systems, achieving cost reduction, productive diversification, and income growth. Such evidence reinforces the potential of the technology as an instrument of social and economic innovation, capable of increasing water efficiency and strengthening the productive resilience of rural Amazonian communities.To support technical decisions and public policies aimed at adopting technologies based on circular economy principles and food security in the Amazon region, this study aims to analyze the implementation costs of the IrrigaPote system in family farming in Northeastern Pará, using classical indicators of agricultural economics.

II. MATERIALS AND METHODS

The methodology adopted in this study is quantitative, applied, descriptive, and comparative in nature, with the unit of analysis being the implementation project of the IrrigaPote System in the Cristo Rei community, located in Vila Rural Barro Vermelho, municipality of Capitão Poço (PA), in Northeastern Pará. The study area is situated in the Am3 climate zone, according to the Köppen classification adapted by [10] and detailed by [8]. The central map presents the geographic division of Capitão Poço and neighboring municipalities, with Capitão Poço highlighted in blue and nearby localities such as Mãe do Rio, Irituia, and Garrafão do Norte in other colors. The Barro Vermelho community is indicated by a red arrow. The main section of the map is titled 'Climatic Typology in the Clay Pot Irrigation Unit in Citrus' (Figure 1) [11].
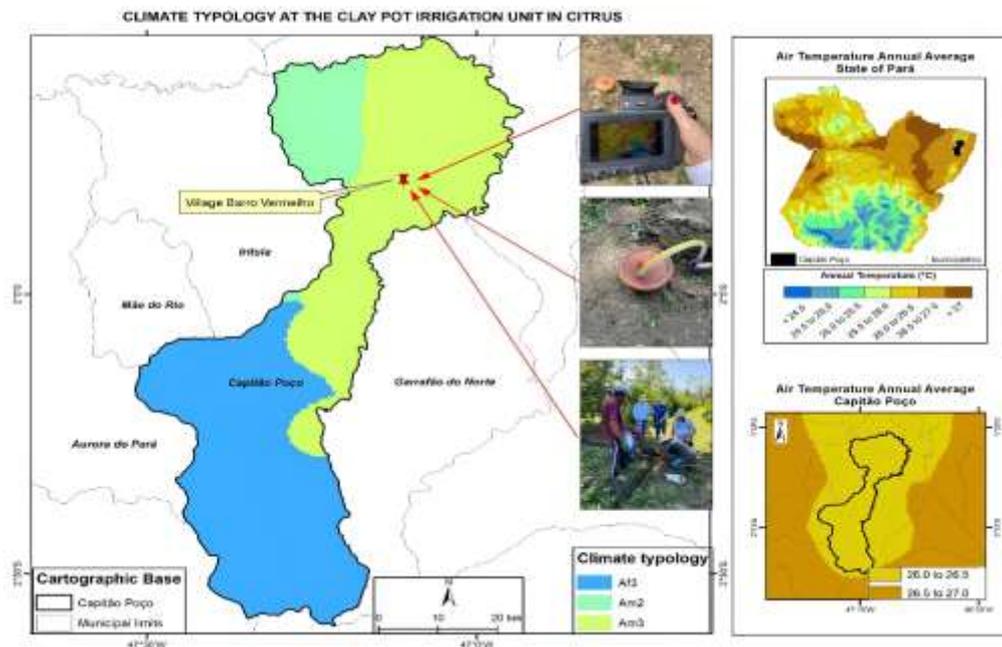

Figure 1. Climatic typology and temperature variation in the clay pot irrigation unit for citrus cultivation in Capitão Poço, Pará.

The analysis refers to the period between August 2024 and August 2025, following the implementation of the irrigation technology using clay pots in an area that already had a lemon plantation, which is the main agricultural crop. Costs, technical performance, economic viability, and farmers' perception regarding the ease of implementation and adoption were analyzed.

It is emphasized that the purpose of the analysis was to characterize the implementation and operating costs of the system, as well as to compare its results under different productive conditions, in order to identify indicators capable of supporting the adoption of IrrigaPote in different contexts of Amazonian family farming.

The economic analysis was developed based on a model spreadsheet for calculating financial indicators, composed of three calculation topics:

✔ Project data (irrigated area, initial investment, lifespan, discount rate, productivity, and product price);

✔ Annual cash flow (revenues, operating costs, and net flow);

✔ Financial indicators: Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (B/C), and Break-Even Point (PN).

The calculation base was the experimental area of 1,440 m², which had an approximate cost of R$ 7,039.50 in August 2024 (considering the cost of the water tank, the price of pots manufactured in the ceramic hub of Icoaraci, transportation costs to Capitão Poço, the price of PVC pipes and connectors, floats, and rubber to connect the PVC pipe and floats to each pot). There were no expenses related to hiring a hydraulic professional, since the farmers in the community carried out the entire system installation themselves. Subsequently, the values were projected for an area equivalent to 1 hectare, enabling a broader analysis of viability. A four-year planning horizon was considered, with estimates of costs, revenues, and cash flow, following the methodology of the Institute of Agricultural Economics (IEA), as described by [12].

Production costs were grouped into the following components:

● Implementation – seedling production, soil preparation and liming, pit opening, and planting;
● Nutritional management – soil analyses, acquisition and application of soil amendments and fertilizers;
● Cultural practices – control of spontaneous plants, pruning, and branch management;
● Phytosanitary management – inspection and control of pests and diseases;
● Harvest – transportation, cleaning, and labor;
● Processing – washing, packaging, and storage;
● Other costs – 1.5% related to technical services and 4% to fees and taxes (CONAB, 2010).

The Total Operating Cost (TOC) was obtained by adding the Effective Operating Cost (EOC) to the item 'Other Costs' (4.5% over the EOC).

The Cash Flow (CF) was calculated as the difference between revenues and total costs, considering both domestic commercialization and the external market, the main destination of the 'Tahiti' acid lime produced in Capitão Poço.

Economic viability indicators

Four evaluation indicators were applied:

a) Net Present Value (NPV)

$$NPV = -I + \sum \frac{CF_t}{(1+K)^t}$$

The project is considered viable when NPV > 0.

b) Internal Rate of Return (IRR):

$$0 = \sum \frac{CF_t}{(1+IRR)^t}$$

Indicates the percentage profitability of the investment; IRR > discount rate confirms feasibility.

c) Benefit-Cost Ratio (B/C)

$$B/C = \frac{VP(Incomes)}{VP(Expenses)}$$

Projects with B/C > 1 are economically attractive.

a) Break-Even Point (BEP)

$$BEP = \frac{CT}{P}$$

Represents the minimum production volume required to cover total costs.

The calculation was based on the costs for implementing the IrrigaPote system over an area of 1,440 m², divided into two modules of 720 m² each, where an Agroforestry System (AFS) has been established with a wide diversification of species: cashew, tomato, cowpea, pumpkin, watermelon, and black pepper, among others. It is important to highlight that the logic behind the IrrigaPote technology follows the methodological principles of circular economy, by promoting the continuous use of resources, reducing water waste, saving hours that farmers would otherwise dedicate if irrigation were carried out using conventional technologies, since the system is fully autonomous, and strengthening the reuse of inputs within the agroecosystem ([13], [14]). As a result of these benefits, there is growing interest among farmers in the Cristo Rei Community to replicate the system, driven by dissemination strategies implemented in the territory. This movement represents an important indicator of the ease of adoption of the technology by family farmers. Figure 1 shows the model of the system already installed in the community, illustrating its operation and potential for replicability, as well as highlighting the role of the clay pot buried in the soil as a supplementary water source during the dry season.

Figure 2. Model of the IrrigaPote system installed in the Cristo Rei community

III. RESULTS AND DISCUSSION

The economic indicators analyzed constitute fundamental parameters for decision-making regarding the adoption of the social technology Irriga Pote in the cultivation of 'Tahiti' acid lime and in family-based agroforestry systems in Northeastern Pará.

Area with 'Tahiti' acid lime cultivation : The implementation of the IrrigaPote system in an area of 1,440 m², equivalent to one projected hectare, presented a total estimated cost of R$ 7,039.50, as detailed in Figure 1. The set of materials used includes 20 L ceramic pots, PVC connections and pipes, water tanks, hoses, and devices for automated water supply management.

The economic analysis (Table 1) shows that the initial investment of R$ 54,209.85 is amortized starting from the second year of production, when the revenue from the commercialization of acid lime exceeds the annual operating costs. The net cash flow becomes positive from the middle of the second year, consolidating in the third year, with annual profits estimated at R$ 41,105.00 ha^{-1}. The calculated indicators reinforce the economic feasibility of the system. The Net Present Value (NPV) of R$ 63,144.04 indicates a return higher than the cost of capital applied, while the Internal Rate of Return (IRR) of 65.79% demonstrates profitability significantly above the adopted discount rate. The Benefit–Cost Ratio (B/C) of 1.16 confirms that discounted revenues exceed total costs, and the Break-Even Point (BEP) is below the average expected productivity for the crop, ensuring an economic safety margin for the producer. These results demonstrate that the IrrigaPote system presents itself as an economically attractive alternative, especially for family farming units seeking to reduce irrigation costs, increase water-use efficiency, and diversify crops in small areas.

b) Area with Technology Transfer – A Case of Circular Economy : In the experimental area of 1,440 m², organized as an Agroforestry System (AFS) and composed of 32 ceramic pots, the total implementation cost was R$ 7,039.50. Each pot has an influence area of approximately 45 m² (9 m × 5 m), creating humid microzones that favor the intercropping of temporary and permanent species. The gross average revenue table indicates total estimated earnings of R$ 17,581.00 in the first and second years, and R$ 25,357.00 from the third year onwards, due to the entry into production of perennial crops, especially black pepper. Among the main cultivated species are cowpea, pumpkin, tomato, watermelon, and cashew, forming a diversified arrangement that reflects the principle of ecological intensification and circular economy.

Positive net profitability already in the first year results from sequential production planning, which combines crops of different cycles and seasonalities, optimizing the use of soil and water. This performance confirms the potential of IrrigaPote as a science-based social technology, capable of integrating economic efficiency, environmental sustainability, and community autonomy. The economic results obtained in this study demonstrate that the IrrigaPote system is financially viable and technically adaptable to the conditions of family farming in Northeastern Pará. This finding aligns with [1], who highlight efficient water resource management as a central element of agricultural sustainability. As pointed out by [15], conventional irrigation methods present economic and environmental limitations, especially in contexts of social vulnerability, indicating that IrrigaPote seeks to overcome these challenges through low cost, operational simplicity, and rainwater reuse.

Considering that under conditions of global warming and the increasing frequency of droughts, researchers point out that the demand for innovative and inclusive irrigation solutions has been steadily rising [16]. In this context, IrrigaPote emerges as an efficient and accessible alternative, capable of maximizing productivity and reducing water losses in humid tropical regions. The system, based on the gradual release of water through ceramic pots, creates humid microzones that sustain high-density productive consortia, as documented by [17] and validated by [8] in the Amazonian context. Experiences in Santarém and Capitão Poço demonstrate its replicability and local adaptability, associated with the strengthening of food security and the economic resilience of rural families. Beyond its technical and financial performance, IrrigaPote also presents social and environmental relevance, aligning with the principles of circular economy and agroecology. By using accessible materials, local labor, and rainwater harvesting, the system reduces waste, reuses resources, and promotes productive autonomy. Thus, it constitutes a social innovation capable of reconciling economic efficiency with ecological sustainability, contributing to the strengthening of family farming in the Amazon.

Table 1. Materials used in the implementation of the IrrigaPote system in an AFS area of 1,440 m² with 'Tahiti' acid lime as the main crop.

ITEM	DISCRIMINATION	Unit	Qt.	Unit.	Total (R$)
	Clay pot (20L)	Pot	32	35.00	1,120.00
2.	PVC pipe	Meter	10	3.00	30.00
3.	PVC fittings	Single item	-	-	300.00
4.	Water tank (1000L)	Unit	1	400.00	400.00
5.	Water tank (2000L)	Unit	1	800.00	800.00
6.	Plastic hose	Meter	50	1.00	50.00
7.	Overflow-prevention float	Unit	60	6.00	360.00

8.	Fortlev Weldable Pipe	Unit	32	25.00	800.00
9.	Duramais Zinc Gutter, Smooth with Cup	Unit	4	165.00	660.00
10.	Fortlev Weldable Pipe 6mm, 6m length	Unit	1	170.00	170.00
11.	Vit Weldable Ball Valve 60 mm	Unit	1	45.00	45.00
12.	Weldable Reducer Bushing 60x25	Unit	1	7.50	7.50
13.	Fortlev Weldable Elbow 25 mm	Unit	2	1.50	3.00
14.	Fortlev Weldable Coupling 25 mm	Unit	28	1.50	42.00
15.	Fortlev Weldable Cap 25 mm	Unit	2	1.00	2.00
16.	Multi-purpose Braided Hose 3/8x3	Meter	9	6.00	54.00
17.	Durepoxi 100g, Pack of 12 – Loctite Henkel	Unit	7	10.00	70.00
	Threaded Clamp	Unit	32	2.50	80.00
	Mesh 4:1, 3m x 2m	Unit	1	110.00	110.00
	Fortlev Weldable T	Unit	21	1.50	31.50
	White Brick (support for water tank)	Unit	150	0.55	82.50
	Cement (for water tank base)	Unit	4	50.00	200.00
	Kimical	Unit	1	7.00	7.00
	C pipe 200 mm	Unit	2	800.00	1,600.00
	PVC Fortlev glue	Unit	1	15.00	15.00
	TOTAL				**7,039.50**

When analyzed based on a conventional structure, the estimates are presented in Tables 2, 3, and 4.

Table 2. Estimated production cost considering 1 ha.

Total production cost	Costs (R$.ha-1)				
	1st year	**2nd year**	**3rd year**	**4th year**	**5th year**
Inputs	4,6821.00	0.00	0.00	0.00	0.00
Crop management practices	318.00	500.00	500.00	500.00	500.00
Alternative cost	7,070.85	75.00	75.00	75.00	75.00
Total cost	54,209.85	575.00	575.00	575.00	575.00
Total (cost R$. cx^{-1})	0.00	0.55	0.55	0.55	0.55
Total revenue (R$. ha^{-1})	0.00	41,680.00	41,680.00	41,680.00	41,680.00
Profit (R$. ha^{-1})	-4,209.85	41,105.00	41,105.00	41,105.00	41,105.00

Table 3. Estimated revenue considering costs, cash flow, and value.

Year	Revenue	Costs	Cash Flow	Present Value (R$)
0	R$ -	R$ 54.209,85	-R$ 54,209.85	54,209.85
1	R$ 41,680.00	R$ 575.00	R$ 41,105.00	35,743.48
2	R$ 41,680.00	R$ 575.00	R$ 41,105.00	31,081.29
3	R$ 41,680.00	R$ 575.00	R$ 41,105.00	27,027.20
4	R$ 41,680.00	R$ 575.00	R$ 41,105.00	23,501.92
			Net Present Value - NPV (R$)	63,144.04
			Internal Rate Return - IRR (%)	65.79%
			Benefit-Cost Ratio – B/C (R$)	R$ 1.16

Table 4. Expected average gross revenue from the production of temporary and permanent crops.

Item	Crops	Harvest	Unit	Qt.	Value		Total
					Unit	Total	
01	Colony bean	1st year	Kg	274	250	685.00	685.00
02	Pumpkin	1st year	Kg	1920	1.30	2,496.00	2,496.00
03	Tomato	1st year	Kg	3200	3.00	9,600.00	9,600.00
04	Watermelon	1st year	Kg	1920	2.50	4,800.00	4,800.00
05	Black pepper	3rd year	Kg	432	18.00	7,776.00	7,776.00
Total 1st year							17,581.00
Total 2nd year							17,581.00
Total after 3rd year							25,357.00

The IrrigaPote system eliminates expenses related to pumping, electricity, and maintenance of pressurized irrigation lines [18], which normally account for 20–30% of the annual cost in conventional citrus farming. In addition, since the float keeps the pot always full, the system operates by capillarity, with minimal losses due to evaporation and percolation, raising water-use efficiency to above 90%.

Considering that annual crops provide complementary and faster income for farmers—especially when vegetables and legumes (such as arugula, kale, cowpea, pepper, tomato, pumpkin, watermelon, among others) are included—these short-cycle productive arrangements generate cash flow within the first months, well before citrus fruiting.

Thus, the payback period of the initial investment is reduced; the Net Present Value (NPV) increases; the Benefit-Cost Ratio (B/C) rises above 2.0, reaching levels typical of well-managed agroforestry systems; and the system becomes resilient to citrus price fluctuations. Therefore, it is emphasized that an additional annual income (R$ 12,000–18,000/ha) from short-cycle crops should be included.

Based on the following values:
- Annual citrus revenue: R$ 41,680
- Annual intercropping revenue: R$ 16,000 (adjustable; use 12–18 thousand depending on field conditions)
- Initial cost (inputs): R$ 38,000
- Annual maintenance: R$ 200 (floats/caps/checks)
- Discount rate: 10% per year

The results of the cash flow (Table 5) accumulated over the five-year period show significant differences between the conventional system and the system adopting the IrrigaPote technology. Both systems presented negative cash flow in the initial year due to implementation costs; however, throughout the evaluated period, continuous cash flow growth was observed in both scenarios, with linear behavior in the conventional system and more pronounced growth in the IrrigaPote system. By the end of the fifth year, the conventional system reached an accumulated cash flow of approximately R$ 153,000.00, while the IrrigaPote system achieved around R$ 313,000.00, representing nearly double the economic return. This superior performance is directly associated with the annual 10% revenue growth during the analyzed period, which can be interpreted as a reflection of greater productive stability provided by efficient water management, since IrrigaPote reduces losses from evaporation and deep percolation, ensuring greater water availability in the plant root zone. According to [20] and [21], high-efficiency irrigation technologies simultaneously contribute to increased agricultural productivity, reduced climate vulnerability, and improved farmer income, especially in family-based systems.

The maintenance of reduced and relatively constant operational costs over the five years reinforces the role of IrrigaPote as a climate change adaptation technology, since conventional irrigation systems tend to present higher energy consumption and increasing costs in scenarios of water scarcity. This characteristic is aligned with the principles of agroecology, which prioritize the efficient use of natural resources, the reduction of dependence on external inputs, and the strengthening of agroecosystem resilience ([22], [23]).From the perspective of the circular economy, the positive financial performance of IrrigaPote highlights the valorization of water resources as a productive asset, by promoting rational water use and minimizing waste. Circular economy applied to agriculture proposes the closing of resource cycles, reuse, and optimization of inputs, resulting in integrated environmental and economic benefits ([24], [25], [26], [27]). In this sense, the progressive increase in net profit

observed up to the fifth year reflects the internalization of these environmental benefits in the economic performance of the system, reinforcing its financial sustainability.

Table 5. Estimated annual cash flow of the IrrigaPote system.

Year	IrrigaPote Revenue (R$)	Annual Growth	Cost (R$)	Net Profit (R$)
1	57,680	—	200	57,480
2	63,448	+10%	200	63,248
3	69,792	+10%	200	69,592
4	76,771	+10%	200	76,571
5	84,448	+10%	200	84,248

In this context, Figure 3 (a) presents an illustration of how the system can accommodate different productive arrangements annually, enabling cumulative gains by the end of the 5th year of adoption. The effects resulting from water-use efficiency, productive resilience, and increasing economic returns can be observed.Thus, when analyzing Figure 3(b), it can be observed that the growth of the cash flow in the IrrigaPote system is not limited to the expansion of economic profitability compared to conventional management, but also reflects the incorporation of environmental benefits resulting from efficient water use, greater capacity to adapt to climate change, and the adoption of circular economy principles. These factors contribute to strengthening the productive and economic resilience of family-based agricultural systems, consolidating IrrigaPote as a technologically viable and environmentally sustainable alternative.
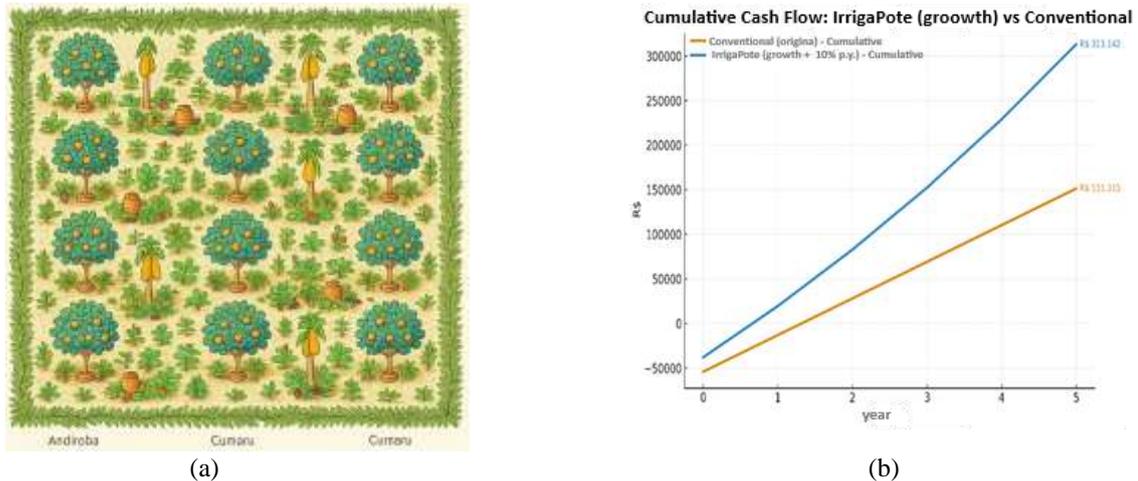

(a) (b)

Figure 3. Schematic design of the productive arrangement with IrrigaPote having citrus as the main crop (a), and the cash flow chart over five years when citrus reaches full production

IV. CONCLUSION

The economic analysis of the IrrigaPote system in the citrus hub of Capitão Poço, considering a five-year time horizon, highlights the consolidation of this social technology as an effective alternative for sustainable water use and the strengthening of family farming in Eastern Amazonia. Unlike conventional irrigation approaches, IrrigaPote combines operational simplicity, low maintenance costs, and high water-use efficiency, promoting a circular economy model that harnesses rainwater and substantially reduces energy consumption and evaporation losses. The results of the economic projection show that the system has affordable initial costs and minimal maintenance, with rapid investment recovery in approximately one year. The financial indicators obtained, such as a positive Net Present Value, an Internal Rate of Return above 60%, and a Benefit-Cost Ratio greater than 1 confirm the attractiveness of IrrigaPote compared to conventional irrigation systems. Furthermore, the structural flexibility of the technology allows for the simultaneous cultivation of short-cycle and perennial species, expanding productive diversification and ensuring income stability throughout the year.The adoption of IrrigaPote in the citrus hub of Capitão Poço, specifically in the Cristo Rei community of Vila Barro Vermelho, revealed indirect social and environmental benefits, such as increased farmer autonomy, appreciation of local knowledge, and reduced productive vulnerability during drought periods. Efficient use of water resources translates into economic gains, food security, and territorial sustainability, contributing to the consolidation of agroecological practices in the Amazonian context.

Given the results achieved, it is concluded that IrrigaPote represents a strategic technological solution for strengthening family farming, combining innovation, water sustainability, and financial viability. It is recommended to expand its adoption in public programs and rural development policies, aiming at disseminating this social agrotechnology across different productive and climatic contexts of the Amazon region.

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