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Research

Identifying system archetypes in Nigeria's rice agri-food system using fuzzy cognitive mapping

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ABSTRACT. Nigeria is a major rice-producing and rice-importing country in Africa, challenged with ensuring rice-food security for its growing population. Successive governments have implemented several strategies to increase local rice production such as rice import restriction policies and agricultural investments. These strategies have yielded results but achieving long-term sustainable growth in Nigeria's rice agri-food system has remained elusive. Addressing food security and sustainability in agri-food systems requires a systems-thinking approach. In this study, we applied two systems thinking techniques, fuzzy cognitive mapping (for describing the system structure and behavior) and archetype analysis (to reveal generic system archetypes and effective strategies to improve the system). Our analysis revealed three system archetypes: limits to success, fixes that fail, and drifting goals. Rice production is limited by low agricultural productivity indicating the "limits to success" archetype. Farmers tend to increase rice area as a "quick fix" to productivity issues but this quick fix leads to unintended consequences such as soil degradation (fixes that fail archetype). Additionally, because of the import-restriction policies generating an unmet demand for rice, the government may face pressure to lower the goal of self-sufficiency falling into the "drifting goals" archetype. However, our analysis shows that suspending import-restriction policies would result in undesirable system states, with reduced demand for local rice and lower rice production. Our results underscore the importance of government policies in increasing rice production sustainably and ensuring food security.

Key Words: *agri-food system; fuzzy cognitive mapping; Nigeria; rice; system archetypes*

INTRODUCTION

Background of study

Rice has become a staple food in Africa (Seck et al. 2013, van Oort et al. 2015). Although Africa has recorded a six percent annual growth in rice production over the last decade (OECD/FAO 2016), rice production in Africa still struggles to meet rising rice demand (van Oort et al. 2015, Van Ittersum et al. 2016). As a result, Africa's rice imports have increased, causing a dependence on the international markets, with risks of economic strains, food insecurity, and conflicts due to the volatility of rice prices (Seck et al. 2013, Mendez-del-Villar and Lançon 2015). For example, the 2008 global price hike resulted in food riots in several African cities in response to the soaring rice prices (Seck et al. 2013).

On the other hand, rice consumption will keep increasing because of urbanization, rising household incomes, and population growth in Africa (Zhou and Staatz 2016, Durand-Morat and Bairagi 2021a, 2021b). However, climate change and variability threaten rice production (Roudier et al. 2011, Terdoo and Feola 2016). Given these issues, many African governments aim to address rice production deficits to increase rice supply at a growth rate greater than rice consumption (Arouna et al. 2021).

In addition to government efforts, there has been a long focus of research on the development of Africa's rice agri-food system, examining the national, sub-regional, and regional potential for growth (Andriesse and Fresco 1991, Balasubramanian et al. 2007, Otsuka and Larson 2013, Saito et al. 2013, Rodenburg et al. 2014, Nasrin et al. 2015, van Oort et al. 2015, Van Ittersum et al. 2016, Niang et al. 2017, Takeshima and Lawal 2018). These strands of literature have highlighted various factors affecting rice agri-food system development, such as macro-economic factors (trade relations, import laws, government expenditure on agriculture), productivity issues emanating from farm technology, soil fertility, rice growing environments, and commercial factors such as prices. These factors represent multiple ways to intervene in a given agri-food system (Foran et al. 2014).

It is widely agreed that there is untapped potential for increasing rice production in Africa, yet rice production still lags behind rice demand. Addressing this gap requires systems thinking rather than linear approaches (Liu et al. 2015, Allen and Prosperi 2016, Zhang et al. 2018, Ruben et al. 2019, Borman et al. 2022). Systems thinking manages the complexity of agri-food systems to ensure desirable outcomes (Foran et al. 2014, Zhang et al. 2018, Bustamante et al. 2021). System thinking is operationalized through various tools and techniques, such as causal loop diagrams, stock and flow models, fuzzy cognitive maps, and archetypes (Senge 1990, Forrester 1994, Coyle and Alexander 1997, Homer and Oliva 2001). These tools and techniques account for the various components of the system that constitute its structure, causal connections, and feedback loops, which result in the system's behavior.

Our study uses archetypes as building blocks to analyze a system as a whole of causal mechanisms (Oberlack et al. 2019). We derive feedback loops, also called causal loops, from fuzzy cognitive mapping and match these system structure components with generic structural patterns, which are the system archetypes. System archetypes are often based on causal loop diagrams (Senge 1990, Kim and Lannon 1997, Wolstenholme 2003), but we innovatively base our system archetypes on fuzzy cognitive maps in this study. Fuzzy cognitive maps are similar to causal loop diagrams in applying graph theory for qualitative system modeling (Voinov et al. 2018). However, fuzzy cognitive mapping incorporates quantitative simulation to analyze the system's behavior, providing information based on its structure and behavior, which can be adjusted toward desirable behaviors. Our study applies these methods to understand and analyze the

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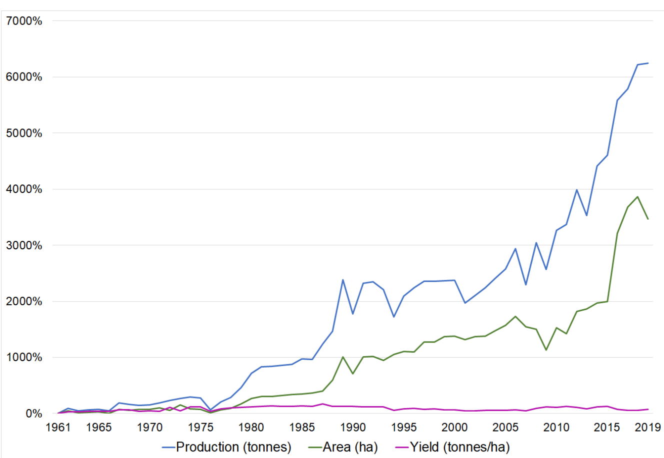
structure and behavior of the Nigerian rice agri-food system and to propose effective solutions to address the problems embedded in the system.

Study area

We identified Nigeria as a suitable study area. Nigeria is Africa's highest rice producer and consumer (FAOSTAT 2022). Nigeria is in West Africa, bounded to the north by the Republics of Niger and Chad; to the South by the Atlantic Ocean; to the east by the Republic of Cameroun; to the West by the Republic of Benin. Nigeria is part of the West African rice belt, Africa's dominant rice-producing and consuming region, which has experienced the highest rice demand growth rate globally (Rutsaert et al. 2013, Mendez-del-Villar and Lançon 2015).

Nigeria has a land area of 92.38 million hectares, with less than 1% equipped for irrigation (FAOSTAT 2022). In Nigeria, rice is mainly produced in four of the six sub-regions of Nigeria: the North central region (31% of national production), the North West region (30%), the North-East region (24%), and the South-East region (8%; USDA 2022). In 2019, Nigeria was the 14th top producer of rice in the world at a volume of 8 million tonnes (USDA 2022). An increase in rice area rather than improved yield accounts for most of Nigeria's rice production increase (Fig. 1). The rice area has increased substantially between 1961 and 2019, whereas the national yield has remained almost unchanged, below 2.5 tonnes per hectare, rising by only 78% between 1961 and 2019 (Fig. 1).

Fig. 1. Changes in rice production (tonnes), harvested area (hectares), and yield (tonnes/hectare) in Nigeria from 1961 to 2019. The percentage increases are indexed relative to their values in 1961 (equivalent to 0). Data sources: FAOSTAT; Image: Authors compilation.



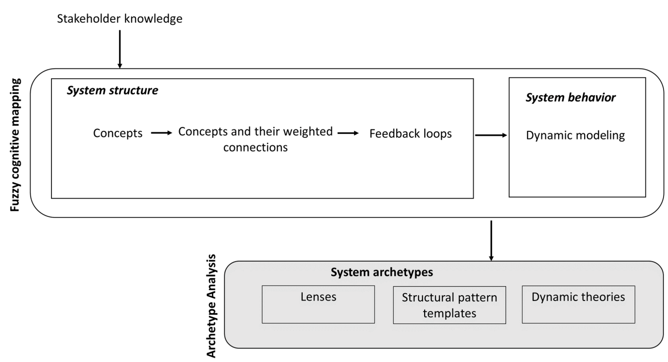
Nigeria is challenged with ensuring rice-food security for its growing population of 200 million people. Nigeria is ranked seventh by population in the world and could rise to third by 2050 (United Nations 2022). Rice production has increased, but so has rice consumption, necessitating rice imports to meet rice demand. By 2035, it is estimated that Nigerians will more than double their rice consumption compared to 2010 (Seck et al. 2013).

The Nigerian government has attempted to achieve rice self-sufficiency through various strategies, including agricultural investments and market protectionist measures such as import-restriction policies. Import bans have been implemented in the past such as those between 1986 and 1995 (Oyejide et al. 2013, Mendez-del-Villar and Lançon 2015). More recently, in 2015 and 2017, restrictions on foreign exchange for rice trade and a ban on imports through seaports and land borders were implemented, respectively (Ugwuja and Chukwukere 2021). These policies aim to boost demand for local rice while creating more support for farming through mechanization, importing high-yielding seeds, and providing subsidies and loans to farmers (Onyiriuba et al. 2020).

METHODOLOGY

The first step in our study was identifying the factors, also called concepts, that make up the system structure. We did so with fuzzy cognitive mapping using stakeholder knowledge gathered through interviews. The system structure was then analyzed to derive dynamics representative of the system behavior. Furthermore, we matched our system structure and behavior to system archetypes and proposed strategies to improve the system. Figure 2 shows how we combined fuzzy cognitive mapping and system archetypes in an analytical framework.

Fig. 2. Analytical framework showing the combination of fuzzy cognitive mapping and archetype analysis.



Fuzzy cognitive mapping

Fuzzy cognitive mapping relies on graph theory to visually represent the system structure as an output of cause-and-effect connections between the system concepts (Yoon and Jetter 2016). The main elements of a fuzzy cognitive map (FCM) are nodes or concepts (C1, C2, C3..., Cn), directed edges (C1 → C2, etc.) as a set of arrows or arcs that represent the connection between concepts. However, a fuzzy cognitive map (FCM) is not just a system visualization or diagramming tool for showing causation. The FCM also operates as a mathematical model, thus providing a dynamic hypothesis and not only an explanatory map (Homer and Oliva 2001). This attribute enables a broader application of fuzzy cognitive mapping in modeling, simulation, what-if analyses, and integrated assessments (Rezaee et al. 2017, Voinov et al. 2018, Bakhtavar et al. 2021).

The FCM is a mathematical model using an adjacency matrix containing all connections' weights (Kok 2009). When a concept changes its state, it affects all other concepts causally linked to it, and the affected concepts subsequently change their state (Jetter and Kok 2014). In other words, concepts evolve dynamically depending on their nodes and spread through the graph until the dynamic output is stabilized (Helfgott et al. 2015). Fuzzy cognitive mapping investigates feedback loops that cause iterating activation and change of concepts through the model until the system reaches a stable state (Nápoles et al. 2016). These dynamics from the initial state toward a stable state provide the principal insights of fuzzy cognitive mapping applications, which can be further applied to understand the behavior of complex systems (Kok 2009, Rezaee et al. 2017). Fuzzy cognitive mapping can handle this dynamic complexity of the system because the system behavior emerges from the change from concepts spreading through other concepts until the system reaches a stable state. FCMs also allow analysis through hypothetical scenarios to investigate how the system reacts to varying conditions. Such scenario analysis is carried out by using different input vectors, which contain activation levels ranging from 0 to 1, resulting in different scenarios of the system (Papageorgiou and Kontogianni 2012).

FCM can be developed through a participatory process as a group modeling exercise (van der Sluis et al. 2019) by eliciting knowledge from stakeholders through interviews (Edwards and Kok 2021) or through a literature review (Jetter and Kok 2014, Olazabal et al. 2018). When using a participatory process or stakeholder knowledge, an FCM typically combines individual cognitive maps into a collective mental model of the system, considered as shared knowledge (Gray et al. 2015, Olazabal et al. 2018). However, it is important to note that an individual's map may be subjective and not thoroughly describe the system. To mitigate this, involving multiple participants and aggregating their knowledge into one map is necessary. This participatory approach captures system complexity and enables stakeholder knowledge to be used for model simulation of system behavior (Kok 2009).

Fuzzy cognitive mapping of Nigeria's rice agri-food system

We interviewed stakeholders to capture their perceptions into an aggregate FCM. We identified stakeholders from key institutions working in rice-related activities, and using snowballing. The participating stakeholders were engaged in rice-related activities, 23 in total, with six from research institutes that not only conduct research but also carry out extension services, six from academic universities, six farmers, and five government officials.

Stakeholder engagement occurred in two rounds. In Round 1, semi-structured interviews were conducted independently with each stakeholder. Knowledge was elicited from stakeholders on the current trends of Nigeria's rice agri-food system, with rice production as the central concept. Stakeholders were asked about the uncertainty and impact of key factors on the system enabling or constraining rice production (interview questions are given in Appendix 1). Next, we qualitatively aggregated stakeholders' knowledge (following Olazabal et al. 2018).

In Round 2, we presented the aggregated results from Round 1 in an online questionnaire. Stakeholders provided weights for each connection presented as pairwise connections (following Roberts 1976). We included a preliminary FCM linking all the connections to visualize the system structure easily. Stakeholders commented on the preliminary FCM and provided weights to pairwise connections. A detailed description of the process of FCM development using stakeholder knowledge is given in Appendix 1 and described fully in Edwards and Kok (2021). The comments and weights provided by stakeholders were aggregated and used to build the FCM, which represents the current system description of the system. The aggregation process was supported with scientific literature and followed established protocol to preserve stakeholders' knowledge while keeping the authors' contribution minimal in the co-production process (Alizadeh and Jetter 2017, Olazabal et al. 2018, Edwards and Kok 2021).

The properties of the FCM such as the indegree, outdegree, and centrality were determined. The sum of the weights of the incoming connections is the indegree and the sum of the weights of the outgoing connections is the outdegree, whereas the centrality is the sum of the indegree and outdegree of each concept. The centrality of a concept reflects how related the concept is to other concepts and thus, its relative importance in the system (Gray et al. 2014). We also identified different kinds of concepts. The driver concepts have zero indegree (i.e., only outgoing connections but no incoming connections from the system) whereas receiver concepts have zero outdegrees. Other concepts affect receiver concepts, but receivers do not affect the rest of the system.

We thereafter conducted dynamic modeling of the FCM using the Dynamic Analysis of Fuzzy Concepts in Evolving Systems (FuzzyDANCES) software version 2.0.1.0, which is part of the COMPASS multi-scale agricultural modeling framework (Groot et al. 2012, as cited in Aravindakshan et al. 2021). For the inference rules in the model, four concepts considered drivers in the system were clamped with a static activation value of +1, whereas the other concepts were set with an initial activation value of 0. This allowed us to produce scenarios of plausible states of the system, by changing the static activation value of the driver concepts from a maximum of +1 to a minimum of +0.1. In all scenarios, we applied an objective function optimized to target value and not within a specified range and a multiplication function in which the new state of a concept is independent of the current state of the concept following the equation:

$$A_i(k+1) = f\left\{\sum_{j=1}^{N}\left(A_j\ (k).\ W_{ji}\right)\right\} \tag{1}$$

where k is the iteration number, A_i(k) and A_i(k + 1) are the state values of concept i at iterations k and $k+1$, A_j(k) is the value of concept j at iteration step k, and W_{ji} is the weight of the connection between concepts j and i. No transformation function was applied, so the concepts were not constrained to a certain range, allowing for quantitative simulation (Stach et al. 2005, Gray et al. 2015).

Sensitivity analyses of the model assess the relative importance of independent variables to the dependent variables (Chan et al. 2000, Lavin and Giabbanelli 2017). We analyzed the model's variance with FuzzyDANCES using the winding stairs sensitivity algorithm (Chan et al. 2000) through 1000 windings per driver. The drivers were varied with a multiplication factor set to a maximum of 1, whereas the other concepts varied according to the matrix multiplication of the model. Using regression analysis, we tested the sensitivity of each driver concept to the other concepts. In the FuzzyDANCES software, we also identified the feedback loops in the system. A balancing feedback loop contains negative feedback and stabilizes dynamics, whereas a reinforcing loop gives positive feedback and accelerates dynamics in the system (Lannon 2012).

Table 1. Archetypes, dynamic theories, and prescriptive actions.

Archetype	Dynamic Theory	Prescriptive Actions
Drifting Goals	The "Drifting Goals" archetype states that a gap between a goal and an actual condition can be resolved in two ways: by taking corrective action to achieve the goal, or by lowering the goal. It hypothesizes that when there is a gap between the goal and the actual condition, the goal is lowered to close the gap. Over time, the continual lowering of the goal will lead to gradually deteriorating performance.	Anchor the goal to an external frame of reference to keep it from sliding (e.g., benchmarking, voice of the customer). Determine whether the drift in performance is the result of conflicts between the stated goal and implicit goals in the system (such as current performance measures). Establish a clear transition plan from current reality to the goal, including a realistic time frame for achieving the goal.
Escalation	The "Escalation" archetype occurs when one party's actions are perceived by another party to be a threat, and the second party responds in a similar manner, further increasing the threat. It hypothesizes that the two balancing loops will create a reinforcing figure-8 effect, resulting in threatening actions by both parties that grow exponentially over time.	Identify the relative measure that is pitting one party against another and explore ways it can be changed or other ways the two parties can differentiate themselves in the marketplace. Quantify significant delays in the system that may be distorting the nature of the threat. Identify a larger goal that encompasses the individual goals of both parties.
Fixes That Fail	The "Fixes That Fail" archetype states that a "quick-fix" solution can have unintended consequences that exacerbate the problem. It hypothesizes that the problem symptom will diminish for a short while and then return to its previous level, or become even worse over time.	Focus on identifying and removing the fundamental cause of the problem symptom. If a temporary, short-term solution is needed, develop a two-tier approach of simultaneously applying the fix and planning out the fundamental solution. Use the archetype to map out potential side effects of any proposed interventions.
Growth and Underinvestment	The "Growth and Underinvestment" archetype applies when growth approaches a limit that can be overcome if capacity investments are made. If a system becomes stretched beyond its limit, however, it will compensate by lowering performance standards, which reduces the perceived need for capacity investments. It also leads to lower performance, which further justifies underinvestment over time.	Identify interlocked patterns of behavior between capacity investments and performance measures. Shorten the delays between when performance declines and when additional capacity comes on line (particularly perceptual delays about the need to invest). Anchor investment decisions on external signals, not on standards derived from past performance.
Limits to Success	The "Limits to Success" archetype states that a reinforcing process of accelerating growth (or expansion) will encounter a balancing process as the limit of that system is approached. It hypothesizes that continuing efforts will produce diminishing returns as one approaches the limit.	Focus on removing the limit (or weakening its effects) rather than continuing to drive the reinforcing processes of growth. Use the archetype to identify potential balancing processes before they begin to affect growth. Identify links between the growth processes and limiting factors to determine ways to manage the balance between the two.
Shifting the Burden/Addiction	The "Shifting the Burden" archetype states that a problem symptom can be resolved either by using a symptomatic solution or applying a fundamental solution. It hypothesizes that once a symptomatic solution is used, it alleviates the problem symptom and reduces pressure to implement a more fundamental solution. The symptomatic solution also produces a side effect that systematically undermines the ability to develop a fundamental solution or capability.	Focus on the fundamental solution. If necessary, use the symptomatic solution only to gain time while working on the fundamental solution. Elicit multiple viewpoints to differentiate between fundamental/symptomatic solutions and to gain consensus around an action plan. Use the archetype to explore potential side effects of any proposed solution.
Success to the Successful	The "Success to the Successful" archetype states that if one person or group (A) is given more resources than another equally capable group (B), A has a higher likelihood of succeeding. It hypothesizes that A's initial success justifies devoting more resources to A, further widening the performance gap between the two groups over time.	Evaluate the current measurement systems to determine if they are set up to favor established practices over other alternatives. Identify goals or objectives that will define success at a higher level than individual players "A" and "B." Calibrate internal views of market success against external indicators to identify potential competency traps.
Tragedy of the Commons	The "Tragedy of the Commons" archetype identifies the causal connections between individual actions and the collective results (in a closed system). It hypothesizes that if the total usage of a common resource becomes too great for the system to support, the commons will become overloaded or depleted and everyone will experience diminishing benefits.	Establish methods for making the cumulative effects of using the common resource more real and immediate to the individual users. Re-evaluate the nature of the commons to determine if there are ways to replace or renew (or substitute for) the resource before it becomes depleted. Create a final arbiter who manages the use of the common resource from a whole-system level.

Archetype analysis

In applying systems thinking, researchers and practitioners must understand the underlying system structure and the resulting system behavior and determine how to improve that structure to generate desirable behavior (Schoenberg et al. 2020). The system structure is first described and often visualized. In our study, we described and visualized the system structure using fuzzy cognitive mapping and then further analyzed the system structure using archetype analysis.

Archetype analysis takes the building blocks of the system (the system structure) and matches them to generic system structures and behavior patterns representing various phenomena in complex systems (e.g., Banson et al. 2016). Archetype analysis can also identify patterns across many cases, which are then grouped (Oberlack et al. 2019, Sietz et al. 2019). Then, each case is defined by a separate archetype (e.g., Václavík et al. 2013).

Our study focuses on the former, taking the building blocks (the system structure) and matching them to system archetypes. These system archetypes are generic, described in the literature, and used to explain complex system structure and behavior (Table 1). These include drifting goals, escalation, fixes that fail, growth and underinvestment, limits to success, shifting the burden, success to the successful, and tragedy of the commons (Senge 1990, Kim and Lannon 1997, Kim and Anderson 1998, Kim 2000). Furthermore, each system archetype has prescriptions for designing systemic interventions (Kim 1995; Table 1).

Archetype analysis can be used as a diagnostic tool: as a lens for deepening inquiry, as structural pattern templates for identifying problems, as dynamic system theories, for predicting behavior, and to reveal embedded strategies to improve a system (Senge 1990, Kim 1995, Kim and Lannon 1997, Wolstenholme 2003). Furthermore, when archetype analysis incorporates stakeholder perspectives in a bottom-up fashion, insights into potential management solutions in the local context can be derived (e.g., Banson et al. 2016) and local findings linked with global findings (e.g., Moallemi et al. 2022).

Studies on agriculture and farming systems (Banson et al. 2016, Sharif and Irani 2016, Brzezina et al. 2017, Neudert et al. 2019, Nyam et al. 2022) have applied system archetypes to identify systemic problems and to propose solutions to achieve desired outcomes. System archetypes applied to agriculture and farming systems draw insights into root causes and underlying interacting mechanisms driving unsustainable outcomes (Neudert et al. 2019, Nyam et al. 2022).

Archetype analysis of Nigeria's rice agri-food system

After collecting stakeholder knowledge on the system and mapping the FCM, we implemented a step-by-step approach to identify system archetypes in Nigeria's rice agri-food system. First, we applied the "lenses" (Box 1) to analyze the stakeholder knowledge. We deepened our inquiry into the system by asking the specific questions provided (Box 1). Next, we compared and matched the system structure (the FCM) with the structural pattern and dynamic theory of the generic system archetypes (Kim 1995; Table 1). Furthermore, we examined the FCM's dynamics, with the scenarios analysis and sensitivity analysis results to further understand how the system responds to change.

Box 1: Lenses to deepen inquiry and identify system archetypes in a system (Kim and Lannon 1997).

Questions to ask when putting on each of the archetype "lenses":

Drifting goals

- Are there goals or standards that are eroding over time?
- Are people focused on achieving the goal or on reducing the discomfort of not achieving the goal?

Escalation

- Are there two or more players of equal power whose individual actions can be perceived as a threat by the others?
- Does each player have the capacity to retaliate with similar actions?

Fixes that fail

- Have actions been taken to respond quickly to a crisis without much consideration of long-term consequences?
- Have similar actions been taken in the past in response to similar crises?

Growth and underinvestment

- Do investments tend to be made as a reaction to growth rather than in anticipation of growth?
- Do problems created by growth, rather than long-range planning, act as the organizational signal to invest?

Limits to success

- Are once-successful programs experiencing diminishing returns?
- Are there limits in the system that are constraining the growth?

Shifting the burden

- Are actions that were taken to alleviate problem symptoms shifting attention away from more fundamental solutions?
- Are there additional consequences that systematically erode the underlying capability of the organization?

Success to the successful

- Are there two or more equal options whose investment decisions are linked in a zero-sum game?
- Does the success of either option depend on initial conditions?

Tragedy of the commons

- Is there a large number of equal players who have free or equal access to a common and limited resource?
- Is the system set up to be self-regulated, with no overarching governing body?

RESULTS AND DISCUSSION

FCM properties

The aggregated FCM has a total of 28 concepts and 64 connections (Fig. 3) with more properties of the FCM such as weights in a connection matrix; a description of concepts is provided in Appendix 1. The indegree, outdegree, and centrality of the concepts are shown in Figure 4. According to our results, the system is influenced mainly by financing and subsidization (C2) and rice area (C21), which have the highest centrality, whereas deforestation and biodiversity loss (C24) and consumer preferences (C9) have the lowest centrality.

Four of the concepts are driver concepts because of their characteristics of high uncertainty and high impact on the system: government import restriction policies (C1), financing and subsidization (C2), insecurity and conflicts (C3), and climate impacts (C25). Two concepts are receiver concepts: the market price of local rice (C8) and greenhouse gas (GHG) emissions (C28). We identified nine feedback loops: six reinforcing feedback loops and three balancing feedback loops (Fig. 5). For example,

Fig. 3. Fuzzy cognitive map of the Nigerian rice agri-food system showing concepts and connections. Red arrows represent inverse or negative connections, blue arrows represent direct or positive connections. The driver concepts are in green boxes and the receiver concepts are in orange boxes.

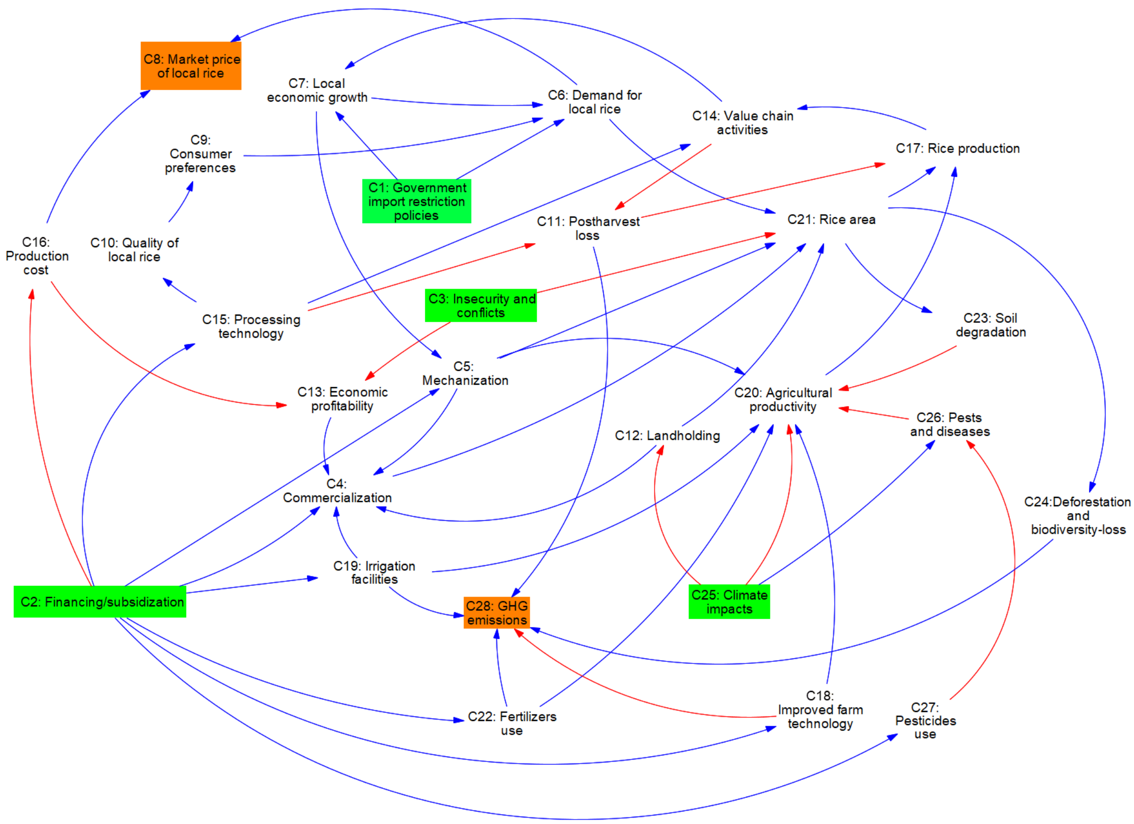


Fig. 4. Concepts in the fuzzy cognitive map of the Nigerian rice agri-food system ordered by the centrality.

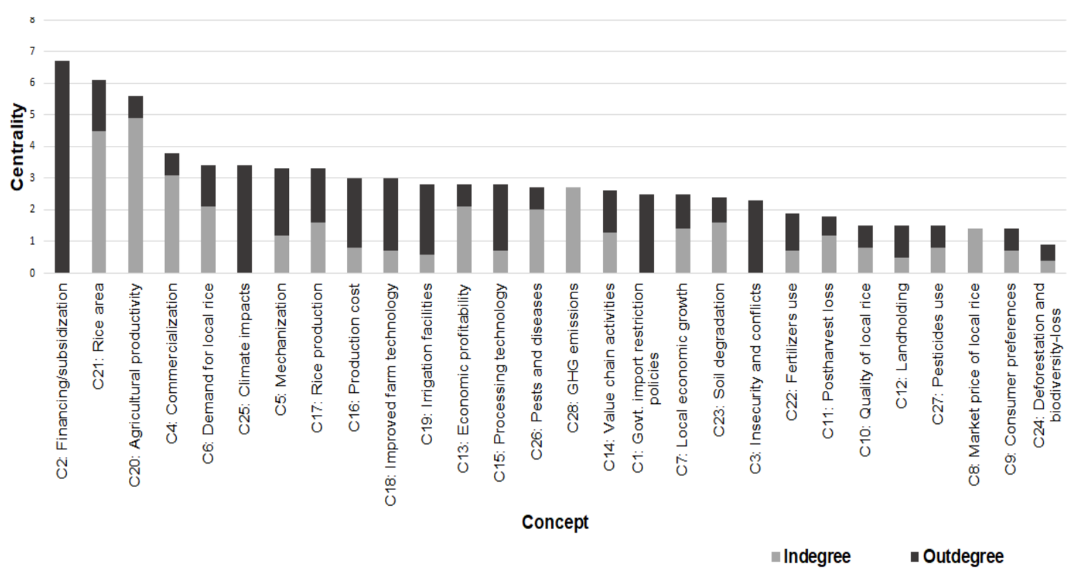
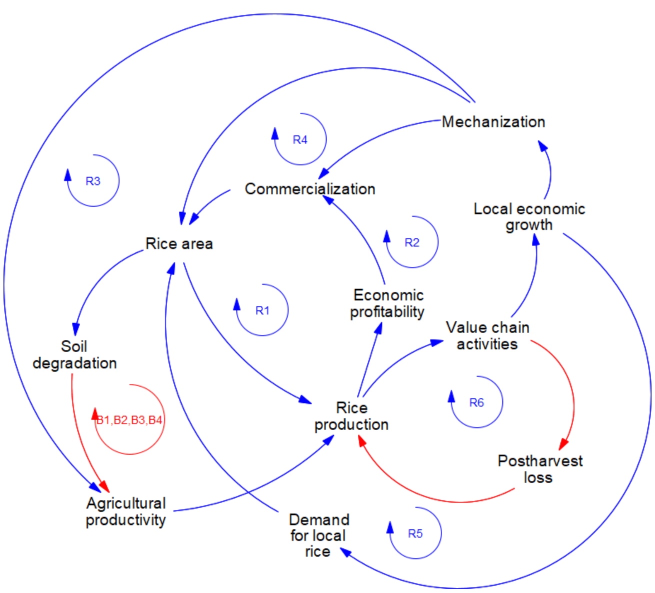


Fig. 5. Reinforcing (R) and balancing (B) feedback loops in the fuzzy cognitive map of Nigeria's rice agri-food system. In the figure, red arrows represent inverse or negative connections, blue arrows indicate direct or positive connections. The loops are: R1: Commercialization - Rice area - Rice production - Economic profitability - Commercialization; R2: Mechanization - Commercialization - Rice Area - Rice production - Value chain activities - Local economic growth - Mechanization; R3: Mechanization - Agricultural productivity - Rice production - Value chain activities - Local economic growth - Mechanization; R4: Mechanization - Rice area - Rice production - Value chain activities - Local economic growth - Mechanization; R5: Demand for local rice - Rice area - Rice production - Value chain activities - Local economic growth - Demand for local rice; R6: Value chain activities - Postharvest loss - Rice production - Value chain activities; B1: Commercialization - Rice area - Soil degradation - Agricultural productivity - Rice production - Economic profitability - Commercialization; B2: Mechanization - Commercialization - Rice area - Soil degradation - Agricultural productivity - Rice production - Value chain activities - Local economic growth - Mechanization; B3: Mechanization - Rice area - Soil degradation - Agricultural productivity - Rice production - Value chain activities - Local economic growth - Mechanization; B4: Demand for local rice - Rice area - Soil degradation - Agricultural productivity - Rice production - Value chain activities - Local economic growth - Demand for local rice.



loop R1 is a reinforcing feedback loop showing how commercialization increases rice area. Rice area expansion increases rice production, which leads to more economic benefits from rice production and further increases interest in the commercial farming of rice.

For the FCM dynamic modeling, the model stabilized without further calibration between 30 and 50 iterations. The sensitivity analysis demonstrated that the system is more sensitive to shifts in financing and subsidization, as seen by the high correlation values, which account for most of the variance in the system (Table 2). Furthermore, the scenarios indicate the direction in which the system will likely move with or without policy interventions (C1, C2), climate change, and insecurity challenges (C3, C25; Fig. 6).

System archetypes in Nigeria's rice agri-food system

We identified three system archetypes: limits to success, fixes that fail, and drifting goals (Figs. 7–9) described below with the potential strategies for Nigeria's rice agri-food system context.

Limits to success (soil degradation reduces agricultural productivity necessitating rice area expansion)

In the limits to success archetype, a reinforcing feedback loop (R) is constrained from accelerated growth by a balancing (B) loop (Fig. 7; Kim and Lannon 1997, Kim and Anderson 1998). We identified the limits to success archetype in Nigeria's rice agri-food system. Rice area expansion leads to environmental consequences, such as soil degradation, declining agricultural productivity, and constraints on rice production (Fig. 7). In the current system, the balancing feedback loops (B1, B2, B3) dampen rice production (R1, R2, R4, R5) through soil degradation-related losses in agricultural productivity, hence serving as a "limit to success" of rice production. The archetype replicates the depletion of natural resources through anthropogenic exploitation (Meadows et al. 1972). By eliminating or weakening the conditions that drive the balancing loop, we eliminate the limiting factor that slows down the performance of the system (Kim and Lannon 1997, Kim and Anderson 1998). Hence, it is important to focus on sustainably increasing agricultural productivity.

One way to achieve an increase in agricultural productivity is through mechanization. In our system, mechanization acts through three feedback loops (R3, R4, and B3: Fig. 5). These loops work through mechanization to increase rice area (R4, B3) or agricultural productivity (R3). However, rice area expansion leads to soil degradation, which limits agricultural productivity. Mechanization can enable or constrain sustainable rice production. The ambiguity of mechanization as an enabler or deterrent of sustainable crop production has been highlighted in the literature, especially for African farms that are the least mechanized globally (Sims et al. 2016, Daum and Birner 2020). In our FCM, mechanization is influenced by government investment through financing and subsidization programs (Financing and subsidization → Mechanization). Another pathway is the diversion of public and private foreign exchange funds previously toward rice imports but now toward agricultural investments in mechanization (Government import restriction policies → Local economic growth → Mechanization). These interacting mechanisms demonstrate food import substitution, which has been successful in creating positive growth in agricultural production in some countries (Kurbatova et al. 2020, Podoba et al. 2020). However, although there is potential success of food import substitution in increasing rice agricultural development, further study should investigate the potential trade-offs with food security within the context of Nigeria's rice agri-food system.

Table 2. Overview of R^2 values and regression coefficients (Coeff) of linear correlations between drivers and concepts. C1: Government import restriction policies, C2: Financing/subsidization, C3: Insecurity and conflicts, C25: Climate impacts.

	C1		C2		C3		C25	
	R^2	Coeff	R^2	Coeff	R^2	Coeff	R^2	Coeff
C4: Commercialization	0.0319	1.2339	0.8779	6.5501	0.0207	-0.9963	0.067	-1.8019
C5: Mechanization	0.0730	0.6756	0.8838	2.3775	0.0046	-0.1697	0.0397	-0.5015
C6: Demand for local rice	0.3179	1.6029	0.6388	2.2988	0.0066	-0.2315	0.0437	-0.5986
C7: Local economic growth	0.1276	1.3319	0.7910	3.3551	0.009	-0.3552	0.0738	-1.0201
C8: Market price of local rice	0.5728	0.9529	0.3369	0.7393	0.0134	-0.1461	0.0837	-0.3669
C9: Consumer preferences	0.0002	0.0054	1.0000	0.3920	0.0001	0.0044	0.0001	0.0048
C10: Quality of local rice	0.0002	0.0077	1.0000	0.5600	0.0001	0.0063	0.0001	0.0068
C11: Postharvest loss	0.0255	-0.5474	0.9001	-3.2873	0.0068	0.2836	0.0646	0.8769
C12: Landholding	0.0002	-0.0063	0.0001	-0.0061	0.0006	-0.0125	1.0000	-0.5
C13: Economic profitability	0.0320	1.0717	0.8389	5.5556	0.0441	-1.2607	0.0823	-1.7328
C14: Value chain activities	0.0319	0.9027	0.8726	4.7788	0.009	-0.4805	0.0833	-1.47
C15: Processing technology	0.0002	0.0097	1.0000	0.7000	0.0001	0.0079	0.0001	0.0085
C16: Production cost	0.0002	-0.0111	1.0000	-0.8000	0.0001	-0.009	0.0001	-0.0097
C17: Rice production	0.0378	1.4932	0.8466	7.1480	0.0111	-0.81	0.1011	-2.4599
C18: Improved farm technology	0.0002	0.0097	1.0000	0.7000	0.0001	0.0079	0.0001	0.0085
C19: Irrigation facilities	0.0002	0.0083	1.0000	0.6000	0.0001	0.0067	0.0001	0.0073
C20: Agricultural productivity	0.1509	-0.5077	0.1451	0.5036	0.1448	0.4982	0.552	-0.9782
C21: Rice area	0.0694	2.4844	0.8452	8.7685	0.0278	-1.5743	0.0579	-2.2854
C22: Fertilizers use	0.0002	0.0097	1.0000	0.7000	0.0001	0.0079	0.0001	0.0085
C23: Soil degradation	0.0845	1.2448	0.8703	4.0416	0.0327	-0.776	0.0161	-0.547
C24: Deforestation and biodiversity loss	0.0694	0.9938	0.8452	3.5074	0.0278	-0.6297	0.0579	-0.9142
C26: Pests and diseases	0.00	-0.0048	0.6563	-0.9714	0.00	0.0065	0.3321	0.6881
C27: Pesticides use	0.0002	0.0111	1.0000	0.8000	0.0001	0.009	0.0001	0.0097
C28: GHG emissions	0.0534	0.8785	0.8457	3.5380	0.0188	-0.5227	0.0806	-1.0874

Fixes that fail (expanding rice area fails to increase production because of low productivity)

The fixes that fail archetype occurs when a "quick fix" solution is implemented to address a problem symptom, but it only temporarily alleviates the problem and has unintended consequences in the long term (Fig. 8; Kim and Lannon 1997, Kim and Anderson 1998). In Nigeria's rice agri-food system, the absence of imported alternatives has increased the demand for local rice. In response to this rice demand, farmers increase rice area but soil degradation occurs, leading to low agricultural productivity and perpetuating a cycle of balancing feedback loops (B1, B2, B3, B4; Fig. 5). Several studies have highlighted the problem of soil degradation in Nigeria as limiting agricultural productivity (Liverpool-Tasie and Takeshima 2013, Olasehinde et al. 2022). Soil degradation is widespread in Nigeria because of agricultural expansion and shorter fallow periods (Onyeiwu et al. 2011, Adenle and Ifejika Speranza 2021). Soil degradation on African arable lands due to low-productivity and agricultural expansion has been reported (Osumanu et al. 2016, Jagustović et al. 2021, Prăvălie et al. 2021).

Historically rice yields have been low in Nigeria (Fig. 1). This low yield trend is also demonstrated in the FCM dynamics. In the current system (scenario A), the concept agricultural productivity stabilizes at a low value (-0.46) whereas the rice area at 7.20 (Fig. 6). This pattern of declining agricultural productivity persists in all scenarios (Fig. 6). To address this issue, a transition is necessary from the current trend of "low yields, large area expansion" to "increasing yields, declining area expansion." According to our results, priority should be given to solutions that improve agricultural productivity, such as improved farm technology, irrigation facilities, fertilizer use, and mechanization.

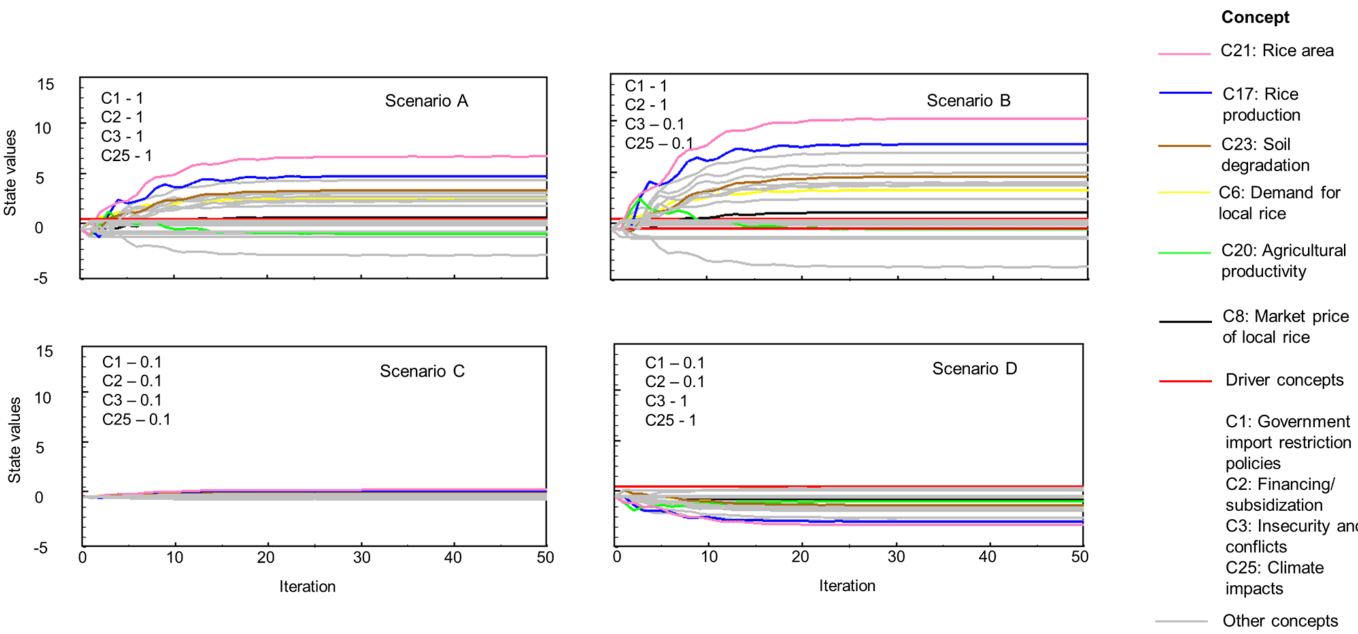
Drifting goals (government import restriction policies creates more food insecurity)

The drifting goals archetype posits that there is a gap between the current state of a system and a desired state and goal of a system (Fig. 9; Kim and Lannon 1997, Kim and Anderson 1998). The gap can be bridged by removing the goal, lowering the goal, or taking corrective action. We identify the drifting goals system archetype from our FCM dynamics under different scenarios (Fig. 6). In the current system, the government prioritizes the goal of increased rice production through import restriction policies and investment in agriculture through financing and subsidization programs. However, in scenarios C and D, when the drivers, government import restriction policies (C1) and financing and subsidization (C2), are "lowered," the system moves to undesirable states (Fig. 6). As a result, scenarios C and D show lower demand for local rice and less rice production than scenarios A and B. The radically different equilibria between the current state of the system (scenario A) and scenarios C and D can be linked to the theories of stability landscapes (Walker et al. 2004), which reflects that the system is not resilient but rather vulnerable to change (Adger 2006, Folke 2006).

Nigeria's rice import restrictions and agricultural financing policies have been inconsistent, leading to instability in food supplies (Oyejide et al. 2013, Onyiriuba et al. 2020). Other undesirable outcomes often accompany such inconsistencies. For example, increased rice import dependency followed the post-ban period of the mid-1990s, undermining import restrictions' gains (Mendez-del-Villar and Lançon 2015).

According to our results, the government's import restrictions have created a scarcity of imported rice, leading to higher demand

Fig. 6. Four scenarios showing the outcome of the change in the influence of the drivers on Nigeria's rice agri-food system. C1: Government import restriction policies, C2: Financing/subsidization, C3: Insecurity and conflicts, C25: Climate impacts.



for local rice. However, this results in higher market prices of local rice (Government import restriction policies → Demand for local rice → Market price of local rice). High production costs additionally increase the market price of local rice, making local rice less affordable and leading to food insecurity (Production cost → Market price of local rice). The demand elasticity of price determines the price response in the rice market and is affected by scarcity, as noted in the literature (Marshall 2009, Naylor and Falcon 2010, Clapp and Moseley 2020). Hence, the market protectionist measures by the government lead to market inefficiencies.

To address these risks, following the dynamic theory and strategies embedded in the drifting goals archetype (Kim 1995; Table 1), we propose that the government adjust their self-sufficiency goals and instead develop effective policies that ensure stable and affordable rice supply while developing rice agriculture (Pingali et al. 2005). The government can provide temporary corrective measures such as micro-level interventions (e.g., social safety nets, cash-based transfers, food access-based approaches, and food supply-based approaches) to protect vulnerable groups (Lorge Rogers and Coates 2002). Offering price volatility buffers can safeguard poor consumers from market inefficiencies (Lombardozzi and Djanibekov 2021). Further research should develop a comprehensive approach that evaluates the time delay between the current state of the system and the target objectives and propose an efficient transition plan.

Reflection on the analytical framework

In their recent article, Piemontese et al. (2022) propose six dimensions for validating archetypes: conceptual; construct; internal; external; empirical; and application validity. We reflect on these dimensions and highlight how we considered these in validating the archetypes. Conceptual validity refers to problem framing (Piemontese et al. 2022). Problem definition is the most important step in modeling a system and gives purpose to the modeling process (Sterman 2000). We elicited stakeholders' knowledge by discussing the current societal problems of rice demand and supply using the interview questions as a guide (Appendix 1) rather than engaging in a structured interview process. We constructed an FCM based on this knowledge, allowing stakeholders to co-produce a model of Nigeria's rice agri-food system without requiring systems thinking or technical skills.

Stakeholder knowledge played a critical role in selecting the attributes, such as concepts and connections, that form the foundation of our map and model. However, we acknowledge potential biases when the number and type of stakeholders involved are limited, which could result in an incomplete understanding of the system's complexity. Therefore, we took several measures to mitigate these potential biases, including engaging stakeholders from various backgrounds, those affected by the problem, and those influencing the system (Gramberger et al. 2015). Additionally, two rounds of feedback involving stakeholders, as well as validation from scientific literature (Alizadeh and Jetter 2017), ensured the model's internal consistency with empirically established relationships and the construct validity of our archetypes. We also combined individual stakeholders' knowledge into one FCM to minimize the impact of individual perceptions (Gray et al. 2015). Adopting these measures provided a comprehensive and contextually relevant system description (Edwards and Kok 2021).

External validity in archetype analysis refers to the extent to which the results are generalizable (Piemontese et al. 2022). Using scientific literature to establish concept names while aggregating stakeholder knowledge also provided external validity to our analysis (Alizadeh and Jetter 2017). We used generalized terminologies in concept naming, allowing cross-comparison with other countries in similar conditions.

Fig. 7. Limit to success archetype (a). structure pattern template. (b) Reinforcing loops R1, R2, R4, and R5 are efforts to increase rice production through rice area expansion. On the other hand, balancing loops B1, B2, B3, and B4 limit the growth in rice production because of low agricultural productivity constrained by soil degradation.

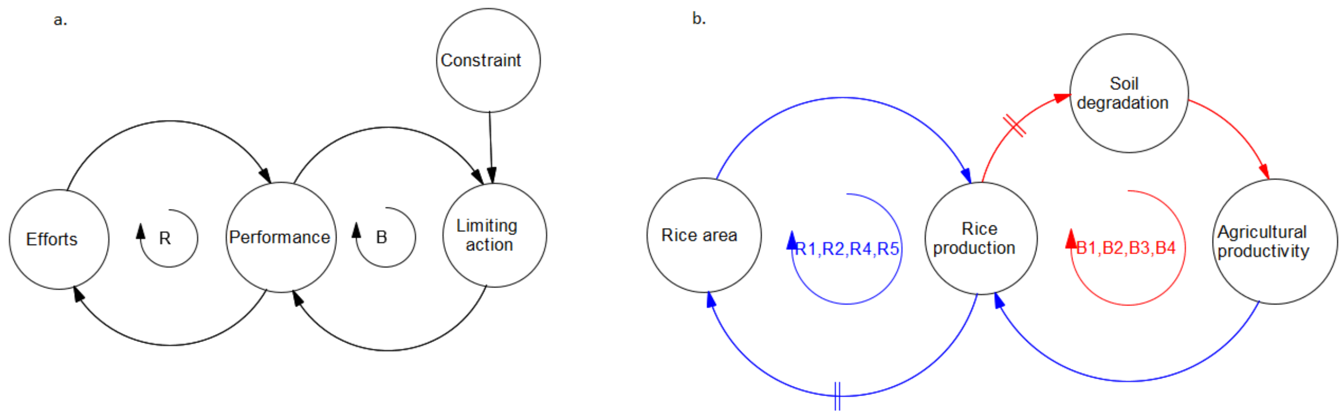
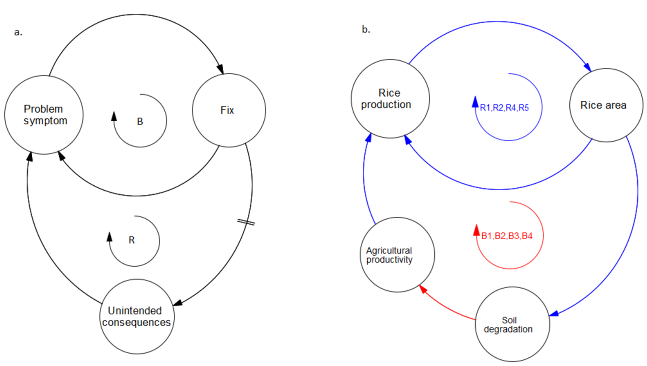


Fig. 8. Fixes that fail archetype (a) structure pattern template. (b) Reinforcing loops R1, R2, R4, and R5 are efforts to increase rice production through rice area expansion in response to increased demand for local rice. Balancing loops B1, B2, B3, and B4 represent the unintended consequences of soil degradation due to rice area expansion.



In archetype analysis, internal validity concerns how well the chosen approach fits the study context. We chose fuzzy cognitive mapping over causal-loop diagrams because the former allowed for the inclusion of stakeholder knowledge in the quantitative analysis of the system (Kok 2009). The sensitivity analysis conducted on the FCM ensured the internal validity of fuzzy cognitive mapping. Fuzzy cognitive mapping and system archetypes served as system analysis thinking tools to understand the structure and behavior of Nigeria's agri-food system. Our results confirm the complementarity and applicability of both tools for system analysis.

For empirical validity, our archetypes align with sustainability outcomes and have credible causal mechanisms. The feedback loops and causal mechanisms, matched with generic system archetypes, portray unsustainable and undesirable problem symptoms in a system. Our study directly demonstrates these problem symptoms and proposes ways to increase sustainability outcomes. Finally, applicability validity is important in sustainability research because it concerns the relevance of findings for decision making and policy making. For each archetype, we proposed strategies for the system to achieve desirable outcomes. Through stakeholder involvement, our study incorporated locally significant knowledge that enhances its suitability for guiding national policies.

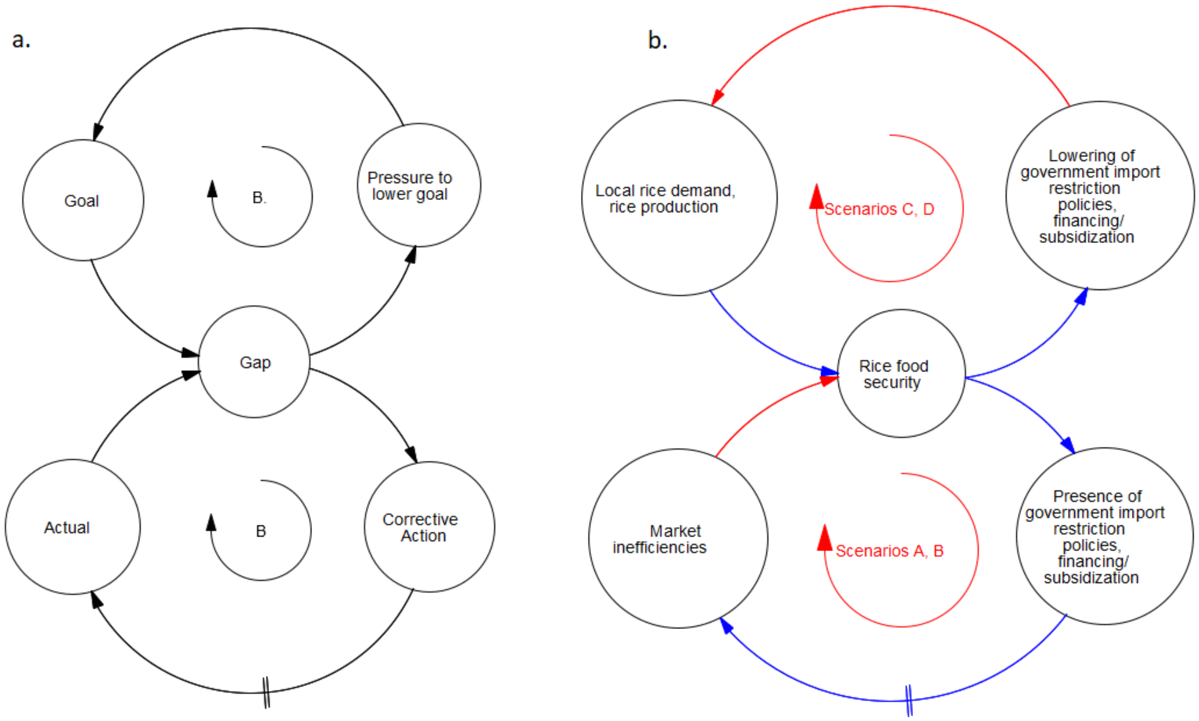
CONCLUSION

Our study acknowledged the complexity of Nigeria's rice agri-food system in ensuring rice food security in a sustainable manner. The structure and behavior of the system were described through fuzzy cognitive mapping and further analyzed using system archetypes (Fig. 2). In addition to the causal mechanisms depicted in the FCM, fuzzy cognitive mapping offers dynamic modeling of the system, allowing system archetypes to be identified through the dynamics of the system and not only through the system structure. The dynamic modeling allowed for sensitivity analysis of the system and scenario analysis providing additional insights into the system. Through this approach, we identified three system archetypes in Nigeria's rice agri-food system: limits to success, fixes that fail, and drifting goals.

The government's priority on increasing rice production drives demand for local rice through import restriction policies. In addition, the government supports local rice production through financing and subsidization programs. In response, farmers convert arable land to rice area to increase rice production. However, this rice area expansion results in soil degradation and low productivity, which limits rice production (limits to success archetype). Our results show that mechanization can increase agricultural productivity in existing rice area. Further studies should investigate the strategies and conditions to maximize mechanization to increase rice production sustainably.

As mentioned above, farmers tend to increase rice area as a "quick fix" to productivity problems, which leads to unintended consequences such as soil degradation (fixes that fail archetype). Soil degradation further decreases agricultural productivity and necessitates further rice area expansion. Therefore, farmers are

Fig. 9. Drifting goals archetype (a) structure pattern template. (b) Government efforts to increase rice food security lead to market inefficiencies. However, system-dampening dynamics result from "lowering" government import restriction policies and financing/subsidization (see Scenarios C, D, Fig. 6).



trapped in a cycle of rice area expansion → soil degradation → reduced agricultural productivity → more rice area expansion. In addition to mechanization mentioned in the previous paragraph as a solution to the limit to success archetype, from our results, improved farm technology, irrigation facilities, and fertilizers directly increase agricultural productivity and, thus, should be the target concepts to improve the system as long-term fixes of the problem of agricultural productivity.

Because of the unmet demand for local rice generated by the import-restriction policies, the government could be pressured to lower the goal of self-sufficiency (drifting goals archetype). However, from our results, suspending import-restriction policies altogether leads to undesirable system states with less demand for local rice and less rice production. Therefore, we propose that the government adjusts the self-sufficiency goals to ensure a stable rice supply, considering the time it may take for local rice production to meet rice demand. Also, poor consumers should be provided temporary micro-level interventions such as price volatility buffers.

The archetypes we have identified provide a valuable starting point for future research to improve Nigeria's rice agri-food system. Our study underscores the importance of government policies in promoting food security and sustainability while offering solutions to longstanding issues such as soil degradation, low agricultural productivity, and market inefficiencies.

Author Contributions:

Glory I. Edwards: Conceptualization, Investigation, Data curation, Formal analysis, Methodology, Software, Visualization, Writing - original draft, Writing - review & editing.
Kasper Kok: Conceptualization, Supervision, Formal analysis, Writing - review & editing, Project administration. Rik Leemans: Supervision, Writing - review & editing.

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Data Availability:

The data/code that support the findings of this study are available on request from the corresponding author, [GIE]. None of the data/code are publicly available because of information that could compromise the privacy of research participants. The research adhered to the ethical guidelines by Wageningen University and Research.

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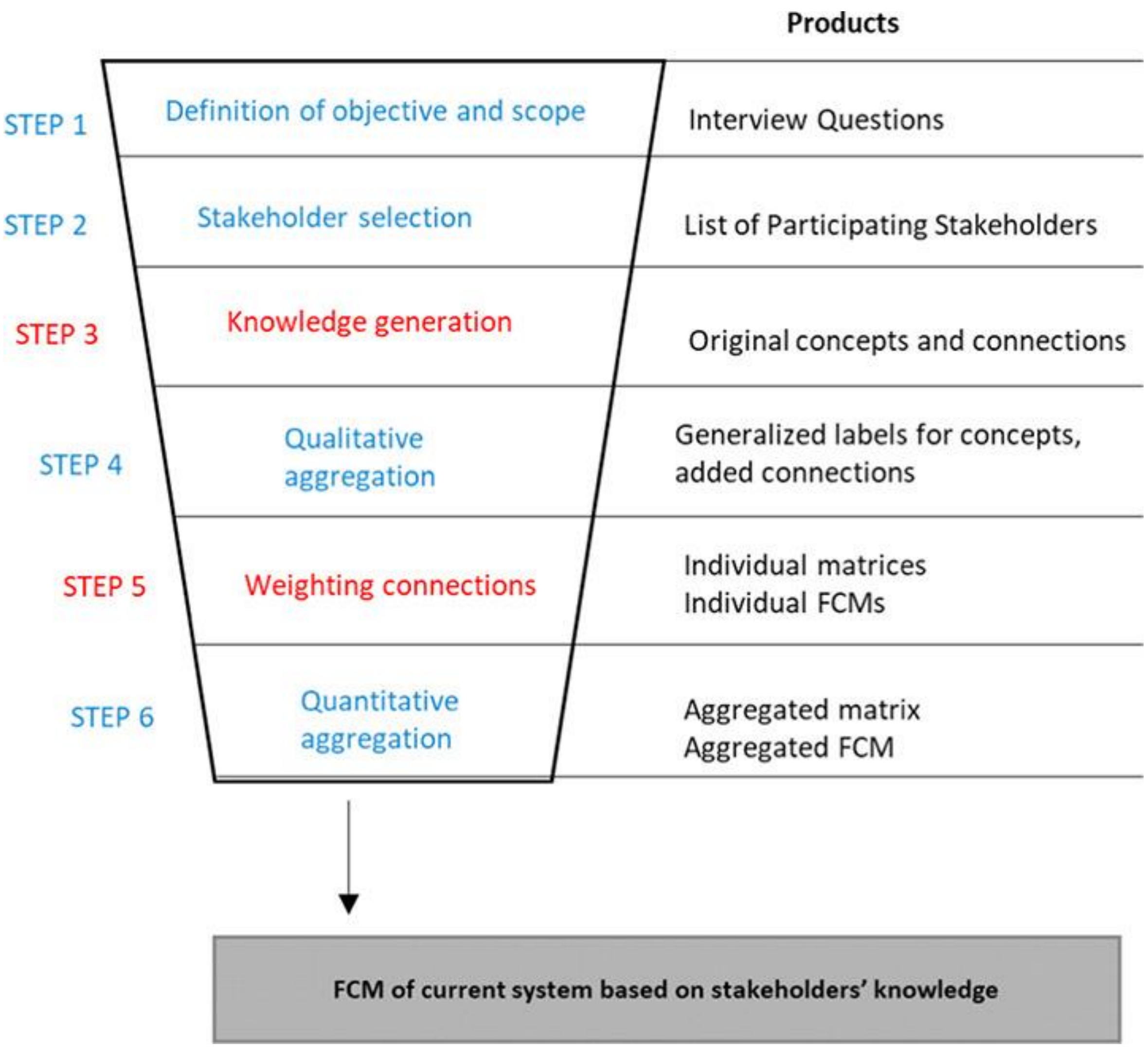
APPENDIX 1 - Fuzzy Cognitive Mapping Process and Outputs

Contents

Process of Fuzzy Cognitive Mapping using stakeholders' knowledge

(Edwards and Kok (2021))



The figure above describes the steps we followed in developing the FCM. We began with defining the study's objective, then to stakeholder selection and eliciting knowledge from stakeholders (Steps 1–3) and next, narrowing stakeholder knowledge by grouping similar concepts under generalized labels (Step 4). Further narrowing occurred as established connections were presented to stakeholders to be weighted (Step 5). Finally, these weights were aggregated to make the final FCM a single representation of stakeholder knowledge of the system (Step 6).

STEP 1: Definition of objective and scope

FCM development begins with defining the objective and the scope of the study. The objective and the scope both guide stakeholder identification and the questions posed to stakeholders. The scope refers to the study area the FCM aims to describe. Delineating the scope is important as discussions at different levels yield different results. For instance, describing a system at the farm level will result in different concepts from describing a system on a larger level such as the national level.

The objective of FCM development for this study was to understand and map the rice agri-food system and the scope was at the national level in Nigeria. The central issue discussed was "What are the drivers of rice production in Nigeria?" As such, rice production became the central concept and the beginning of FCM diagramming.

STEP 2: Stakeholder selection

Integrating multiple perspectives in understanding a complex system is highly dependent on the participating stakeholders, which makes stakeholder selection very important. Stakeholder selection was based on the Prospex-CQI method (Gramberger et al. 2015).

C = Criteria: Defining criteria and categories for stakeholder groups. The criteria are that stakeholders must have an interest or influence in rice production; and that stakeholders are either affecting or affected by the system.

Q = Quota: Setting a specific minimum quota for all categories. Four categories were present - academia, research institute staff (also extension workers), farmers, and government agencies.

I = Individuals: Identifying individuals that fit the categories, with the overall selection fitting the quotas set. We began by contacting stakeholders affiliated with institutions and then within each stakeholder category, other individuals were reached using snowballing. Participating stakeholders consisted of multi-actor and multi-scale sets of stakeholders.

STEP 3: Knowledge generation

Semi-structured interviews were held with each individual over the telephone to elicit knowledge. The same interviewer conducted all the interviews to reduce bias and risks of losing essential knowledge (Olazabal et al. 2018). Stakeholders were asked to respond to the questions according to their perception, experience and/or expertise. Interview sessions ranged from 30 to 90 min in duration. All the interviews were conducted within three months.

At the start of the interview, the researcher explained the study's objective and scope to the stakeholder. Stakeholders were to consider as wide a range as possible of concepts/factors/drivers, including social, economic and environmental factors influencing rice production. The stakeholders were asked to describe the relationships and interconnections between concepts and rice production (the central concept). No predefined list of concepts was provided for stakeholders. The interview questions (in the next section) guided the discussion with stakeholders. Depending on the stakeholder's response, follow-up questions were asked to obtain more detail while keeping rice production the central focus of the discussion.

STEP 4: Qualitative aggregation

In this step, we collated a list of concepts mentioned in all stakeholder interviews. Then, we further analysed these concepts by clustering similar concepts/terms together. To support this aggregation, we conducted a content analysis of scientific publications in the field of rice that refer to the case study country, Nigeria.

STEP 5: Weighting connections

Stakeholders participated in a 2nd episode by completing an online form. Stakeholders were presented with connections to be weighted as pairwise relationships using qualitative terms, which we converted to quantitatively assigned weighted edges between −1 and 1. These pairwise relationships allow computation of the cumulative strength of connections between the concepts with weighted edges, highlighting these connections as a system (Gray et al. 2015).

Stakeholders were asked to choose from the qualitative values – strong, medium and weak, to weigh the connections one after the other. We asked the stakeholder, "How much does concept A influence concept B (Strong, medium or weak impact)?" (Wei et al. 2008, Carvalho 2013). The perceived amount of change a concept contributes to another is what we used and not the measure of certainty of the connection. A causal loop diagram (a result of the previous steps) was provided in the online form to enable stakeholders to easily visualize the entire system while they carried out pairwise association weighting. The online form also contained a glossary of the original concepts in clusters and their generalized labels. The data were downloaded as spreadsheets and the qualitative weights were assigned the numerical values 0.9, 0.5, 0.1 for strong, medium and weak connections, respectively.

STEP 6: Quantitative aggregation

The individual weightings per stakeholder are coded into separate spreadsheets to form adjacency matrices representing individual FCMs (Diniz et al. 2015). In the matrices, connections between concepts that are not part of the FCM were assigned a weight of zero and where connections exist, the weighted value was entered. Finally, to build an aggregate FCM, the weighting outcomes for the participating stakeholders were quantitatively aggregated by using the mean value per connection.

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Interview questions used to guide stakeholders' engagement for FCM building

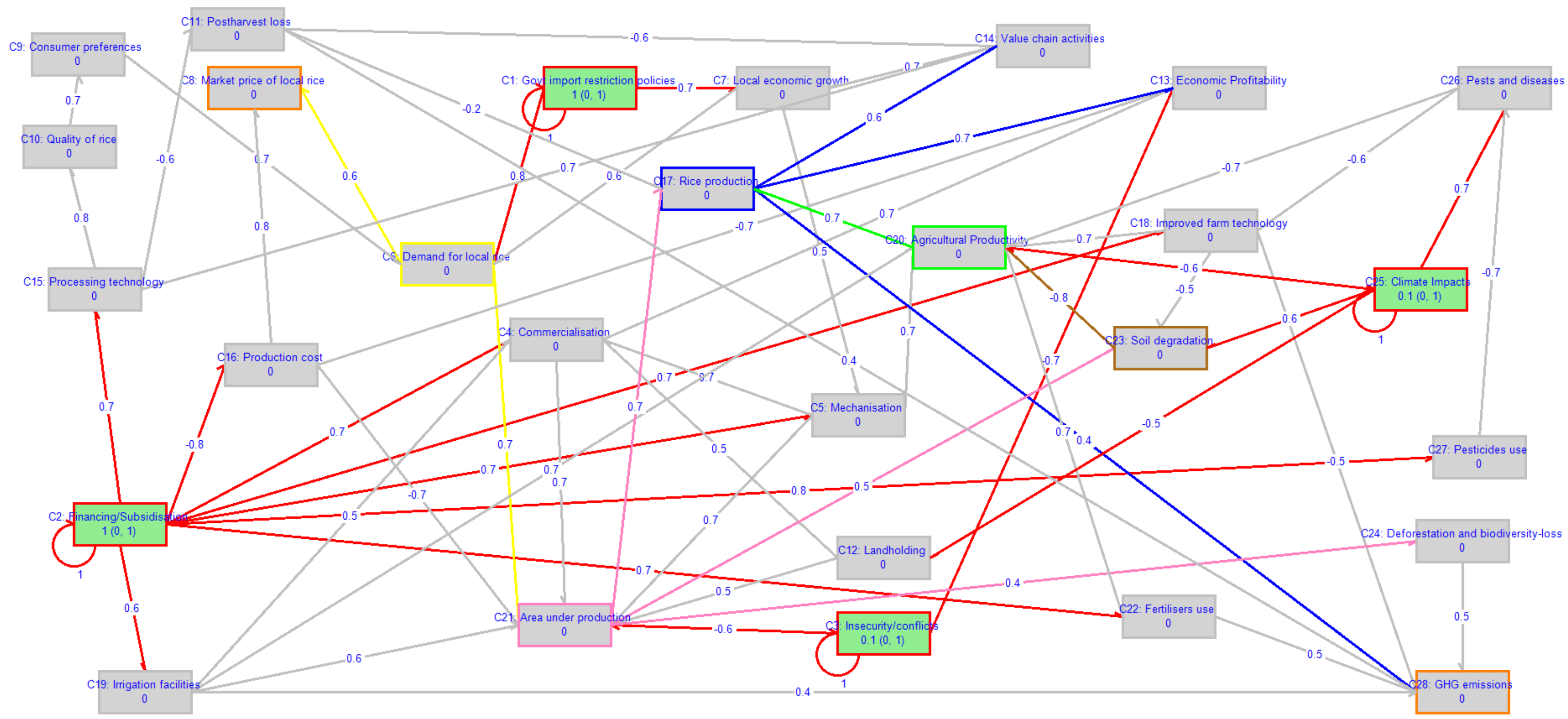
Stakeholder information	1. Name, gender, organization, and the objective of your organization?
	2. a) What is your organization's key focus regarding rice? Is it one or 2 of the following? Production, research, policy.
	b) What are the main tasks and responsibilities in your current role?
Current system	3. How is the current rice production situation in Nigeria?.
	4. What factors influence rice production in Nigeria?
	5. Is there a relationship between these factors? Positive and negative relationships.
	6. What factors are influenced by rice production in Nigeria?
	7. Identify 3 drivers that impact the nation's rice production sector? Think at a bigger scale such as national, international, global, and external drivers etc.
Actors	8. Who are the most important actors /stakeholders?
	9. Who are the most affected stakeholders?
Trends	10. Do you see certain trends in these factors in the last ten years?

Connection matrix of the fuzzy cognitive map of Nigeria's rice-agri-food system

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28
C1	1	0	0	0	0	0.8	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C2	0	1	0	0.7	0.7	0	0	0	0	0	0	0	0	0	0.7	-0.8	0	0.7	0.6	0	0	0.7	0	0	0	0	0.8	0
C3	0	0	1	0	0	0	0	0	0	0	0	0	-0.7	0	0	0	0	0	0	0	-0.6	0	0	0	0	0	0	0
C4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0
C5	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0.7	0	0	0	0	0	0	0
C6	0	0	0	0	0	0	0	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0
C7	0	0	0	0	0.5	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C9	0	0	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C10	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.2	0	0	0	0	0	0	0	0	0	0	0.4
C12	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0
C13	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14	0	0	0	0	0	0	0.7	0	0	0	-0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15	0	0	0	0	0	0	0	0	0	0.8	-0.6	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C16	0	0	0	0	0	0	0	0.8	0	0	0	0	-0.7	0	0	0	0	0	0	0	-0.7	0	0	0	0	0	0	0
C17	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4
C18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0	0	-0.5	0	0	-0.6	0	-0.5
C19	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0.6	0	0	0	0	0	0	0.4
C20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0
C21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0.5	0.4	0	0	0	0
C22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0	0.5
C23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.8	0	0	0	0	0	0	0	0
C24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5
C25	0	0	0	0	0	0	0	0	0	0	0	-0.5	0	0	0	0	0	0	0	-0.6	0	0	0.6	0	1	0.7	0	0
C26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.7	0	0	0	0	0	0	0	0
C27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.7	0	0
C28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fuzzy Cognitive Map of Nigeria’s rice-agri-food system

Map from FuzzyDANCES v. 2.0.1.0 (FuzzyDANCES- Dynamic ANalysis of Fuzzy Concepts in Evolving Systems. Developed by Farming Systems Ecology Group - Wageningen University).



Description of concepts in the fuzzy cognitive map of Nigeria's rice agri-food system

Concept	Description
C1: Govt import restriction policies	Government import restriction policies and measures to reduce import dependency and increase local production.
C2: Financing/Subsidization	Funds from the Government, donor agencies, and private-public development partnerships benefit farmers and other participants in the value chain, e.g., the Anchor Borrowers' programme. Planned subsidization of farm inputs, energy and infrastructure.
C3: Insecurity/conflicts	Herdsmen-farmer conflicts, communal clashes and other internal conflicts causing unrest and losses.
C4: Commercialization	The farming of rice, not just for family use but for commercial sale; access to markets
C5: Mechanization	The use of machines and machinery in farm processes
C6: Demand for local rice	Consumers demand locally grown rice as opposed to other alternatives
C7: Local economic growth	Local economic growth that increases the well-being of the local people
C8: Market price of local rice	The current price at which local rice is bought or sold as determined by demand and supply.
C9: Consumer preferences	Consumers' preference for local rice over imported rice and preference for local rice as a staple food
C10: Quality of rice	The physical and physiochemical properties of milled rice
C11: Postharvest loss	Losses after harvest due to milling processes, storage processes etc. leading to quality and quantity degradation.
C12: Landholding	To own or be able to rent land plots suitable for rice cultivation
C13: Economic profitability	Net returns from the production of rice
C14: Value chain activities	Processes of postharvest handling to move rice from an agricultural product to a finished product for consumers
C15: Processing technology	Processing technology in postharvest processes such as threshing, willowing, parboiling, etc.
C16: Production cost	The total cost incurred in the cultivation and production of rice as a food crop
C17: Rice production	The cultivation and production of rice as a food crop
C18: Improved farm technology	Access and adoption of improved technology such as seed varieties and improved management practices that provide technological or genetic improvements in crops.
C19: Irrigation facilities	The availability of irrigation facilities that allow for all-year-round planting, improved water management, and the effectiveness of programmes such as transforming irrigation management in Nigeria (TRIMMING)
C20: Agricultural productivity	Overall agricultural productivity is endogenous to production factors such as land, labour, and input.
C21: Rice area	Arable land used for rice production
C22: Fertilizers use	Substances, whether natural or synthetic applied to add nutrients to soil or plants to improve plant growth.
C23: Soil degradation	The physical, chemical and biological decline in soil quality leading to a decline in soil fertility and other conditions.
C24: Deforestation and biodiversity-loss	Loss of natural forests and loss of biological diversity associated with agricultural area expansion
C25: Climate Impacts	Changes in the frequency, intensity and variability of climate conditions.
C26: Pests and diseases	Rice pests and diseases such as blasts, birds, blight etc.
C27: Pesticides use	Agro-chemicals for pests and disease control
C28: GHG emissions	Methane and Nitrous oxide emissions from rice cultivation