REVISTA CONTRIBUCIONES A LAS CIENCIAS SOCIALES

Ba theory applied in clay pot irrigation for smallholder farmers in brazilian Eastern Amazon

Teoria do Ba aplicada na irrigação com potes de argila para pequenos agricultores na Amazônia Oriental brasileira

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REVISTA CONTRIBUCIONES A LAS CIENCIAS SOCIALES

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ABSTRACT
The objective of this work was to apply the theoretical "Ba" of knowledge management in the "Ba" space, having as its place of evolution the Technological Reference Unit (TRU) with clay pots that reuse rainwater to keep crops irrigated with clay pots on rural properties, in the Eastern Brazilian Amazon. Installed in 2016 in the community of Lavras in Santarém, being a place frequently visited by those interested in learning about the technology. The irrigation has low energy consumption, as the rainwater is distributed to the pots by gravitational force and it is possible to diversify agricultural crops, types of arrangements and different strategies to provide new financial gains for rural producers, due to the possibility of production in dry periods. The TRU is a space where research, teaching, extension and rural producers work in evolutionary partnership. The analysis of main components showed that farmers significantly expanded their knowledge, adding quality of life and improving family income, after installing IrrigaPote. The location is typical of a "Ba" space with sustainable collective learning, pointing out indicators in the social, environmental and economic scope, which can be replicated by rural family-based farmers interested in the efficient use of water, in irrigated crops anywhere in the world terrestrial.

Keywords: water management, tacit and explicit, sustainable agriculture, family farming.

RESUMO
O objetivo deste trabalho foi aplicar a teoria do "Ba" na gestão do conhecimento, tendo como local de evolução a Unidade de Referência Tecnológica (TRU) com potes de argila que reaproveitam a água da chuva para manter as lavouras irrigadas com potes em propriedades rurais, na Amazônia Oriental Brasileira. Instalado em 2016 na comunidade de Lavras em Santarém, sendo um local frequentemente visitado por interessados em conhecer a tecnologia. A irrigação tem baixo consumo de energia, pois a água da chuva é distribuída aos vasos pela força gravitacional e é possível diversificar culturas agrícolas, tipos de arranjos e diferentes estratégias para proporcionar novos ganhos financeiros aos produtores rurais, devido à possibilidade de produção em períodos secos. O TRU é um espaço onde a pesquisa, o ensino, a extensão e os produtores rurais trabalham em parceria evolutiva. A análise dos componentes principais mostrou que os agricultores ampliaram significativamente seus conhecimentos, agregando qualidade de vida e melhorando a renda familiar, após a instalação do IrrigaPote. A localização é um típico espaço "Ba" com aprendizagem coletiva sustentável, apontando indicadores no âmbito social, ambiental e econômico, que podem ser replicados por agricultores familiares rurais interessados no uso eficiente da água, em culturas irrigadas. em qualquer lugar do mundo terrestre.

Palavras-chave: gestão da água, tácito e explícito, agricultura sustentável, agricultura familiar.

1 INTRODUCTION

The irrigation technologies are instruments capable of solving problems such as water scarcity in the soil and meeting the water demand of plants. In global terms, forecasts point to increases in irrigated area in the coming decades, reaching 402 Mha by 2030, with 40 Mha in developing countries (Darko et al., 2017). The use of simple, low-cost, and easily applicable solutions is a strategy that generates social impacts and promotes improvements in the quality of life of farmers (Christofidis, 2013). Irrigation technology that uses clay pots has shown successful results under arid soils (Araya et al., 2011), using the same strategies of a simple and low-cost irrigation solution. This technology was developed in Brazil in a partnership initiative with Ethiopia (Martorano et al., 2018) and has shown successful results, supporting new decision-making strategies both in terms of saving water in arid regions, when compared to conventional irrigation systems, and adding value to farmers' annual income (Gebru et al., 2018).

The Embrapa Eastern Amazon team developed an innovative solution for the IrrigaPote project in western Pará that autonomously supplies the pots with rainwater (Martorano, 2020). The technology was evaluated as a sustainable business due to its strong social, economic, and environmental performance (Siqueira et al., 2018). The Technological Reference Unit (URT), installed on a rural family farm, became a popular destination for visits, field days, news articles, radio and television interviews, and social media posts about the IrrigaPote project, highlighting the environmental service provision potential of irrigated cultivation (Carlos et al., 2021). As a result, the URT became a center of knowledge sharing about clay pot irrigation (Carlos & Martorano, 2020).

In the context of knowledge management, we wanted to use theoretical bases for transforming knowledge into technological assets and products, where people apply the knowledge they have acquired in different contexts to promote changes (Agwu et al., 2022). From the perspective that physical, virtual, and mental places can provide transformative elements, where people identify, categorize, create, store, transfer, and, above all, share knowledge, it is possible to apply the concept of Ba (Nonaka, 1991). The Ba theory advocates that places of coexistence are sources of creativity and transformation, as individuals, the primary and primordial source of knowledge, are able to circulate and interact in these spaces to bring new benefits to organizations (Nonaka & Takeuchi, 1995, Moresi et al., 2022). This work aimed to apply the theoretical bases of knowledge management in the Ba space, having as its place of evolution the Technological Reference Unit (TRU) with clay pots that reuse rainwater to keep crops irrigated with clay pots on rural properties in the Eastern Brazilian Amazon.

2 MATERIALS AND METHODS

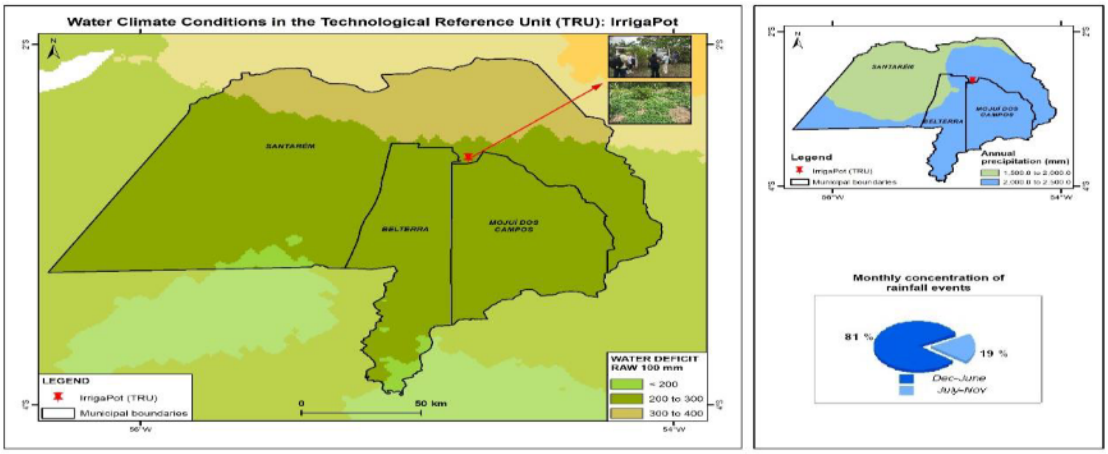
This paper evaluated the knowledge generated in the Technological Reference Unit (TRU) after seven years of implementation of the IrrigaPote project in the TRU in the family Based farmer area in the community of Lavras, in Santarém, in the eastern Brazilian Amazon. We structure this work by contextualizing the Ba theory, analyzing the knowledge generated and shared in the TRU. Explicit knowledge, in a form of sentences, texts and illustrations is used to make it easier for farmers to understand simple and low-cost irrigation technologies. We obtained important results by applying methods to obtain tacit knowledge, derived from shared individual perceptions, due to the proximal relationships established in the IrrigaPote space, since 2016, in the west of the state of Pará, in the Eastern Amazon.

After the implementation of the irrigation system through the IrrigaPote project, we applied different methods to identify changes in the actions carried out on the rural property as an indication of positive transformations in social, economic and environmental aspects. Conversation circles, mental maps and questionnaires with answers of multiple choices. The signing of the Free Consent Form reinforces that the field research followed ethical principles to obtain information from rural family-base farmers, where the TRU is operational.

The methodological assumptions of the “Ba” space were applied, considering that the TRU knowledge is shared between teaching, research, rural extension institutions, artisans and rural producers, professionals who integrate different federal institutions state and municipal bodies, non-governmental organizations (NGOs), farmers who live in the community of Lavras in Santarém, Pará.

In the region, 81% of the rainfall volume is concentrated in the period from December to June, and the remainder (19%) occurs erratically between July and November. The annual rainfall regime in the study area varies between 2,000 to 2,500 mm, but in surrounding areas, the annual rainfall can vary between 1,500 to 2,000 mm. The estimates of Water Balance were made using the method of Thornthwaite & Mather (1955). It is possible to observe that water deficit values vary between 200 and 300 mm, considering a readily available water (RAW) in the root zone of annual crops equal to 100 mm (Martorano et al., 2017) as observed in Figure 1.

Figure 1. Water supply and requirement for crops in IrrigaPot project



Source: Authors, (2023)

2.1 RESEARCH CONCEPTUAL FRAMEWORK

The research aimed at the development and adoption of technologies in agricultural sciences, knowledge is studied from different perspectives and approaches. Traditional knowledge, which farmers accumulate through daily practices in the field, becomes transferable to subsequent generations based on examples of successful results for specific agricultural crops (Wanderley, 2003). This knowledge is fundamentally precise and supported by experimental observations, enabling them to recognize and utilize available local resources (Altieri & Nicholls, 2008).

The relationship between humans and nature in rural areas helps express human knowledge based on adopted agricultural practices, integrating socio-environmental realities into the production of knowledge (Faria & Woortmann, 2009). The knowledge of farmers represents specific local knowledge that integrates a wide range of social, technical, and environmental factors. This knowledge operates within networks with specific inputs and outputs that contribute to the learning process (Stuiver et al., 2004).

Considering that the irrigation technology at the TRU has a high potential for replicability, records in the visitors' book were analyzed to identify the origin, number of family farmers, diversity of public and private institutions, and periodicity of visitors. Knowledge is an essential resource in the innovation process of agricultural irrigation technologies because it enables the production of food based on sustainability assumptions (Bloch, 2008). The management of this newly created knowledge involves identifying and facilitating the use of tacit knowledge, which is potentially useful when it becomes explicit (Moresi et al., 2022). However, sharing tacit knowledge requires individuals to also share their personal beliefs about the situation with other team members (Nonaka et al., 2002), and this process is extremely fragile.

Based on the Ba space theory (Nonaka et al., 2006), this study aims to identify processes capable of promoting the replicability of irrigation technology using clay pots with a water storage system utilizing rainwater supply in each region of interest. The model of dynamic knowledge conversions, which serves as a logical framework for this analysis, is discussed from the perspective that organizational knowledge creation is a dynamic and continuous interaction between tacit and explicit knowledge (Nonaka & Takeuchi, 2007). The four areas of Ba correspond to the four stages of the SECI Model, and each Ba supports a specific conversion process, illustrated in Figure 2. This positive feedback contributes to accelerating the knowledge creation process, enabling the successful implementation of the IrrigaPote project.

Figure 2. The types of Ba and knowledge conversion phases or SECI model

Source: Created by authors Adapted from Nonaka & Konno (1998).

2.2 TYPE OF DATA AND DATA COLLECTION

This study included all the farmers who participated in the IrrigaPote project in 2016 in the Lavras community. The primary data collection tool was a questionnaire, administered in the form of a participatory diagnostic. A personal interview was conducted in two phases: the first phase involved interviewing heads of households to analyze their perceptions of knowledge development before and after the implementation of this agro-technology, and the second phase involved interviewing family members to understand their perspectives on the knowledge created and the changes experienced by their parents who regularly assist their parents with tasks on the rural property.

2.3 DATA ANALYSIS

Multivariate analysis techniques were applied to evaluate the possible interrelationships between the variables and the corresponding observations, and to explain these variables in terms of their inherent dimensions, based on the analysis of main components, with 30 observations and eight variables, based on data obtained using the free choice target collage technique. After explaining the dynamics for obtaining the data and securing the participants' consent through the Free Consent Form. Thirty words were selected that summarized the evolution of knowledge in the "Ba" space regarding social, environmental, and economic aspects. Information that was already part of the tacit knowledge of each group was marked with an "X," indicating their knowledge before the implementation of the TRU, considering the Yes and no options.

To facilitate data analysis in the freely accessible SAS (Analytics & Solutions Software) tool, the variables were identified with lowercase letters and numbers. The exact sequence is as follows: (a) economy; (b) production cost; (c) production chain; (d) yield; (e) income; (f) profit; (g) productivity; (h) planning; (i) monitoring; (j) evaluation; (k) seasonality; (l) intercropping; (m) sustainability; (n) environmental service; (o) ecosystem service; (p) seasonality environment; (q) water reuse; (r) water footprint; (s) rainfall; (t) evaporation; (u) evapotranspiration; (v) thermal comfort; (w) climate change; (x) thermal gradient; (y) conservation; (z) preservation; (1) temperature; (2) species; (3) atmosphere; and (4) photosynthesis. Analyzes were carried out, represented by the Biplot graph, Cluster Analysis by the method of linking the mean with the Dendrogram graph and Correspondence Analysis, as an ordering method.

3 RESULTS

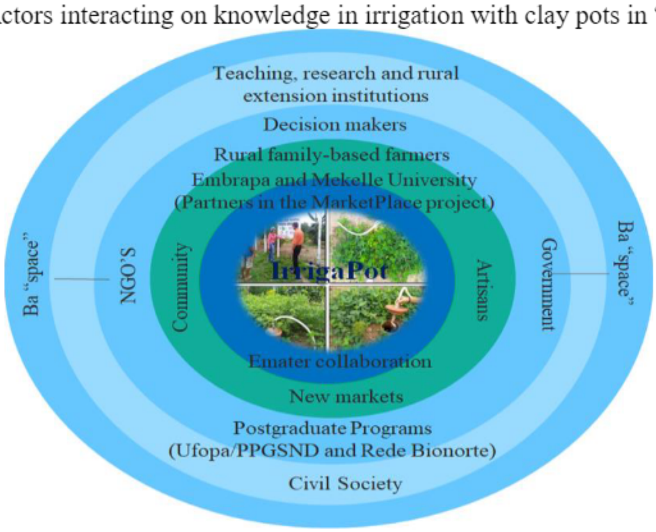
3.1 IDENTIFICATION OF KNOWLEDGE CREATED IN DIFFERENT ACTORS

In 2016, a multidisciplinary team of researchers from Brazil and Ethiopia combined knowledge from different fields, including natural sciences (physics, plant physiology, hydrology, and meteorology) and social sciences (economics and sociology), to develop a project aimed at addressing the shortcomings of rainfall irrigation systems used by smallholder farmers. This explicit knowledge culminated in the development of a field reference through experimentation, where farmers integrated tacit and explicit knowledge. Our results aligned with the spiral evolution of knowledge conversion and the self-transcending process, from the socialization process to internalization on the spiral model (SECI) proposed by Nonaka et al. (2000).

The technology still needs to be more widely adopted in the Lavras community to reach more farmers. As the technology spreads, the knowledge of these procedures becomes technical expertise internalized as individual tacit knowledge. According to Nonaka et al. (2002), knowledge is implicit in "Ba," where it is then acquired through one's own experience or reflections on the experiences of others.

Figure 3 shows the integrated actors involved (non-governmental organizations; EMBRAPA: Brazilian Agricultural Research Corporation; EMATER: Technical Assistance and Rural Extension Company) in the context of irrigation technology with IrrigaPote. It is possible to observe that the actors are presented in two main categories, identified by intellectual capital, indicating that each participant acquires knowledge with the consolidation of the project, expanding from the activities, experiences that multiply and interconnect over time and "Ba" space.

Figure 3. Actors interacting on knowledge in irrigation with clay pots in "Ba" space.



Source: Authors, (2023)

In terms of intellectual capital, the model encompasses the research and teaching institutions that participated in the project's development. This includes fundraising through an international grant, installation of the irrigation system with clay pots, maintenance, and dissemination of results in various communication channels, technical visits to review the system, training to promote the acquisition of new skills through training courses, and postgraduate research and projects. Farmers participated not only as beneficiaries of the technology but also as active contributors, sharing knowledge with other social actors. Members of research entities, higher, secondary, and elementary education institutions, government agencies, and non-governmental organizations (NGOs) are examples of actors who shared knowledge during visits to the TRU.

The second group encompasses financial and material resources, including all the stakeholders responsible for providing the necessary equipment for the technology, enabling its adoption and consolidation in rural family-based properties. The process commences with the identification of the artisan, followed by the acquisition of materials (e.g., buoys and connectors) and the installation of the system to deliver water through PVC pipes to the pots. This is succeeded by the installation of gutters to capture rainwater from the roof's base and the acquisition of seeds and seedlings to ensure the full utilization of the TRU area. The active participation of stakeholders is crucial in decision-making regarding the introduction of new agricultural crops, the care and maintenance of pots during cultivation practices, the identification of adjustments to the production calendar, and the exploration of new productive opportunities.

The project fostered stronger relationships and generated knowledge that disseminated in various ways, making the technology accessible to society. The interactions among stakeholders are constantly evolving and dynamic, reinforcing the interconnectedness of the project. The concept of the "Ba" space predates the IrrigaPote project (Berhe et al., 2015; Martorano et al., 2018). Knowledge creation occurs when entities (individuals, groups, organizations) transcend the boundary between an old and a new evolutionary state to acquire new knowledge. This transition necessitates the establishment of novel conceptual frameworks and interaction structures, which provide constraints guiding entities through knowledge creation cycles. Consequently, entities coexist with their environment, subject to both internal and external influences, and the entities involved (Silva et al., 2016).

The rural property has become a regional benchmark, as local farmers recognize the couple who have implemented irrigation technology using clay pots on their property (Carlos & Martorano, 2020). The adoption of knowledge following the system's installation has spurred changes, primarily due to the frequent visits to the TRU, reinforcing the notion that the appropriation of knowledge derived from a successful technology yields readily discernible social benefits.

The development and/or adoption of a particular technology by specific communities reflects its potential to address specific social needs. Notably, technological advancements and social changes have benefited farmers by enhancing pre-existing cultural practices in manual plant watering, aiding decision-making, and guiding farmers in new directions capable of transforming the very essence of pre-existing social norms.

3.2 IDENTIFYING THE PRESENCE OF "BA" SPACE IN CLAY POT IRRIGATION AND KNOWLEDGE TRANSFORMATION

Organizations and inter-organizational networks cannot create knowledge themselves, but they can foster positive and constructive relationships between actors and their environment. Consequently, the exchange of data, information, opinions, collaboration, and mobilization on a project driven by the need to address the unknown converge to form an effective "Ba" space for knowledge expansion within organizations (Teixeira, 2019). The process also involves the interdependence between agents and the environment's offerings and possibilities, which sets limits on knowledge creation as actors engage with their environment and begin to synthesize tacit and explicit knowledge within a given space. In these spaces, knowledge and experiences can be shared, solidifying the phases of socialization, externalization, combination, and internalization described below. The "space" dedicated to the knowledge socialization phase represents the physical and virtual settings where individuals share feelings, emotions, experiences, and mental models (Nonaka & Konno, 1998).

The project team in Brazil actively pursued the automation of the low-cost irrigation process. During the manufacturing of clay pots by artisans from the Icoaraci Center, the entire pottery process was meticulously documented through videos and photographs. Additionally, equipment for monitoring parameters such as soil and air temperature and relative air humidity was procured. A Demonstration Unit (DU) was installed at Embrapa Eastern Amazon, and a lecture was delivered during the 39th Agriculture and Livestock Fair in Santarém to showcase the low-cost technology for efficient water utilization. The participants expressed keen interest in installing new units of the IrrigaPote project, having gained valuable insights into the utilization of rainwater for agricultural purposes during the dry months from August to November

(Martorano, 2020). Table 1 provides detailed evidence of the "Ba" space, highlighting the successful integration of explicit and tacit knowledge.

Table 1 Evidences of "Ba" space

Tacit and Tacit	Tacit and Explicit	Explicit and Explicit	Explicit and Tacit
Origination	Dialoging	Systematizing	Exercising
Identification of a recurring problem in small producers	Training of reference unit producers	Reports, photographic records and videos	Testimonials from farmers and their families in the reference field
Researchers and community meetings	Composition of a work team from different countries	Technology diffusion in academic forums and fairs	Experience of researchers working with technology
Creating local partnerships for the project	Field days and field trips on the property.	Scientific publications	
Socialization between multiple knowledge, contexts and perceptions		Technical visits and experimental fields	
		Technology specifications	

Source: Authors, (2023)

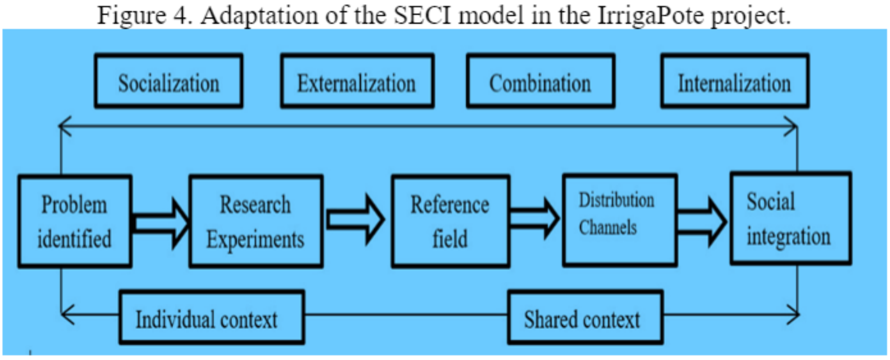
It is crucial to highlight the visibility the project has brought to the community following the implementation of the TRU in Santarém, which has become a benchmark for practical classes in various academic disciplines, field days for organic producers, foreign and national visitors, and researchers. The dissemination of results at national and international levels reinforces that these "Ba" spaces align with the Sustainable Development Goals (SDGs).

The implementation of new technology facilitated the acquisition of valuable knowledge among farmers regarding the water replacement system for plants (Carlos & Martorano, 2022). This knowledge appropriation can be attributed to the spiral evolution of knowledge conversion (tacit and explicit) within the self-transcending process. The spiral model, known as the SECI Model, encompasses the transition from socialization to internalization (Nonaka & Toyama, 2003).

It is crucial to highlight that the knowledge conversion phases unfold within a continuous spiral of knowledge creation. This dynamic process involves the interplay between tacit and explicit knowledge, amplified through four distinct conversion modes. As the spiral expands in scope, it delves into ontological dimensions (CEN, 2004).

The internalization phase is still in its nascent stages, with multiple stakeholders expressing interest. However, the technology is undergoing testing with new pots to boost adoption rates, enabling more farmers to gain hands-on experience and internalize the knowledge associated with its application. Consequently, the knowledge acquired through this experience transforms into technical expertise, internalized as individual tacit knowledge. Organizations can foster knowledge creation by facilitating interactions between explicit and tacit knowledge across diverse knowledge domains (Lima et al., 2010). Our study presents a schematic representation (Figure 4) demonstrating the feasibility of adapting the knowledge creation and transformation model "Ba" to the phases of the IrrigaPote system.

Figure 4. Adaptation of the SECI model in the IrrigaPote project.



Source: Created by the authors (2023) adapted from Nonaka & Takeuchi (1995) and Nonaka & Toyama (2003)

As asserted by Nonaka & Konno (1998), the internalization of knowledge is driven by individuals' actions and practical applications. For instance, internalization occurs when individuals apply the knowledge gained from reading technical manuals provided by equipment manufacturers or attending training courses related to the acquired equipment and materials. This knowledge solidifies when put into practice during testing, repair, or safety procedures. This theory underscores the potential for creating knowledge in a more structured and comprehensive manner.

In this way, it is possible to verify the existence of “Ba” spaces within the TRU intended for free communication between visitors, such as, for example, animal breeding pens, food service areas, Balconies, experimental fields, agroforestry systems (SAF) and “spaces” around the pots that always experience a flux of people. The existence of these “spaces” is not always perceived as an environment of free communication between them. During moments of socializing, the knowledge that is shared is not limited to issues related to irrigation technology, since it is assumed that everyone is more comfortable, so that sharing is spontaneous to the flow of knowledge.

The presence of "Ba" spaces within the TRU, such as animal breeding pens, food service areas, balconies, experimental fields, agroforestry systems (SAF), and open areas around the pots, facilitates informal interactions among visitors. These spaces, however, are not always perceived as conducive to open communication. Nonetheless, these informal interactions play a crucial role in the dissemination of knowledge within the TRU, as they encourage farmers and visitors to engage in spontaneous exchanges of information that extend beyond irrigation technology.

Rural producers are perceived by other participants in the production chain as requiring updated knowledge, skills, and competencies to meet evolving market demands characterized by increasingly stringent standards, quality requirements, and product innovation expectations. They become integrated agents within the production chain, engaged in continuous learning and knowledge acquisition from diverse sources and requirements. This approach aims to enhance competitiveness across the chain's various links while mitigating management risks (Binotto et al., 2013). Consequently, one of the key challenges lies in effectively managing information and making informed decisions in this uncertain environment. For this, it is necessary not only to process information, but also to create information and knowledge Nonaka & Takeuchi, 1995).

The knowledge combination phase embodies the systematization of concepts within a knowledge system, as new concepts are derived from explicit knowledge during the preceding phases. In light of this, we endeavored to determine whether there exists a systematization of these concepts within a knowledge system. However, not all concepts are codified. Considering the inherent tendency to systematize information, the utilization of a knowledge system proves invaluable, as it facilitates the identification of existing knowledge within organizations. Corrêa (2018) outline several methods that contribute to the location of knowledge within an organization.

The IrrigaPote project lacks the financial resources for dedicated training, and this deficiency could hinder learning and the adoption of new practices, as training serves as a crucial tool for the development of new and existing knowledge. Moreover, the absence of training in the use of new technologies can result in inefficiencies in task execution and service delivery, leading to an excessive expenditure of time.

It is noteworthy that knowledge can be internalized by individuals through the process of undertaking new tasks or activities, a concept defined as "learning by doing" by Nonaka & Takeuchi (2007). In order to enhance the degree of learning internalization, it is recommended to increase the involvement of local producers in the development of new activities within the IrrigaPote project.

The socialization phase encompasses the identification of problems, planning activities, testing of applied technologies, and conducting experiments to demonstrate their feasibility. It is recognized as the phase where tacit knowledge is captured among the involved actors.

The externalization phase marks the creation of a reference field where interactions between all supply chain actors foster awareness of the project and facilitate interactions based on perceptions about the customer-evaluated system. The creation of new concepts using analogies, a slight pattern of agreement emerged among the suggestions received from TRU visitors, indicating that the information gathered during meetings is, whenever possible, translated into new concepts through analogies, metaphors, and models.

According to Binotto et al. (2013), externalization refers to the transformation of tacit knowledge into explicit knowledge, often employing language, metaphors, and analogies. Our findings indicate that all actors utilize mechanisms to express their understanding and interpretations of the observed technology. Regarding the availability of "spaces" for showcasing ideas, opinions, and suggestions, producers expressed a favorable attitude towards these "spaces," as evidenced by a significant degree of agreement in the average response trend observed during the dynamics.

Conversely, producers begin to internalize the externalized knowledge, and the knowledge accumulated in the previously discussed "Ba" space is utilized by family members and fellow producers. Regarding the socialization of knowledge through manuals and documents, the responses unanimously indicated a high degree of agreement that the use of documents and manuals facilitates knowledge sharing among actors directly involved in the IrrigaPote project.

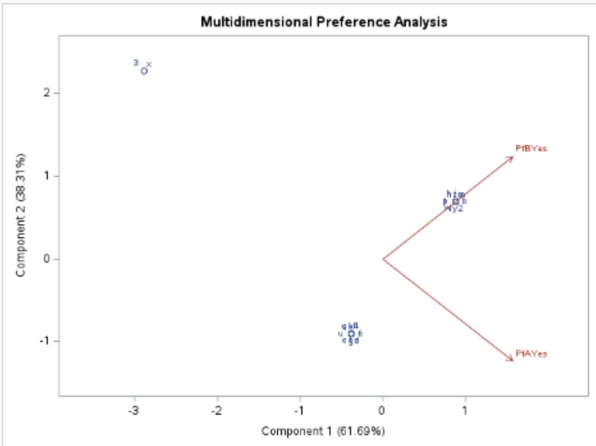
3.3 PRODUCERS' PERCEPTION ANALYSIS OF THE KNOWLEDGE DOMAIN GENERATED BEFORE AND AFTER THE IRRIGAPOTE PROJECT

The principal component analysis (PCA) illustrates how each group of variables contributes to the overall variance in the data. In the survey, the first component accounts for

61.69% of the variance and influences the perceived knowledge acquired after the IrrigaPote project, as indicated by the first quadrant. Consequently, from the children's perspective, there has been an enhancement in the mastery of concepts such as planning, monitoring, seasonal variability, production costs, climate change, conservation, and species identification.

The second component is primarily the impact of the knowledge generated by the IrrigaPote project on the producers' perspective, depicted in the second quadrant with a variation of 38.31%. The producers observed a progression in their comprehension of concepts such as evapotranspiration, evaporation, productivity, yield, profit, water replacement, water footprint, crop consortium, sustainability, and ecosystems, as illustrated in Figure 5. This setting serves as a prototypical "Ba" space for sustainable collective learning, as the knowledge contained in the 30 words to which they responded "Yes" are powerful indicators in the social, environmental, and economic domains, with potential for replicability of efficient water usage in rural agriculture families worldwide.

Figure 5. Biplot representing a multidimensional analysis with perceptions of the Knowledge acquired in a view of producers and their parents after the IrrigaPote project



Source: Authors, (2023)

4 DISCUSSION

The influence of word-of-mouth, publications, and social media has affirmed the technology's ability to maintain agricultural production by replenishing water to plants during droughts, further supporting the positive impacts of this technology. The technology proposed by the IrrigaPote project exhibits high potential for replicability and also reinforces the expansion of knowledge dissemination about sustainable practices, making it suitable for application in other areas of the Brazilian territory Siqueira et al. (2018).

Our findings confirm that the continuous presence of researchers, educators, extension agents, students, visitors from various nationalities, farmers, and communication professionals played a pivotal role in expanding knowledge in a multifaceted manner for all residents of the rural property using IrrigaPote. While research conducted by Florentino et al. (2019) has demonstrated the intricate and challenging dynamics of ceramic production in Pará, the methodology developed in their study also emphasized the potential of utilizing clay artifacts as an engaging ethod to integrate diverse forms of knowledge, each with its unique characteristics, as the foundation for the knowledge base of Amazonian residents.

Several factors have potentially contributed to the establishment and growth of the ceramic industry in the Amazon region: (a) the abundance of clay raw material deposits, (b) proximity to the primary consumer center and its connection to the border, and (c) a large supply of unskilled labor compensated by low wages (Florentino et al., 2019; D'Antona et al., 2020). Driven by environmental concerns and global pressure, the judicial system has stepped up efforts to safeguard water and forest resources (Nascimento, 2012; Lewandowski et al., 2018), aiming to increase access to sustainable technologies like irrigation. Our research demonstrates IrrigaPote's capacity to generate long-term positive externalities, such as the knowledge accumulation observed in the "Ba" space throughout this study.

The technology's simplicity and low cost, coupled with its alignment with sustainability indicators in the economic, social, and environmental spheres, make it highly adaptable. In alignment with the 17 Sustainable Development Goals, we observed that the system adheres to SDG 06 (Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), particularly considering the potential for increased severity of droughts in many regions of the world under climate change scenarios. Additionally, the technology aligns with SDG 17 (Partnerships for the Goals) due to its ability to foster collaboration among educational, research, extension institutions, and rural producers.

The system's high replicability extends to landscaping areas and educational gardens across various regions, with the potential for international scalability. This scalability can help reduce the vulnerability of populations that face food insecurity during dry periods due to a lack of simple and affordable irrigation technology. The IrrigaPote project has attracted potential users, primarily family-based farmers who are part of the organic producer networks in the municipalities of Santarém, Belterra, and Mojui dos Campos, as well as international visitors.

5 CONCLUSIONS

The study demonstrated that the TRU (Territorial Unit of Research) is indeed a center for advancing knowledge on the efficient use of water in crops irrigated with clay pots. This space in the URT (Urban-Rural Transition) extended beyond the physical dimension, as the principal component analysis revealed a significant expansion of farmers' knowledge, with positive impacts on quality of life, rural family income, and environmental quality following the implementation of the IrrigaPote project.

We identified the phases of the SECI model that corroborate the advancement of knowledge on rural properties following the project's implementation. The challenge of the technology lies in its replicability, which could serve as a promotion strategy in payment policies for environmental services, as the TRU clearly demonstrates indicators in provision, regulation, support, and culture. The adoption of the technology provides a low-cost irrigation solution for family-based producers, where water replacement occurs mechanically through the reuse of rainwater stored in water tanks, ensuring that the pots remain full and enabling plants to maintain their water supply during periods of soil moisture deficits.

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