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RESEARCH ARTICLE

A serious game to design integrated crop-livestock system and facilitate change in mindset toward system thinking

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Abstract

In integrated crop-livestock systems (ICLS), crops and animals interact in space-time, generating synergistic properties. ICLS design and implementation are more complex than specialized systems design due to their multiple interactions. Hence, appropriate and innovative methods and tools are required to facilitate design of sustainable ICLS systems. We created a serious game (named SIPA game) as part of a thematic workshop (Farm Coaching) in which gaming fosters participants to attempt ICLS design strategies and experience farm-performance-related consequences. The game was built to provide experiential learning, as the farmers assume the role of farm designers. Besides, researchers and advisors act as mediators of the final scenarios, contributing to reflections on the concepts mobilized and the related technical challenges. We ran four workshops with 90 players in southern Brazil and interviewed 12 ICLS farmers to evaluate their perceptions. The interviews showed that the SIPA game allowed farmers to associate what they had learned in Farm Coaching with their practical experience. The SIPA game encouraged farmers to rethink their performance criteria, shifting from a focus on each component (either crops or livestock) to focusing on the whole system integrated. The game allowed analyzing contrasting scenarios according to their decisions on the groups. Regarding the farmers' perceptions of peer participants, they indicated crop or livestock backgrounds as an important point of debate. Overall, the game served as a platform for exchanging knowledge and perspectives on ICLS farm design among farmers, researchers, and advisors. Newer versions and scale-up of the game to reach many farmers are expected to be developed, as the game seems to be a promising learning tool for inspiring the adoption of ICLS. The SIPA game is the first tool specific to ICLS farm design that employs system thinking and budget planning associated with temporal soil space use.

Keywords Participative approach · Learning experience · Crop rotation · Land use · Farm model · Scenario conception

1 Introduction

Integrated crop-livestock systems (ICLS) are recognized as an efficient way to improve the sustainability of farming systems by complementarities and synergism provided from crop and livestock, including functional diversity, nutrient recycling, closing the loop of energy cycles, the efficiency of resources usage, and enhancement of ecosystem services (Bonaudo et al. 2014; Garrett et al. 2020). Carvalho et al. (2010) highlighted that an essential aspect of integrated systems is a precise and deliberate purpose of integration and a holistic perspective besides simple crop rotation or income diversification. Successful integration improves the synergistic relationships among components (i.e., the whole is greater than the sum of its parts) and results in enhanced social (including community), economic, and environmental sustainability, in addition to improving the livelihoods of farmers (FAO 2010).

To achieve the synergistic effects from ICLS, it is necessary switch from specialized systems and explore how integration will be established, taking sustainable transitions into account. ICLS designs are more complex than specialized systems owing to the multiple interactions of their

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components; hence, appropriate methods and tools are required to facilitate learning, reflections, testing multiple combinations, and assessing contrasting scenarios (Moraine et al. 2014). Furthermore, there is a paucity in methodologies that enable design learning, mindset changing, and provide access to land-use decision-making (Speelman et al. 2014). In this regard, interactive formats as games can help to improve co-designing (Voinov et al. 2016), and enable farmers to take time off their daily routine for a moment of reflection and planning. In this sense, role-playing games, in which players take another role than the one they have in real lives (i.e., a student playing with the role of farmer), might have better long-term outcomes than just watching a simulation, as this kind of gaming provides a safe environment in which the players can be the protagonists, allowing for exploration with a balance between embeddedness and distance from the situation (Berthet et al. 2016).

Duru et al. (2015) identified the need to develop learning-oriented tools to create a language shared among researchers, extension workers, farmers, and other stakeholders. The authors emphasize the importance of boundary objects such as board games, cards, cognitive or geographic maps, and computational models to assist in simulations of the spatiotemporal distributions of crops, livestock, and semi-natural habitats. Overall, the use of boundary objects can stimulate learning, negotiation, and collaboration necessary in the implementation of new agricultural system concepts (Klerkx et al. 2012) such as ICLS.

Several serious games have previously been proposed as ICLS learning tools (Table 1). One of the most recent is SEGAE, an online game representing a dairy-oriented ICLS in a European production context (Jouan et al. 2020). The game was tested with students with specialized training and was successful in making them acquire interdisciplinary knowledge. Sylvopast game and another role-playing game (no named) have the forestry component integrated and were both analyzed based on land-use decisions from a group of farmers (Etienne 2003; Salvini et al. 2016). Dynamix explores ICLS at the regional level via exchanges among farms (Ryschawy et al. 2018). The game explores the challenge of establishing trade relationships, including logistical factors. Forage Rummy was conceived to be used at the farm level by simulating year-round forage crop production and animal feeding requirements (Martin et al. 2011). Despite the diverse functionality of each of these existing games, there is still a lack in the literature of tools that simplify the complexity of ICLS to favor learning centered around system thinking and planning. A tool to engage participants in a learning experience promoting mindset change would be important to encourage farmers in transitions toward sustainable ICLS.

Considering the importance of learning experience and the lack of a serious game specific to ICLS farm design, there is a need to develop a serious game, in which farmers experience

Table 1 Examples of serious games that address integrated crop–livestock systems. The components of the integrated system that are directly addressed in each game and the scale of use are presented as game objectives.

Serious game	Source	ICLS components	Target audience	Scale of use	Goal
SEGAE	Jouan et al. (2020)	Soil, dairy cattle, forest, and crops	Students	Farm-level online simulation	Assesses impacts of farming practices on indicators related to sustainability
Sylvopast	Etienne (2003)	Forest, grass, and sheep	Farmers	Landscape level (between livestock and forest farmers from a set region)	Supports the negotiation process during the establishment of a silvopastoral management plan
Role-playing game	Salvini et al. (2016)	Forest, coffee, and beef and dairy cattle	Farmers	Farm-level simulated scenarios	Explores the consequences of land-use decisions on assets
Dynamix	Ryschawy et al. (2018)	Feed and manure	Students and farmers	Landscape level (integration among farmers in a set region)	Designs technical and organizational scenarios for establishing trade relationships (buying/selling) among farmers
Forage Rummy	Martin et al. (2011)	Beef and dairy cattle, and crops	Students and farmers	Farm-level real data simulation	Engages farmers and extension services to be the main players in livestock system design and evaluation

system thinking and planning by coupling business budget and temporal resource allocation (Figure 1), Accordingly, the objectives of this study were (i) to develop a serious game as a tool for co-design profitable ICLS that exploit the synergies between livestock and crops and encouraging a broader discussion on ICLS sustainability beyond budget, and (ii) to engage participants in a learning experience centered around system thinking and planning to promote changing practices toward ICLS adoption.

In this article, we first present the SIPA game and its advancement through the Farm Coaching workshop editions—where the game was applied (Section 2). Then, we show game session outputs, and, through semi-structured interviews, we analyze farmers' perceptions of their experience in gaming (Section 3). We also discuss the potential and limits of the SIPA game as a simple tool for addressing the complexity of ICLS and inspiring change in mindset toward system thinking.

2 Material and methods

2.1 Overview of Farm Coaching

ICLS have been adopted in Brazil, especially in the recent years (Garrett et al. 2020). However, it is still challenging because designing such systems involves dealing with barriers beyond the technical dimensions of ICLS. In this context, the SIA (Serviço de Inteligência em Agronegócios), an advising company in Brazilian agribusiness, together with ICLS researchers from public universities belonging to Aliança SIPA (ICLS Alliance), developed a workshop for actors involved in ICLS design. The workshop was named Farm Coaching and had the objectives of supporting the participants' mindset changing from specialized toward ICLS and dealing with psychological barriers to ICLS adoption. To achieve these objectives, it was conceived with a blend of technical (carried by advisors and researchers) and personal (carried by a psychologist) approaches. The workshop consisted of four steps, and in the third step, a serious game session was held to provide a practical dimension to the content presented in the previous steps. Consequently, a game was designed specifically for this workshop and was named the SIPA game—SIPA is the acronym of ICLS in Portuguese.

Four Farm Coaching workshops were conducted between 2017 and 2019. Additional information on the whole initiative in which the game sessions are placed is provided in a report by Moojen et al. (2022). Three workshop editions were held in Porto Alegre, the capital of Rio Grande do Sul, Brazil, and one in Cascavel, a city located in western Paraná, Brazil. A total of 61 farmers and 29 other actors (three students, six project managers, 15 advisors, three farm managers, and two sales representatives) attended the workshops (Table 2). Each edition of the workshop included approximately 22 participants, divided into four groups comprising five to six participants. The resulting 16 groups from the four sessions were named alphabetically (Table 2). All groups managed to complete the triennial planning assembly within the time limit of approximately 3 h.

2.2 Development of the SIPA game

The SIPA game was based on a hypothetical farm located in southern Brazil. The initial scenario represented a typical farm profile, where beef cattle and crops were produced but not integrated, with most of the annual budget allocated for crops. The participants were invited to assume the role of advisors and co-design a 3-year land-use plan. The players were given three resources: (i) game rules, (ii) a model, and (iii) a board game.

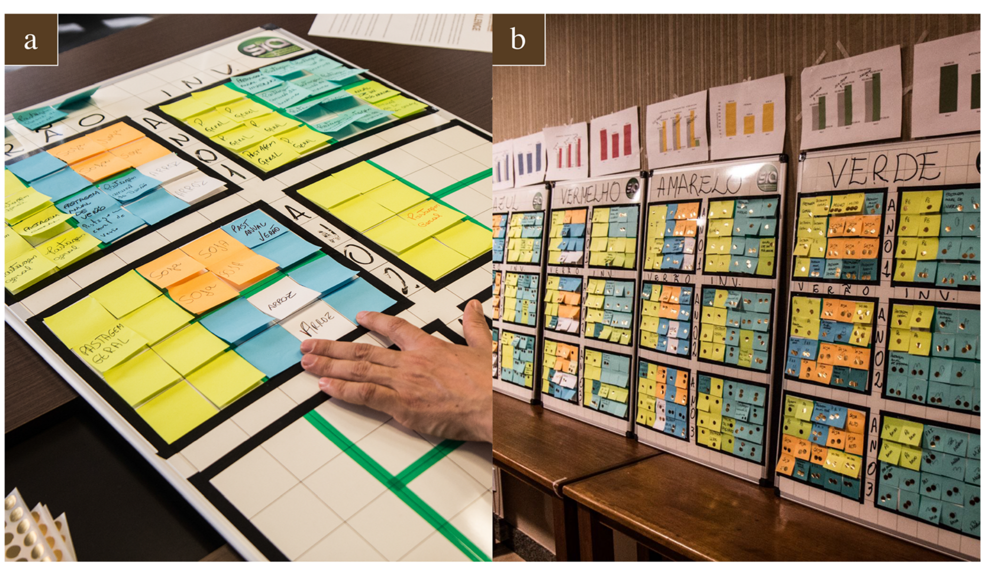

Fig. 1 **a** Land-use planning being represented in a board. **b** Scenarios of ICLS. Photo credit: Tom Peres.

Table 2 Game versions applied in each Farm Coaching edition. Three versions were developed and customized according to location, local crop, and relief division. Each edition had four groups; they are named alphabetically, as indicated at the bottom of the table. Porto Alegre is the capital of Rio Grande do Sul State, and Cascavel is located in Paraná State (both states are in the southern region of Brazil).

	Farm Coaching edition			
	1st	2nd	3rd	4th
Year	2017	2018	2019	2019
Location	Porto Alegre	Porto Alegre	Cascavel	Porto Alegre
Participants	22	20	24	24
Farmers	17	12	19	13
Game version	1	2	3	3.1
Local crop	Rice	Rice	Beans	Rice
Geographic relief	Uplands × lowlands	Uplands × lowlands	Arable × sloping lands	Uplands × lowlands
Groups	A B C D	E F G H	I J K L	M N O P

The cash crops chosen for the game sessions corresponded to those mainly cultivated in southern Brazil. Soybeans (11,881,000 ha), corn (3,696,000 ha), wheat (1,839,000 ha), rice (1,106,800 ha), and beans (511,000 ha) were the main crops harvested in the 2018/2019 harvest (CONAB, 2020). As 90% of the rice cultivation area is located in the Rio Grande do Sul State and 77% of the bean cultivation area in Paraná State, both were chosen as local crops (Table 2). Additionally, the geographic relief division was customized to the region in which the workshop was held (Table 2). In the Porto Alegre editions of the game, the division was between uplands and lowlands. The lowlands represented the traditional land use of paddy fields with intensive rice monocropping based on intensive soil tillage and fallow periods between rice crops (Martins et al. 2017). In the Paraná edition, division was between arable and sloping lands. Sloping lands makes mechanization difficult but are suitable to livestock production (Table 2).

2.2.1 Boundary objects in the game

Star and Griesemer (1989) defined boundary objects as "objects which are both plastics enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites." The use of manipulated boundary objects can be: material objects - as cards to represent designs - and computer objects - as models to evaluate them (Martin 2015). In the SIPA game, two boundary objects were included: (i) a model and (ii) a game board.

i) Model mechanism that integrates land use and investment level decisions

We created a model in Microsoft Excel® to integrate land use and the level of direct costs (budget allocation and livestock versus forage budget). The model has three tabs, the first tab is where the fixed parameters following parameters are inserted: the cost, income, and stoking capacity (animal units per hectare − just for pastures) for each of the crop or pasture options at each of the three investment levels (low, medium, and high). The advisors provided the model parameters, namely: direct costs, income, and the stocking capacity of pastures, based on their current experience in the region (Table 3). The proportions between the level of investment and the expected results were maintained. The values were rounded to facilitate discussion.

On the second tab of the model, it is where players make land use and investment choices; they experience six different responses: they may have cash and stocking capacity surplus, lack or be adequate. On this tab, each choice had conditioning formulas to the data from the first tab corresponding to the option and investment level and multiplied the number of hectares chosen. Automatically, financial budget and

Table 3 Parameters by crop/pasture option and level of investment. Exchange rate used: 1 $ (US dollar) = 4 R$ (Brazilian reais), January 2020; stocking capacity occurs only in pasture options. *AU*, animal unit (450 kg live weight); *PTP*, perennial tropical pasture; *ATP*, annual tropical pasture; *tPAR*, temperate pasture after rice; *AtP*, annual temperate pasture.

		Direct costs ($/ha)			Income ($/ha)			Stocking capacity (AU/ha)		
Level of investment		Low	Medium	High	Low	Medium	High	Low	Medium	High
Summer options	Soybeans	375	500	750	469	650	975	0	0	0
	Corn	250	375	500	325	500	675	0	0	0
	Beans	350	625	950	500	825	1275	0	0	0
	PTP	25	150	250	50	300	700	1.2	3.5	5
	ATP	100	200	300	150	394	650	2	3.5	5
	Rice	1000	1250	1500	1100	1437	1775	0	0	0
Winter options	tPAR	112	187	262	137	287	462	0.85	1.8	2.5
	AtP	75	150	225	131	275	450	0.85	1.8	2.5
	Native pasture	0	12.5	25	25	62	100	0.5	1	1.5
	Wheat	250	1500	500	300	469	650	0	0	0
	Cover crop	25	50	75	0	0	0	0	0	0

livestock versus forage budget were calculated. In each situation of lack or surplus, players have three strategies to choose from or combine (Figure 2). For example, if a group choose to increase the area and investment in a perennial pasture, they were likely to have an excess of stocking capacity resulting in a need to buy more animals. If they choose this strategy not having enough money, they were required to choose one of the following strategies: decrease pasture level of investment (i.e., $ by hectare), decrease pasture area (i.e., hectares), or choose pastures with lower stocking capacity. Finally, there is a third tab with the main outputs of the model presented as graphs for analysis between years: financial budget, gross revenue, gross costs, gross margin (total and per hectare), a total of animals purchased, and gross margin considering the herd increase. The last output parameter is necessary to compare scenarios where there is an increase of herd by purchasing animals, and part of the money becomes immobilized. The value of animals purchased is added to the average margin in this parameter. Without this parameter, it would induce to avoid the purchasing of animals as there would be no return on margin per hectare.

ii) Material for representing ICLS in space-time

A game board was designed to represent land use (Figure 3). It could be filled freely by the participants, as they were considered the designers. The groups were supported by researchers and SIA advisors that comprised a "support team" responsible for assistance with solving questions during the game. The primary function of the game board was to present the results of each group in space (crop rotations and between-relief divisions) and time (two periods in a year and over three years). Thus, it allowed a visual comparison of the different strategies adopted by the groups.

2.3 Game session

Each game session began with an explanation of the game (approximately 30 min). Then, the participants were divided into small groups to simultaneously co-design ICLS. The participants in the groups were chosen to ensure similar combinations of occupations (all groups contained farmers and other actors), ages, sex, and relatives (e.g., when siblings participated) in all groups to enhance debate during the co-design process. All groups received the abovementioned boundary objects and were allowed 3–4 h to play. In the game session, advisors facilitated several group interactions but avoided direct interference in their decisions. Finally, players presented their ICLS farm-design scenarios. Then, the advisors and researchers facilitated a discussion of each scenario and between scenarios (approximately 1 h). This broader discussion brought an overview of the outputs and the considerations of the choices made in the game, not only on the budget, but also focused on other aspects of sustainability (e.g., environmental impact of the crop rotations; social impact on farmers in relation to speed of change between years).

2.3.1 Game rules

The rules were conceived based on the knowledge of advisors and researchers derived from actual farm cases in southern Brazil. All the proposed rules were tested in the model prior

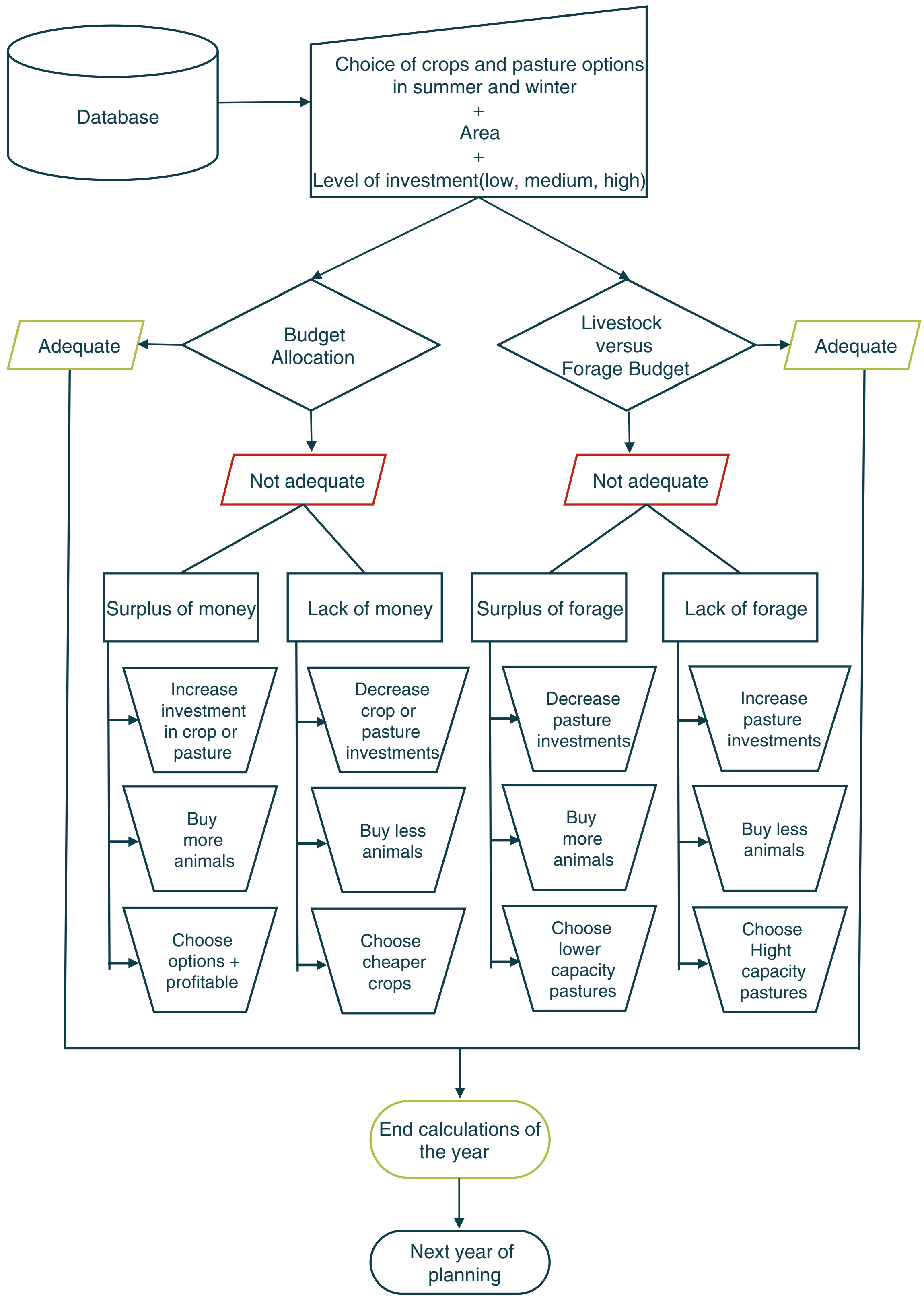

Fig. 2 Flow diagram of the model used in the game. The quadrilateral on the top indicates the main action of the players; this results in 2 main responses (diamonds) related to money and stocking capacity of the pastures; when results are not adequate, players can choose three isolated strategies (trapezoid) or a combination of strategies. The end of calculations is when both money and stocking capacity do not lack or have surplus.

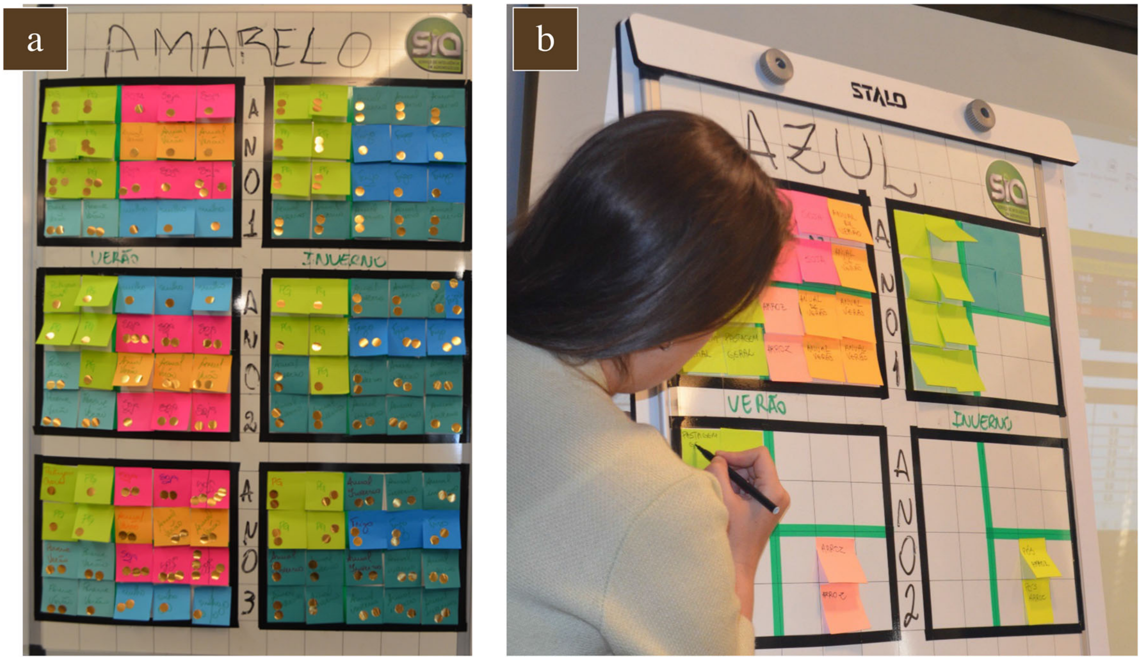

Fig. 3 Pictures from the game session of the 4th edition of Farm Coaching. **a** Boardgame of one group. On the board, a 1000-ha farm map is represented six times, showing the land use in summer/autumn and winter/spring for 3 years of rotations. Each sticky note represents 50 ha, and their color represents the type of land use (soybeans are displayed in pink; native pasture in light green; annual tropical pasture in orange; maize in blue; perennial tropical pasture in light blue; wheat in dark blue; and annual temperate pasture in dark green). The round gold stickers on each post-it represent the level of investment (one sticker = low level, two stickers = medium, and three stickers = high). **b** A participant filling the board; the green lines inside each farm map indicate the relief divisions (lowlands and highlands) and native pastures. Photo credit: Fernanda Moojen.

to the game sessions to ensure feasibility. The rules were presented to the participants as follows:

A. "The total area of 1000 ha must be planned to be used for 3 years with agriculture or livestock in both summer and winter seasons."

The aim of rule A was to encourage crop and livestock production in all potential areas and inspire players to consider crop rotations in their space-time planning. Unlike the initial scenario where crops are prioritized, with this rule, players need to distribute the financial resource in the total area and, as money is limited, this makes the game challenging.

B. "To optimize the available machinery, the minimum area of the summer crops should be 300 ha each year."

The aim of rule B was to constrain players to be focused on crop-livestock integration balance. The rule prevented players from only using livestock in the entire area and being in coherence with the initial scenario where there is infrastructure for agriculture in use.

C. "The carrying capacity of the system should support a herd equivalent of at least 1000 animal units (450 kg live weight) in both summer and winter."

D. "The balance of the carrying capacity should be prioritized, avoiding both shortage (overgrazing) and excess (waste of resources) of forage in both seasons. The tolerance for a miscalculation was defined as the equivalent to 50 animal units."

The aim of rules C and D was to optimize forage budgets for livestock by challenging players to distribute pasture resources throughout the year according to the herd of each year. Players cannot finalize the year planning until they reach the correct balance, i.e., the maximum difference of 50 animal units from support capacity (5% of the total herd).

E. "The hypothetical farmer desires to reinvest his profit from year 1 and year 2 into the farm and would like to spend part of the annual budget to purchase cattle and increase the herd as an investment."

The aim of this last rule was related to the wishes of the "hypothetical farmer" (i.e., the financial objectives) in the game be equivalent for all groups. The first-year budget was restricted to the players' choices; however, owing to the reinvestment rule, the players were required to consider different budget scenarios over the 3 years. Additionally, the decision to increase the herd included investing money in purchasing cattle and having enough on-farm pasture to feed the herd over the year to achieve the balance of carrying capacity (in line with rule D).

2.4 Analysis of game outputs and farmer surveys

The outputs of the games, both from the model (financial budget, gross revenue, gross costs, gross margin (total and per hectare), a total of animals purchased and gross margin considering the herd increase) and the boards (land-use choices in space (crop rotations and between-relief divisions) and time (two periods in a year and over 3 years)) were compiled, and the results were discussed in the following session. The results from each edition of Farm Coaching were presented; although comparisons between groups in each Farm Coaching edition were possible, comparisons between editions were not, owing to the differences in the models, tables, and regional adaptations.

After each Farm Coaching workshop, 12 farmers (presented as F1–F12) were selected for individual online interviews to evaluate their perceptions of the game and understand how they associated the game with real-world conditions in their farms. The interviewees were chosen from farmers who participated in one of the Farm Coaching editions, had SIA monitoring on their farms, and utilized integrated systems (rather than just cattle or crops). The interviews, all conducted by the same interviewer, were semi-structured, lasted about 1 h each, and were carried out between February and May 2020. After the interviews, they were transcribed and subjects common to several farmers were clustered. Some excerpts from the interviews are presented in Section 3 to illustrate the impressions of these farmers.

3 Results and discussion

3.1 Outputs from SIPA game sessions in Farm Coaching workshops

When compiling crop usage in the game (Figure 4), participants used 60–100% of the options available. Several crops appeared with 100% frequency (soybean, perennial tropical pasture, and annual temperate pasture), and the lowest use (25%) was for cover crops. Cover crop use was discouraged despite their potential benefits for soil and water conservation comparting to fallow, as they were the only non-revenue-generating option (do not improve economic resilience), without any food production (do not improve efficiency of land use) or stocking capacity for livestock (de Oliveira et al. 2014). Also, the presence of animals in moderate grazing intensities, comparting to cover crops not grazed, influence nutrient recycling, and improve soil aggregation, microbial activity, and chemical attributes (Carvalho et al. 2010).

In the editions held in Porto Alegre, the options of "rice" and "pasture after rice" were added to the game, and only three of the 12 groups chose not to use rice crop and, consequently, the pasture after rice. F11 had rice experience on his farm and stated, "I tried to explain to other players how rice was planted in a soil with water and about rice plots […] Because the soybean, corn, wheat crops are logical, one ends cultivation after another," (referring to the fact that the production of rice irrigated with levees involves water distribution logistics, advance preparation of levees, and a significant amount of machinery). Additionally, F10 demonstrated his point of view regarding rice as a risky crop and compared it to his region "Wear of machinery is very high. The prices for renting land are very high. The input price is very (dependent) on the fertilizer input […] If it gets cold in January you (can) lose the crop harvest, if it stops raining and there is no water, you (can) lose the crop harvest. It is similar to (growing) wheat in my region, it is a high investment for a low return."

Wheat was an option in all FC editions, but players in the first two editions did not choose it, and in total, only 44% of the groups utilized it. Despite its positive results in the game, farmers related it to bad personal experiences. Considering the conditions at his farm, F10 stated "Wheat today is like that: the cost of a hectare of wheat well done (high investment in technology) is more than a hectare of soybeans for you to plant. And the risk is very high because lack of cold loses production, lack of heat in winter loses production, if it rains too much you lose production, if it rains less, you lose production […] And if you have an excellent, excellent crop, it rains 3–4 days at harvest, the crop loses 30%, the HW (hectoliter weight - measure of wheat quality) drops, and the value drops." The farmer's discussion regarding the use of rice and wheat, which involve operational challenges and risks in practice, was one clear example of how farmers made associations with reality. This implied that game has context-relevant content as it provided a realistic but simple representation of the ICLS practiced in southern Brazil. Ryschawy et al. (2014) have also been successful in connecting their serious game with reality and have presented this association as a crucial point in the game's relevance to users.

Increases in stock of cattle (through the purchase of animals) were explored by all groups, according to "rule E" of the game. In the first edition, the purchase of animals was not considered an expense in the system, leading to a significant increase in the herd. In the second, third, and fourth editions, 308 animals, on average, were purchased over the 3 years of simulation (representing an increase of 30.8% compared to the initial stock), varying between 180 and 529 among the groups. The gross margin (gross revenue − gross costs) increased over the 3-year simulation. This was expected because, following

Farm Coaching edition

		1st				2nd				4th				3rd				
	GROUP OF PLAYERS	A	B	C	D	E	F	G	H	M	N	O	P	I	J	K	L	Frequency
Summer options	Soybean	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	100%
	Corn	✗	✗	✗	✓	✗	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	69%
	Bean	*	*	*	*	*	*	*	*	*	*	*	*	✓	✗	✓	✓	75%
	Perennial tropical pasture	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	94%
	Annual tropical pasture	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	100%
	Rice	✓	✓	✓	✓	✓	✗	✓	✓	✓	✗	✓	*	*	*	*	*	75%
Winter options	Temperate pasture after rice	✗	✓	✗	✗	✓	✗	✓	✓	✓	✗	✓	*	*	*	*	*	50%
	Annual temperate pasture	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	100%
	Native pasture	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	94%
	Wheat	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✗	✓	44%
	Cover crop	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗			✗	✗		✓	25%
	Frequency	60%	70%	60%	70%	70%	60%	80%	70%	90%	70%	100%	80%	78%	78%	78%	100%	

Fig. 4 Crops and pastures chosen by groups in Farm Coaching game sessions. White represents the absence of the crop, whereas blue represents its presence, over the 3 years of rotation. *Crop was not available due to regional context.

the rules, the margin was re-invested in years 2 and 3, which allowed for greater investments in existing crops and the adoption or augmentation of more expensive crops. The sum of the gross margin per hectare over the 3 years of simulation was \$ 654 ± 149, \$ 450 ± 58, \$ 647 ± 80, and \$ 531 ± 62 (average ± standard deviation among groups) for the first, second, third, and fourth editions, respectively.

In each game session, we noted that the different scenarios proposed by the groups reached similar economic results, although the groups followed different farm-design strategies. Reaching similar economic results between groups was not a predefined objective but emerged in the discussion during the crossed presentation of the scenarios. These results demonstrated that no simple, optimal solution exists, and that contrasting strategies leading to diverse spatial configurations (i.e., that impact environmental and social sustainability) can be comparable in terms of economic performance (Etienne 2003). In this sense, the fact that the game spreadsheet included multiple interconnected possibilities (see Figure 2) allowed players to experience single-loop learning by incremental improvement of action strategies (i.e., changing the investment level and proportions of crops and pastures in the total area), and double-loop learning by revisiting assumptions and changing the governing variables (i.e., choosing to use or not each crop or pastures due cause-effect in the system budget and land-use rotations; choosing to re-focus the design to increasing herd due animal benefits in the ICLS) (Argyris and Schön 1996; Pahl-Wostl 2009).

3.2 Farmers' perceptions of their experience playing SIPA game

The SIPA game was developed to be played in groups and not individually to promote discussions and sharing knowledge among participants during co-design and with researchers and advisors when comparing ICLS scenarios. Lacombe et al. (2018) have concluded their review on designing agroecological farm systems by demonstrating the importance of creating "reflexive arenas" that support farmers' changes on their farms. The groups were pre-defined based on a profile analysis to promote participant diversity. The diversity was noticed by F11 as "The main issue, which I remember most, is the need for understanding between different profiles of people […] it was even more difficult than the game itself." Debates were attributed to cultural aspects, such as livestock or crop farm backgrounds. This was illustrated by F8 regarding his group "It was a little conflicting, because there were defenders of a certain product, of a certain crop. The defenders of only purchasing cattle, only the part of the livestock. So, you had to really show the balance in this game, in the simulations and try to contain that urge, if you have a surplus of cash, 'let's buy cattle, cattle, and cattle.' But wait! There is no point in buying, buying, if I'm not going to have (enough) food."

The management of the herd in relation to forage budgets was an aspect of the game's connection with reality. Some farmers raised concerns that, in the game, they had to retain the animals throughout the year, contrary to the common practice of buying calves to fatten on pastures during winter (between two soybean crops). This practice of fattening for a short period (i.e., approximately 4 months) has been possible with appropriate pasture management (Wesp et al. 2016), but is only applicable for farmers who work purely with fattening, without cow–calf operations in which animals are raised over all year round. In addition, livestock management is challenging on farms with a high percentage of summer crops. In such cases, pasture area in winter is significantly higher because it often corresponds to the entire area of summer crops; in contrast, during the summer, the animals overgraze the smaller areas, creating an imbalance. This is well addressed in our game because it is necessary to balance both the supply and the demand for pastures and ensure balance between seasons.

In this work, the focus was on the analysis of the farmers' impressions; however, it would be important to further explore the contribution of the Farm Coaching methodology in terms of training of ICLS advisors. Besides, the game was designed not only for farmers, as Farm Coaching also attracted other actors. Therefore, it is important to emphasize the need for integrated system training for this audience group as well. Garrett et al. (2020) have reported on the specialized nature of advisory systems as a negative driver in promoting extension services for the implementation and management of integrated systems.

3.3 SIPA game as a simple tool for addressing the complexity of ICLS and inspire change in mindset toward system thinking

To implement an innovative farming system, the design of the alternative systems is required (Martin et al. 2013). In this sense, to allow transitions toward an integrated system, an alternative design from specialized systems that consider both crop and livestock attempting to strengthen synergistic relationships is necessary. However, the multiple components and interactions that characterize ICLS remain a methodological challenge (Stark et al. 2018). Overall, the SIPA game had a satisfactory balance between representing ICLS reality (i.e., more complex systems to design and access), and being a simplification of and ICLS (i.e., to allow its "playability") in the learning process.

Regarding ICLS context, we also highlight the importance of SIPA game mechanism that encouraged farmers to rethink their performance criteria. This implied a shift from looking at the performance of each component (either crops or livestock) to focusing on performance per unit land. This meant designing and evaluating the production of the whole system, rather than the farmers' usual crop-oriented planning. However, to achieve this change in mindset, some aspects of system thinking are required: (i) understanding interconnections among various parts and the whole and (ii) viewing a situation/problem from different perspectives (Church et al. 2020). These authors said that all farmers may inherently be system thinkers, but great variation exists in the degree to which they make connections within and beyond their production systems. Therefore, our game could help in promoting system thinking to be applied during decision-making on farms.

Ditzler et al. (2018) has stressed that tools for analyzing agricultural systems must be designed for targeted audiences; thus, it is necessary to account for the complexity of the tool and language, cultural, and institutional barriers. In this sense, our game proved to be well designed for the target audience, as participants, after a brief introduction, were able to play and practice the ICLS concepts presented. Hernandez-Aguilera et al. (2020) have reported that well designed games can generate emotional experiences and may also inspire farmers to change their behavior. For farmers who have not yet adopted integrated systems, games can be much more effective tools in changing participants' mindset compared to models because they are easy to use and explanatory, and have tangible objects that assist in the learning experience.

3.4 Critical analysis of the game and insights

The construction, use, and study of serious games in agriculture have increased significantly in the past two decades and have proved to be an innovative way to accelerate dialogue and learning (Hernandez-Aguilera et al. 2020). However, despite increasing availability, the designed tools have not always been effectively adopted by farmers and advisors owing to factors such as bad performance, insufficient ease of use, and insufficient relevance to the user (Rose et al. 2016). We propose several improvements that can be incorporated into our serious game to address these constraints. First, pre-set system boundaries were provided to players as a hypothetical farm, i.e., using identical initial scenarios to start the game. This facilitates the final dynamics of the game where the scenarios were compared; however, it could not accurately represent the actual farms undergone by the farmers who play the game. Therefore, as an improvement, and perhaps as an additional stage after the game session, a realistic model, based on the game but with an initial menu for registering actual areas and data, could be used. Consequently, farmers would be able to simulate scenarios to be implemented, like in Forage Rummy (Martin et al. 2011), where the context of the game is based on the data of each farmer.

Another improvement pertains to the need for skilled facilitators in the final discussion because the model has no constraints and serves only to simulate people's decisions. Thus, it is important to include indicators such as risk, workforce, complexity, and sustainability indicators. Hence, the automatic display of indicators may facilitate the analysis and interpretation of the scenarios designed. The SEGAE serious game is an example with automatic sustainability indicators, obtained by compiling scores (Jouan et al. 2020). Another source that can be added to the game is the "IDEA" method

(IDEAv4), which contains 53 indicators to analyze Farm Sustainability (Zahm et al. 2019). Their pedagogical tool was developed to be easily calculable and interpretable by a farmer, an advisor, or a student.

After playing the SIPA game, some players questioned whether the model accounted for reducing the use and cost of herbicides via appropriate grazing management and fertilization strategies. These questions were linked to results from two ICLS experiments presented in the Farm Coaching workshops: (1) winter-grazed cover crops reduced the number, the density, and the seed bank of weed species, when compared with those in non-grazed cover crops (Schuster et al. 2016), and (2) fertilization strategies with ICLS increased energy production per unit of nutrient applied (Farias et al. 2020). In the future the SIPA game may explicitly include these themes, or new games could be proposed during Farm Coaching to address these themes, as they are recent concepts and require a learning process to be implemented.

In the SIPA game, we focused on the rearing of grass-fed ruminants because grazing animals are important in the dynamics of nutrient cycling in the soil (Carvalho et al. 2010). Pastures are also a cheap forage source, and the production of pastures in Brazil can be planned throughout the year. This has contributed to the idea of using a spreadsheet with only a grass-fed option. However, some players proposed the use of grain for animal feed; hence, it would be necessary to adapt the model more robustly, considering animal requirements and feeding options. The game could also detail livestock practices, for example, allow variations in animal species (e.g., adding dairy cattle) and include herd division based on animal categories, as proposed by Martin et al. (2011). Finally, an easier proposition to improve discussion in the game would be to include variations in the prices of both cattle and crops, as reported by Ryschawy et al. (2014). This would demonstrate that more diversified systems tend to be less affected by market variation (de Oliveira et al. 2014).

4 Conclusions

Our findings indicate the potential of the SIPA game as a learning process and as a platform for exchanging ICLS knowledge and perspectives among farmers, researchers, and advisors. The game acts as a tool that helps in inspiring the adoption of ICLS. In addition, the game allowed players to understand the logic in ICLS decisions despite being a simplification of reality. Based on these positive experiences, the development of new versions include more sustainable indicators automatically displayed, and the application of the SIPA game is expected to continue with new groups, thereby engaging participants in a learning experience centered on system thinking and planning. The game is easily scalable for other regions of Brazil and even other parts of the world, using regional adaptations for the parameters inserted in Excel. The pedagogical strength of the game could be exploited by agricultural students and advisors and could empower them in helping farmers co-design sustainable ICLS.

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Code availability Not applicable

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Data availability All data generated or analyzed during this study are included in this published article

Declarations

Conflict of interest The authors declare no competing interests.

Ethics approval Not applicable

Consent to participate The participants to the study were informed about the conditions and the purpose of this research study and gave informed oral consent to participate in the research. The data was anonymized after the end of the interviews ended.

Consent for publication The authors affirm that the farmers who participated in the survey provided informed consent for publication of anonymized data.

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