Can invasive plants improve drought resilience? A participatory approach in Northern Nigeria

Abstract

Innovative solutions are required to fight against the uncontrolled expansion of invasive species worldwide. Hadejia Valley, in Northern Nigeria, is being colonized by cattail (*Typha spp*.), causing environmental and food security problems. Livestock activities are key for guaranteeing food security in this region, but they are compromised during the dry season. A nature-based solution is proposed that takes advantage of the invasive plant to produce silage to feed animals during the dry season and, thus, reduce the impact of cattail. To improve the adoption of this technology we propose a participatory approach using fuzzy cognitive maps to enhance the adaptation to local conditions and future implementation. We perform focus groups and face-to-face interviews with 312 people. Participants show high willingness to adopt the technology and we find positive gender-related impacts related to business opportunities. However, we also identify barriers, such as the lack of knowledge and affordability, that could be addressed by taking advantage of the social capital in the region.

Keywords: Invasive plants, Fuzzy cognitive mapping, Livestock, Silage, Action research

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1. Introduction

Disturbances of invasive species on ecosystems have been widely studied (Early et al., 2016). Currently, more than 14,000 plant species have developed outside their place of origin in a natural manner (Pysek et al., 2017). Due to climate change, ecosystems are more fragile and prone to invasion. This is aggravated by the fact that invasive plants impoverish ecosystems, causing a negative feedback loop (Bolpagni, 2021; Gaertner et al., 2014). In addition to the environmental challenge, these species cause direct problems for humans related to agricultural production, health and well-being (Shackleton, Shackleton, & Kull, 2019). On balance, invasive species pose an increasingly important challenge which can only be addressed assuming the complex nature of the systems they affect (Sullivan and York, 2021). Moreover, the United Nations has declared the 2021-2030 the ecosystem restoration decade and coping with invasive species is one of the main issues in this regard.

Traditional control efforts to either slow down the invasion or minimize their impact include chemical (herbiciding), mechanical (i.e. cutting or pulling up) and physical (i.e. prescribed burning or solarization) means. These measures are highly expensive since they must be applied on large areas and scientists wonder whether it is better to eradicate or control the invasion under limited budgets (Adams and Setterfield, 2015). Besides the high cost of control measures, expected outcomes are often uncertain and only noticeable in the long-term, which raises the challenge of their implementation (Weidlich, Florido, Sorrini, & Brancalion, 2020). The aforementioned has led to most of traditional control programs being unsuccessful (Dawkins and Esiobu, 2016). This is magnified in developing countries because they lack the means to effectively deal with invasive species. Moreover, models suggest that, under no control scenarios, non-native plants will spread rapidly, mainly due to climate and land-use changes (Vicente et al., 2013). All this makes it imperative to develop innovative measures to control invasive plants.

In this paper we analyze an “eradication by utilization” control approach, as introduced by Tessema (2012). The core idea is that, giving economic value to invasive plants, population would be incentivized to harvest them. We focus on the invasive cattail (*Typha spp.)*, a genus of semi-aquatic perennial plants, that has ravaged Northern Nigerian wetlands, resulting in flooding, disease propagation and reduction of agricultural yields (Ayeni, Ogunsesan, & Adekola, 2019). *Typha* project[i] proposes to use the biomass of this invasive plant to produce silage[ii] and thus, obtain a new feed resource for livestock that can be stocked and used during the dry season and drought episodes, when feed is scarce. This silage has proven to be a good alternative to low-quality forages although further research is needed dealing with increasing its nutritive value (de Evan et al., 2023). It is noteworthy, that livestock activities account for 30% of the agricultural added value in West African Sahel (Godde, Mason-D’Croz, Mayberry, Thornton, & Herrero, 2021) and during drought spells herders struggle to feed their animals (Traore, Chang, Rehman, Traore, & Rauf, 2020). Furthermore, climate change, together with the increase of livestock herds and the agricultural land expansion, is meant to put more pressure on the limited feeding resources (Brottem and Brooks, 2018; Faye et al., 2022). This way, the cattail-based silage is an opportunity that can be exploited to increase the feeding resources pool.

The adoption of novel technologies in developing countries remains low, although the extensive promotion done by local governments and international organizations (Ruzzante, Labarta, & Bilton, 2021). Furthermore, the innovative and disruptive nature of the proposal, together with the complexity of the problem to be solved, makes it imperative to propose innovative methodologies to involve stakeholders and make them part of the solution. Participatory approach or action research is becoming increasingly important in various fields of knowledge, but it is even more relevant in the field of adoption of technologies related to agriculture and the environment (Luján Soto et al., 2021).

The objective of this paper is to analyze the perceptions of the stakeholders dealing with the adoption of the silage in order to identify the main barriers and drivers they might cope with and the potential effects the adoption could have on social, health, food and economic aspects. This way, this article presents the application of a participatory approach that seeks to involve stakeholders from the outset, paying special attention to gender and collective action issues, which have proven to be key aspects in social-ecological challenges (Cohen et al., 2016; Sullivan and York, 2021). To do so, a fuzzy cognitive mapping (FCM) approach (Kosko, 1994; Özesmi and Özesmi, 2003) is used to relate the variables involved in the problem and the solution of the cattail invasion through the development and adoption of the novel cattail biomass-based silage.

The spread of invasive species poses a serious threat, particularly in developing countries where resources are limited. This work contributes to the literature with an innovative case study of "eradication by use" and demonstrates how the involvement of potential beneficiaries is crucial for guiding and developing nature-based solutions that mitigate this issue and benefit the community. We propose an application of FCM to analyze the impact on livelihoods of a double-dividend technology (increasing drought resilience while reducing the impact of an invasive plant). We also perform a participatory approach, regarding a relevant but little explored issue, in a highly vulnerable area of a developing country, with substantial illiteracy rates. Finally, we focus on gender differences of the technology adoption which constitutes a major knowledge gap when considering capacities to adapt and innovate (Sullivan and York, 2021). With all this, on the one hand, we intend to show how participatory approaches, followed by FCM to disentangle complex systems, can be carried out in developing countries. On the other hand, the results from the FCM provide useful insights for successful scale-up plans and reveal the potential impact cattail-based silage could have on the invasion, economy and livelihoods, as perceived by stakeholders.

The remainder of this paper is organized as follows. Section 2 highlights the impact of the cattail invasion on the case study and covers the context of livestock activities in West Africa and the challenges it faces and describes the data collection and preprocessing, and the methodological approach followed to build the FCM. Section 3, reports the results of the FCM under different scenarios and Section 4 discusses the results and proposes policies that should be considered for future successful scale-up plans. Finally, Section 5 concludes.

2. *Material and Methods*

2.1. CASE STUDY

The irrigation schemes in Northern Nigeria, and specifically the Hadejia-Nguru wetlands (HNW), are suffering the cost of invasive plants, since in recent decades, with the colonization of the invasive cattail, there have been problems of flooding, disease and reduction of agricultural yields (Ahmed, Agodzo, Adjei, Deinmodei, & Ameso, 2018). HNW is located in the Sahel zone of Nigeria (Fig. (1)) and cover approximately 8,000 km^2. These wetlands provide work to about 1.5 million farmers, herders and fishermen (Ayeni et al., 2019) and it has also high importance in terms of biodiversity conservation as many migratory birds use them as breeding ground (Takekawa et al., 2015).

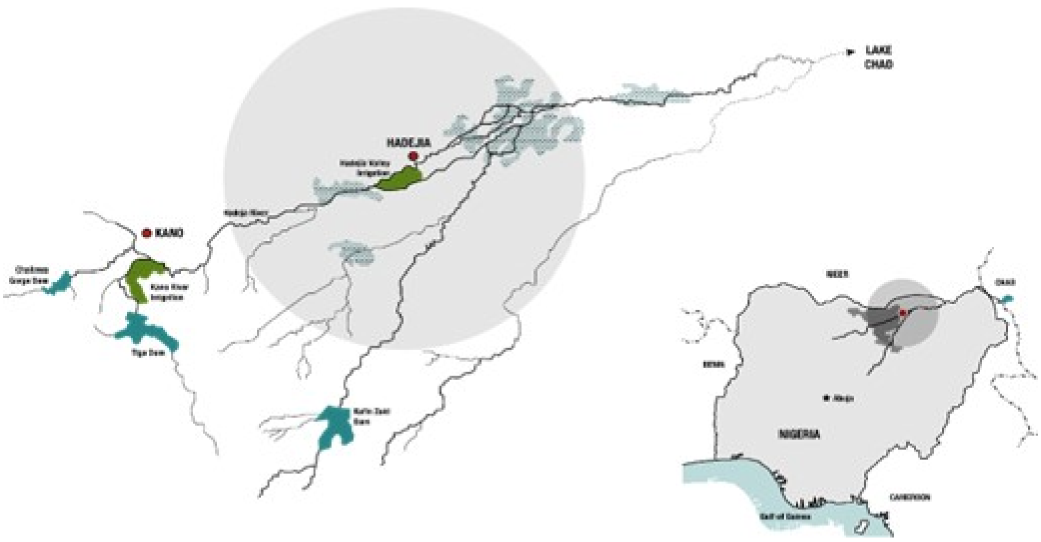

Figure 1. Location of Hadejia Valley in Nigeria (Source: Typha Project website)

Dealing with livestock activities, 46 % of households in Hadejia Valley are involved in cattle production and 42% in small ruminants (sheep and goats) production (FMWR and World Bank, 2017). During the dry season (September-May) many herders abandon Hadejia Valley and begin transhumance in search of pastures. Climate change has already affected grazing lands (Stanimirova et al., 2019) and it is expected that rangeland net primary productivity will decrease 42% by 2050 under RCP4.5 and 46% under RCP8.5 in western Sub-Saharan countries (Trisos et al., 2022).

Furthermore, conflicts between farmers and herders are becoming increasingly important due to the increasing scarcity of resources, provoked by the expansion of the agricultural frontier and climate change (L. V. Brottem, 2020). The growing presence of terrorism in the area is also altering transhumance patterns putting more pressure on scarce pastures (George, Adelaja, Vaughan, & Awokuse, 2022), leading Nigerian grazing lands to suffer the tragedy of the commons (Aderinto, Ortega-S., Anoruo, Machen, & Turner, 2020). As a further factor to be considered, it is expected that the number of herds will increase because of population growth and rising incomes. This, together with the fact that the available surface will dwindle due to desertification and the variation in precipitation and temperatures, will step up the challenge of feeding the animals. In this context, increasing fodder resources could improve livestock activities (Mertz et al., 2010).

2.2.PARTICIPATORY APPROACH AND FCM

Our methodological approach is based on a participatory research, also known as action research, which encourages horizontal interaction among researchers and stakeholders in the technology design and adoption process, integrating local scientific knowledge and reducing power imbalances (Luján Soto et al., 2021). In this way, bottom-up ideas are generated, and stakeholders are more easily motivated to apply what they have learned. Therefore, action research has a double benefit. It generates knowledge that can be used by policy makers when designing strategies to foster technology adoption (bottom-up ideas) and it makes implementation easier since stakeholders have been considered during the whole process (social learning). This way, stakeholders will be keener on adopting the technology, thus, controlling in a better way the expansion of cattail.

The participatory approach was done through a FCM, a causal qualitative graphical representation of the dynamics in a system based on the understanding of individuals, which may include local or expert knowledge (Özesmi and Özesmi, 2003). These graphs contain concepts or factors depicted by boxes which are linked by arrows representing their causal relationship. The intensity of connections can range from -1 to 1, where negative (positive) values represent negative (positive) causal effects. The higher the absolute value, the greater the causal relationship will be, with values close to 0 indicating weak causality. FCM is an adequate tool to identify the main dimensions of the agro-ecosystem in relation to the project's objective as perceived by the potential beneficiaries, discovering drivers, barriers and impacts of the adoption of cattail-based silage, and the relationships among them.

This methodology is increasingly being used to model social-ecological relationships and potential outcomes of ecosystem restoration and conservation programs (Baker, Holden, Plein, McCarthy, & Possingham, 2018; Gray et al., 2017; Hunter, Britz, Jones, & Letnic, 2015). It is a helpful method for modelling systems in which resilience is to be increased (Johnson et al., 2012), to ease adaptation and mitigate potential risks (Devisscher, Boyd, & Malhi, 2016). It has also been applied to analyze climate-smart technologies adoption (Luján Soto et al., 2021). In addition, this approach permits to consider qualitative data and simulate dynamic systems as opposed to traditional statistical methods, which makes it especially valuable when there is a lack of information (Hossain and Brooks, 2008), as in many developing countries. However, most of the studies focus on high-income countries and developing ones remain clearly underrepresented in the FCM literature. This could be because of the complexity of eliciting stakeholders' opinions in these regions.

2.3. DATA COLLECTION

Normally, a FCM is built directly by the stakeholders, but, in this case, due to the large number of people involved and their limited formal education, the process was set up in four stages. As a kick-off, the project was presented to the stakeholders during an inception workshop. At a second step, after sharing information with stakeholders on the project, 7 focus groups were conformed, 3 of women and 4 of men, separated by gender because of cultural traditions. The focus groups were conducted with the help of trained local partners with semi-structured and open questions about their livestock activities and the perceived benefits and main concerns regarding the adoption of cattail-based silage. A balanced composition of participants by gender was intentionally pursued and 31 women and 38 men participated. In the third step, based on the results of focus groups, a face-to-face questionnaire was designed and conducted for men and women in the same household. Sample selection was random among eight local communities but restricted to those households engaged in livestock activities. A total of 168 men and 144 women between 18 and 68 years old were interviewed. Subsequently, the collected data was used to construct the FCM.

2.4. FCM DEVELOPMENT PROCESS

The map was exclusively built on stakeholders' perceptions. For this purpose, the influencing variables and their causal relationships were identified from the focus groups and questionnaires results, respectively. The intensity of the relationships was estimated on the basis of a Likert scale. In this way, an intensity equal to unity would be produced if all the individuals gave the highest importance to that fact and an intensity equal to 0.5 could be either because all the individuals gave it a medium importance, or because half of the individuals gave it a maximum importance and the other half a null importance. Eq. (1) shows how the intensity of the relationship was calculated. Based on the intensities and the causal relationships the adjacency matrix is built.

$$I = \frac{\sum_{j=0}^{4} jN_j}{4N} \tag{1}$$

Where:

j= The score of the Likert scale (0,1, 2, 3 or 4)

N_j= Number of people that selected the option j

The FCMs were separately done for women and men to consider gender issues. We aggregated the maps based on Banini and Bearman (1998), where the aggregated FCM is obtained by weighting, both by the number of respondents in each group (n_i) and by the decisional weight of each group (p_i) (See Eq. (2) and Eq. (3)).

$$E_C = \sum_{i=1}^{I} \pi_i \; E_i \tag{2}$$

$$\pi_i = \frac{p_i \frac{n_i}{N}}{\sum_{i=1}^{I} p_i \frac{n_i}{N}} \tag{3}$$

Where N represents the total number of respondents, E_c the aggregated adjacency matrix and E_i the adjacency matrix for group i. Based on a question dealing with the power to make important decisions, we determined a decisional weight of 2/3 and 1/3 for men and women, respectively. Fig. (2) shows the methodological flowchart.

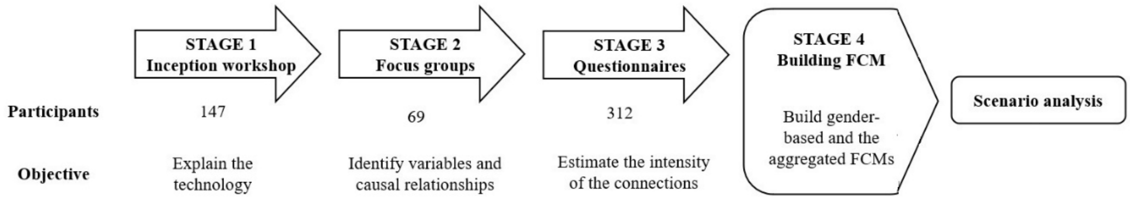

Figure 2. Methodological flowchart

2.5.FCM ANALYSIS

First of all, typical FCM analysis metrics such as the density, indegree and outdegree values, and centrality are studied as proposed in Özesmi and Özesmi (2003). The clustering coefficient or the density of the FCM is an index that explains the connectivity degree of the variables. The higher the density of the map, the greater the connections between the variables will be, which may be interpreted as a catalyst for change (Özesmi and Özesmi, 2004). The outdegree value [od(v_i)] shows the cumulative strength of factors exiting the variable while the indegree value [id(v_i)] represents the cumulative strength of factors entering the considered variable. Variables can be classified according to their indegree and outdegree values in 3 categories: Transmitter variables (od>0 and id=0), receiver variables (od=0 and id>0) and ordinary variables (od>0 and id>0). Transmitter variables may be interpreted as barriers or drivers of the system, and receiver ones explain the impact other variables provoke. Having many receiver variables is an indicative of the complexity of the map and transmitter variables indicate that there exist top-down influences (Eden et al., 1992). Finally, the centrality (c_i) of a variable is the sum of the outdegree and indegree values and reflects its importance in the system.

FCMs are a great tool to perform scenarios and test how a certain action or policy might affect the system (Kok, 2009). We build the scenarios multiplying the adjacency matrix by a state vector *A* (unity vector in this case) over multiple iterations *t* as performed in Ballesteros-Olza et al. (2022). We use the activation rule with self-memory (Eq. (4)) for the iteration process based on Kosko (1994) and modified by Stylios and Groumpos (2004).

$$A_j^{(t+1)} = f\left(k_{1,i}\sum_{\substack{i=1\\i\neq j}}^{I} A_i^t w_{i,j} + k_{2,j}A_j^t\right) \tag{4}$$

Where A_j^{t+1} is the value of concept *j* at iteration *t+1*, *f* is a threshold function, A_i^t is the value of concept *i* at iteration *t*, $w_{i,j}$ the weight of the causal connection between concepts *i* and *j*, and A_j^t the value of concept *j* at iteration *t*. k_1 and k_2 are two coefficients that must be between 0 and 1 and may be different for each concept. The selection of these coefficients depends on the nature of the concept. Following Kosko (1994), we assume that k_1=1 and k_2= 0 for every concept. We use the sigmoid threshold function as in Solana-Gutiérrez et al. (2017) (Eq. (5)).

$$f(x) = \frac{1}{1+e^{-\lambda x}} \tag{5}$$

Where λ is a positive number that determines the steepness of the function. We set its value to 1 as in Ballesteros-Olza et al. (2022).

We perform 3 different analyses of the FCM: (1) We study the aggregated FCM considering the hypothetical scenario where cattail silage exists and compare it with the current situation in which stakeholders do not take advantage of this resource. We do this by eliminating the *Cattail silage adoption* variable. This way, we simulate a hypothetical scenario where cattail silage can be produced and adopted and compare it to the current state of the system or baseline scenario. (2) We also analyze gender differences and (3) we perform both positive and negative scenarios. In the negative scenario, we fix the *Cattail invasion* variable to 0.9 (based on stakeholder's perceptions on the increase of the cattail population in the last 10-20 years). In the positive scenario we simulate that a program fostering collective action in harvesting and preparing *Typha*-based silage is implemented (we fix the *Collective action* variable to 0.9).

3. *Results*

3.1.BASELINE SCENARIO: WITH AND WITHOUT CATTAIL SILAGE

Fig. (3) presents the aggregated FCM and Fig. (4) the steady state values of the system after convergence with and without the *Cattail silage adoption* variable. These results reveal that the cattail silage technology would incentivize weeding (+0.12 compared with the current situation). However, results on cattail population reduction are more modest (-0.02).

The expected outcome on livestock activities is much stronger (+0.15). Moreover, the two main constraints to livestock activities, feed cost and feed non availability, would be reduced by 0.19 and 0.20, respectively. During the focus groups, many stakeholders argued that during the dry season or in dry spells, feed non availability is the main concern. Even if they had enough money to buy feed, they would not have the possibility to buy it because of its scarcity.

The increase in the feeding resources pool would reduce the conflict between farmers and herders (-0.22). In addition, stakeholders perceived that this new technology could generate new business opportunities related to its value chain (+0.15). Many participants in the focus groups, especially most vulnerable ones (women and youth) highlighted that they intended to produce silage to sell it.

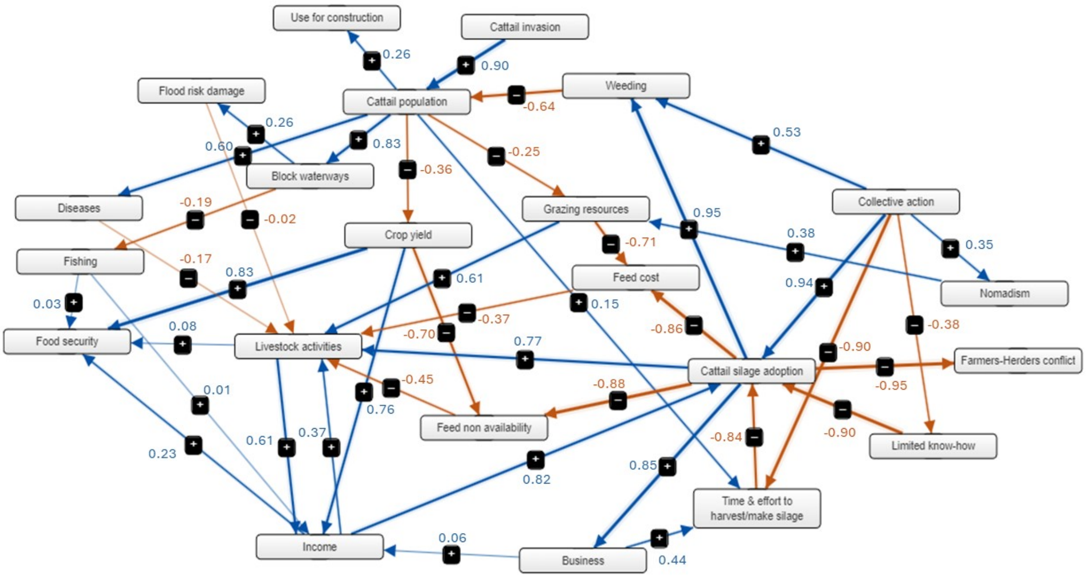

Figure 3. Aggregated Fuzzy cognitive map. Blue (red) lines represent positive (negative) connections, and the numbers represent the intensity of that connection

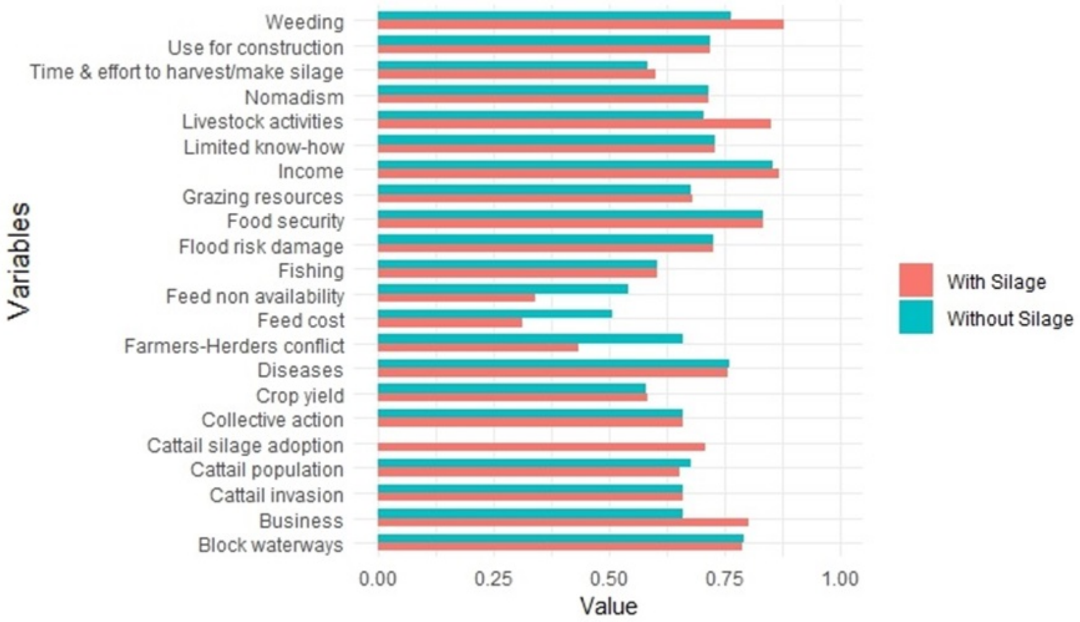

Figure 4. Steady state values of the system with and without cattail silage

Table 1 shows a summary of the main indices of the aggregated FCM when the cattail silage is adopted. The high number of connections per concept (1.9) indicates that there are many relationships between variables which may be interpreted as an indicator that the system is easily modifiable, as stakeholders options have more impact (Özesmi and Özesmi, 2003).

Index	**Value**
Connections	42
Concepts	22
Density	0.0868
Transmitter variables	2
Receiver variables	3
Ordinary variables	17

Table 1. Indices of the aggregated Fuzzy Cognitive Map

Fig. (5) summarizes the importance of each concept according to the outdegree and indegree values. The variables related to cattail (*Cattail silage adoptio*n and *Cattail population)* are the most central ones followed by *Livestock activities*. *Collective action* (also known as social capital), which includes aspects such as membership to organizations, feeling of togetherness or trusting others, stands out as a highly relevant concept. In our study, more than 2/3 of the sample declared they belonged at least to one organization and 85% of the respondents stated that the feeling of togetherness in the village or neighborhood was “very close”.

In the middle of the ranking, we find variables related to the impact of the cattail invasion (*Crop yield*, *Feed non availability*, *Feed cost* or *Grazing resources*) and concerns that may constrain the adoption of the silage such as *Time & effort to harvest/make silage* or *Limited know-how*. Indeed, during the focus groups stakeholders were worried about not being able to produce a quality silage and the possible ill effects it could have on the animals. Furthermore, some interviewees underscored that the presence of poisonous reptiles amidst the weed could deter the collection of cattail.

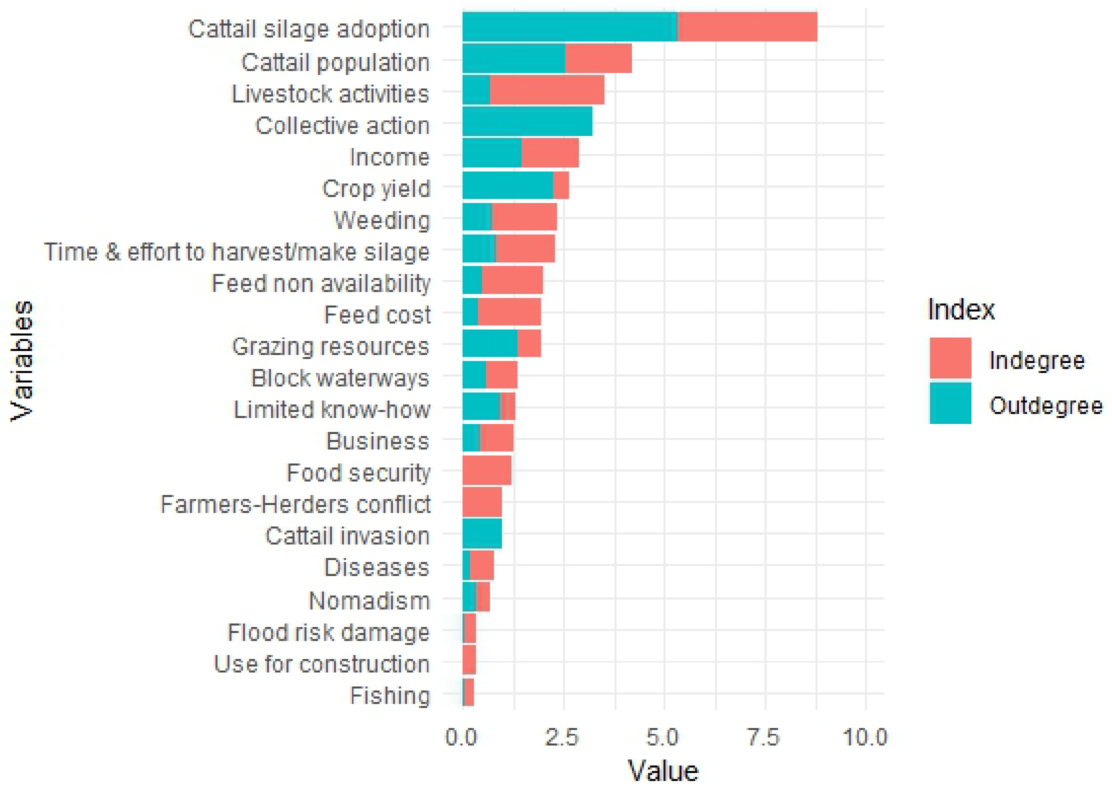

Figure 5. Outdegree and indegree values for each concept in the aggregated map

3.2.GENDER DIFFERENCES

Concepts in the gender-based FCMs were similar except for the *Use for construction* variable, which was not mentioned by women. However, the intensity of some connections did vary substantially. The objective of this subsection is to test which gender is more sensitive to the effects of the cattail invasion, on whom more efforts should be made to foster adoption and what would be the effects of the cattail silage on the system according to men and women. Fig. (6) shows the difference in the steady state values for the gender-based FCMs with and without the *Cattail silage adoption*.

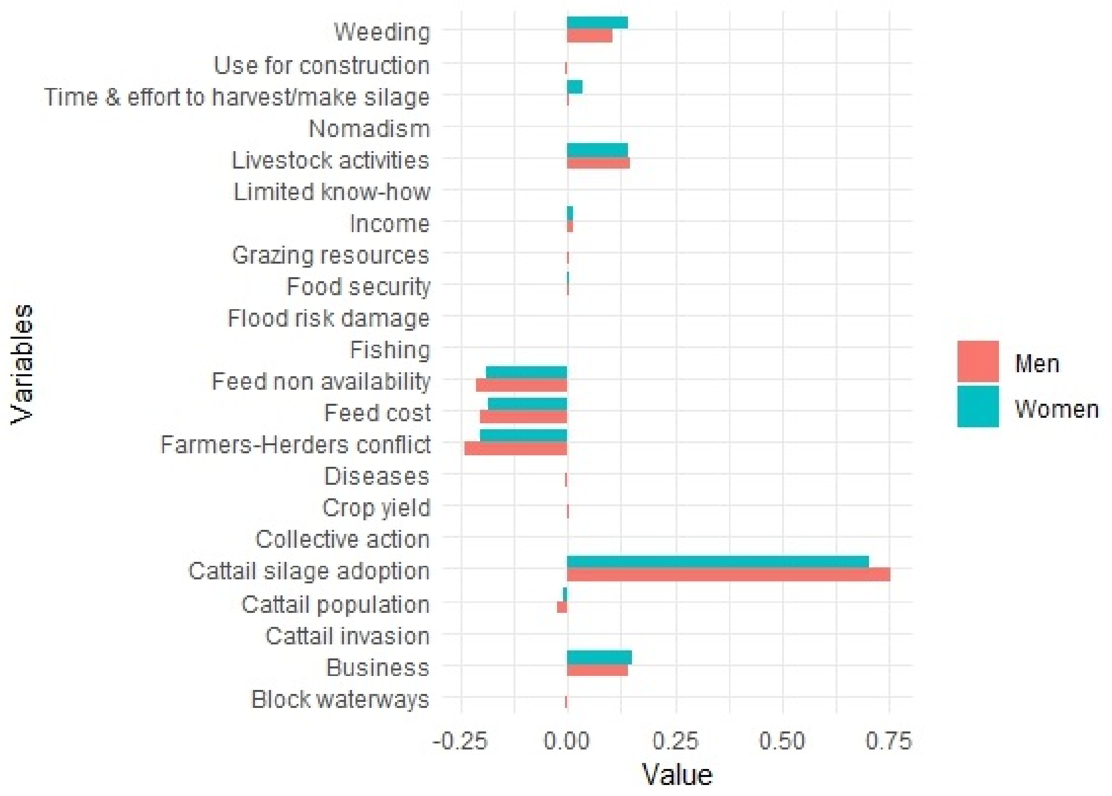

Figure 6. Differences in the steady state values of the gender-based FCMs with and without adoption

As compared to men, women are more aware of the detrimental effects of the cattail invasion (i.e. Diseases and the effect of *Typha* invasion on grazing resources and crop yield). However, they are more skeptical regarding the reduction of the cattail population and conflicts between farmers and herders accomplished by the introduction of this new practice. This could be derived from the fact that women, in general, stay at home and do not know exactly the dynamics of this clash.

At the present time, men are the ones in charge of weeding, but the introduction of the cattail silage could lead women to become involved in silage preparation and even its commercialization. Regarding the concerns related to the adoption of the technology, women feel that time and effort to harvest and make silage would be a greater barrier for the adoption. Perceptions on the positive impact of the silage on *Livestock activities*, *Feed cost* and *Feed non availability*, in relative terms, are larger for women, which are, in general, in charge of small ruminants. Moreover, this new technology is seen as a new business opportunity mostly by women, who suffer larger unemployment rates.

3.3. SCENARIO ANALYSIS

In the negative scenario we conduct a model simulation assuming that the invasion continues or increases its rate due to climate change or human activities. The model reached stationarity after 20 interactions. Fig. (7) illustrates the relative changes in the values of the variables between this scenario and the baseline scenario shown in Fig. (4). The variables on which the increase in encroachment would have the greatest effect are those directly affected by the cattail population, according to stakeholders, such as *Crop yield* or *Block waterways*. However, if silage is available and people adopt it, the impact of an increase in the level of invasion is minor (i.e. all the differences are smaller in absolute values).

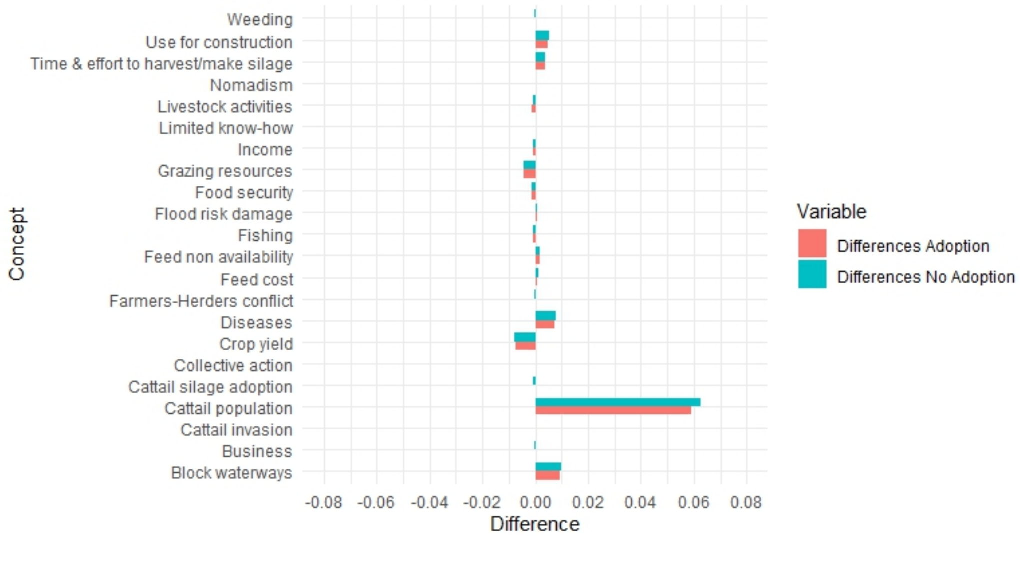

Figure 7. Differences between the negative scenario (Cattail invasion variable is set to 0.9) and the baseline scenario considering that it does exist adoption and it does not.

In the positive scenario, we simulate which would be the impact of increasing collective action regarding the adoption of silage and its possible effects. This could be achieved by holding workshops, or conducting demonstrations on how to make the silage or regarding the positive impact this product can have. In this scenario, we set the value of *Collective action* to 0.9. Fig. (8) illustrates the relative changes in the values of the variables between the positive scenario and the baseline scenario shown in Fig. (4).

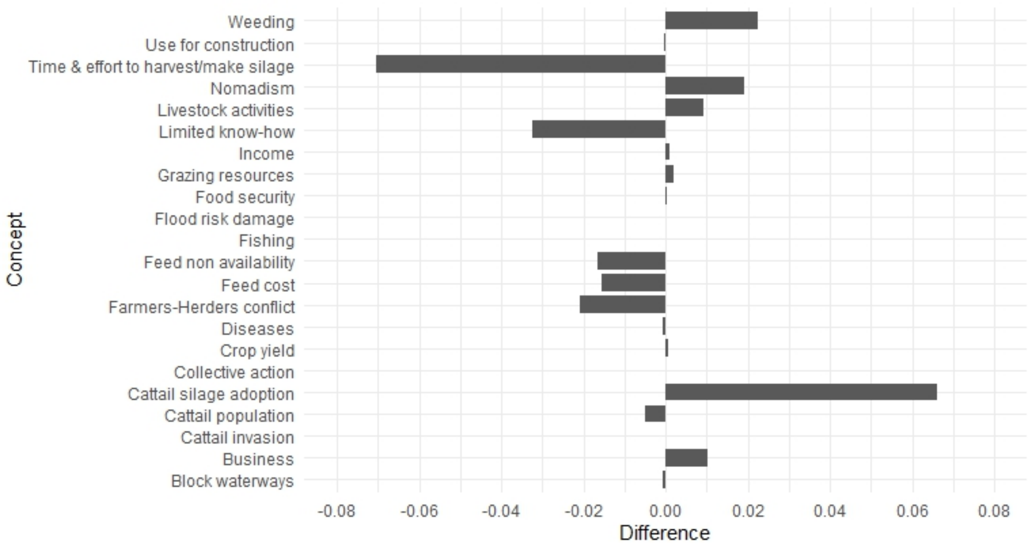

Figure 8. Differences between the positive scenario (Collective action is set to 0.9) and the neutral scenario in which adoption is not fostered by increasing collective action.

When promoting collective action, the main concerns that diminish the adoption of the silage (*Time and effort to harvest/make silage* and *Limited know-how*) are reduced and this makes the *Cattail silage adoption* increase compared to the baseline scenario. We see that the adoption of silage enhances the variables related to livestock activities, feeding the animals and it reduces the conflict between farmers and herders too. However, the stakeholders feel that the impact over the cattail population would not be as high as desirable.

4. *Discussion*

The FCM analysis indicates that stakeholders harbor doubts regarding the efficacy of adopting silage to diminish the proliferation of the invasive cattail, primarily due to its extensive spatial occupancy and rapid growth and reproductive rates but they consider it could have a buffer effect and mitigate its impact in critical areas. The skepticism related to the ecological restoration effect stands in contrast to the optimism surrounding the potential benefits that cattail silage could confer upon the livestock sector. Introducing a novel source of feed into the available resource pool has the potential to alleviate resource scarcity during the dry season or droughts, events that pose significant threats to livestock activities and food security. Consequently, animals could be better nourished, thereby avoiding weight loss, which would enable farmers to refrain from selling them prematurely. This, together with decreasing mortality rates, could prevent herders from falling into a poverty trap (Carter and Barrett, 2006). Given that nearly half of the population in the Hadejia Valley is engaged in livestock rearing, the overarching impact of cattail-based silage on local communities could be substantial.

As a consequence of increasing the feed resources pool, herders would not be forced to migrate to unexplored unstable areas. Furthermore, the adoption of silage would render herders somewhat less reliant on weather conditions and afford them greater flexibility in determining the commencement of transhumance. As a result, livestock would be less inclined to encroach upon unharvested croplands, thereby potentially mitigating conflicts between farmers and herders. In fact, Nnaji et al. (2022) highlight the need to foster new practices and technologies to tackle this conflict.

Cattail silage value chain encompasses various stages, including plant harvesting, transportation, processing, and storage. It is remarkable that new products' value chain can boost development in low income areas (Olmedo, van Twuijver, & O'Shaughnessy, 2021). Each of these stages presents opportunities for the development of new businesses, particularly for groups facing challenges in accessing the current labor market, such as women and young people. Hence, it is imperative to furnish these groups with appropriate infrastructure and tailored tools to facilitate their engagement in these activities. For instance, distributing smaller bags designed to accommodate the physical characteristics of women could stimulate adoption. This approach would align economic development in the region with the enhancement of living conditions for vulnerable groups.

However, none of the benefits will materialize unless a substantial portion of the population adopts this technology. Constraints related to limited expertise, potential adverse effects on animals, and the effort involved in preparing silage emerge as primary factors that could undermine adoption. To avoid these issues, organizing workshops and demonstrations that illustrate the process of producing quality silage efficiently can serve as an effective solution to promote adoption. Moreover, experimental collaborations with farmers could be conducted to demonstrate that silage poses no detrimental effects on animals. In addition, to reduce the time and effort required to harvest or make the silage, public administration or donors could subsidize the purchase of the machinery necessary (i.e. shredding machines) to carry out the process efficiently. Weeding tools customized for this plant and designed to minimize the threat of poisonous reptiles should also be developed and subsidized.

These initiatives could be channeled through local organizations. In fact, many studies highlight the importance of social capital in sub-Saharan Africa (Kansanga, Luginaah, Bezner Kerr, Lupafya, & Dakishoni, 2020) and it has proven to be an opportunity to enhance adaptation to climate variability in this region (Ombogoh, Tanui, McMullin, Muriuki, & Mowo, 2018). For instance, workshops and demonstrations could be hosted in these organizations. Primarily, a small group could be trained, and, at a second stage, they could act as information disseminators. Moreover, to foster vulnerable groups' entrepreneurship, in addition to targeted information and workshops on how to prepare silage bags, subsidies could be provided for the purchase of material by the organizations and subsequently shared by their members. This way, the total cost would be lower and information dissemination could be increased.

Furthermore, leveraging social capital can serve as a catalyst for synergies between herders and farmers. For example, herders could contribute to the eradication of cattail from areas adjacent to croplands and facilitate large-scale ensiling processes directly in the fields. Subsequently, during the dry season, herders could utilize these fields, situated near water sources, to provide silage for their animals, simultaneously fertilizing the land. This reciprocal arrangement would afford herders access to both water and animal feed, while farmers benefit from the clearance of cattail and natural fertilization of their fields.

5. Conclusion

Fighting invasive species is a persistent struggle in many developing countries. Moreover, climate change, in addition to its own consequences regarding food security or the increase in the probability of extreme events such as droughts, is accelerating their spread and impact. On another note, livestock activities are key to the survival of millions of people in sub-Saharan Africa. Drought events, the expansion of the agricultural frontier, and conflicts are putting more pressure on the availability of grazing lands, resulting in a lack of feed for the livestock. All these factors make it necessary to introduce new practices to increase the availability of feed.Our work contributes to the literature through a participatory approach in an innovative case-study on “eradication by use” that can provide valuable guidelines to other areas in developing regions.

In this article, we focus on Hadejia Valley (Northern Nigeria) that has been ravaged by the invasive cattail (*Typha spp.*). We assess stakeholders’ perceptions about an innovative “eradication by use” approach based on adoption of a cattail-based silage to feed the animals during the dry season. This way, stakeholders would be incentivized to weed the cattail, reducing its population while increasing the feed resources pool. To analyze the potential impact of this technology, we suggest a participatory approach and build a Fuzzy Cognitive Map considering 312 stakeholders’ perceptions. This approach is especially valuable to engage them and underpin the adoption of new practices. We propose a way to implement this approach in vulnerable areas with high illiteracy rates dividing the process into 4 stages.

The stakeholders perceive that this double-dividend technology could reduce the feed cost, improve livestock activities, and reduce the conflict between farmers and herders while mitigating the population of the invasive plant. Women are more skeptical about its benefits and have major concerns that could undermine the adoption of the silage. However, they perceive that it could be an opportunity to develop new businesses related to its value chain. Therefore, to unleash the full potential of this technology, it is necessary to carry out gender-based policies to reduce skepticism. Moreover, strong social capital and collective action can be used to promote information. To this end, local organizations could act as information sharing hubs, holding workshops and demonstrations for instance. In addition, gender specificities should be considered in a scale-up program through demos and information.

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Figures and Tables

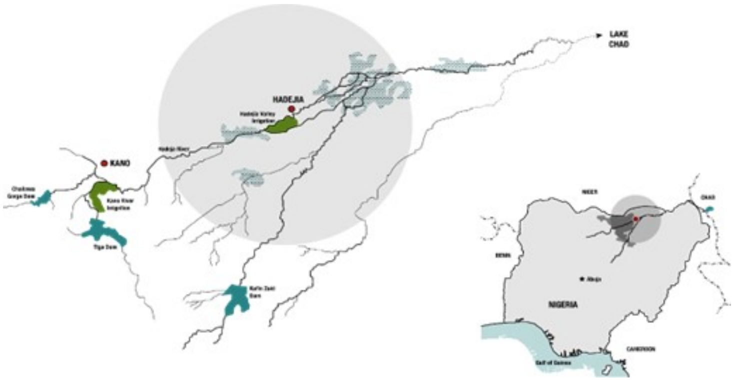

Figure 9. Location of Hadejia Valley in Nigeria (Source: Typha Project website)

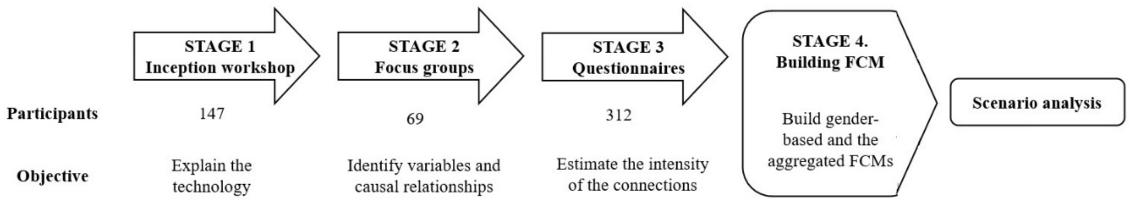

Figure 10. Methodological flowchart

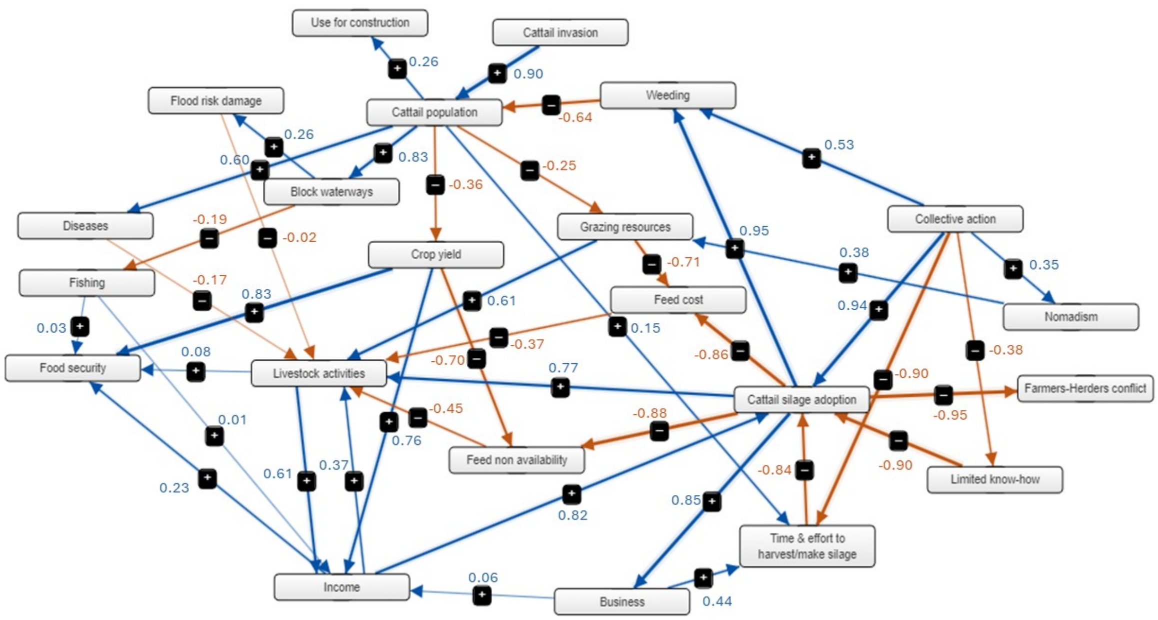

Figure 11. Aggregated Fuzzy cognitive map. Blue (red) lines represent positive (negative) connections, and the numbers represent the intensity of that connection

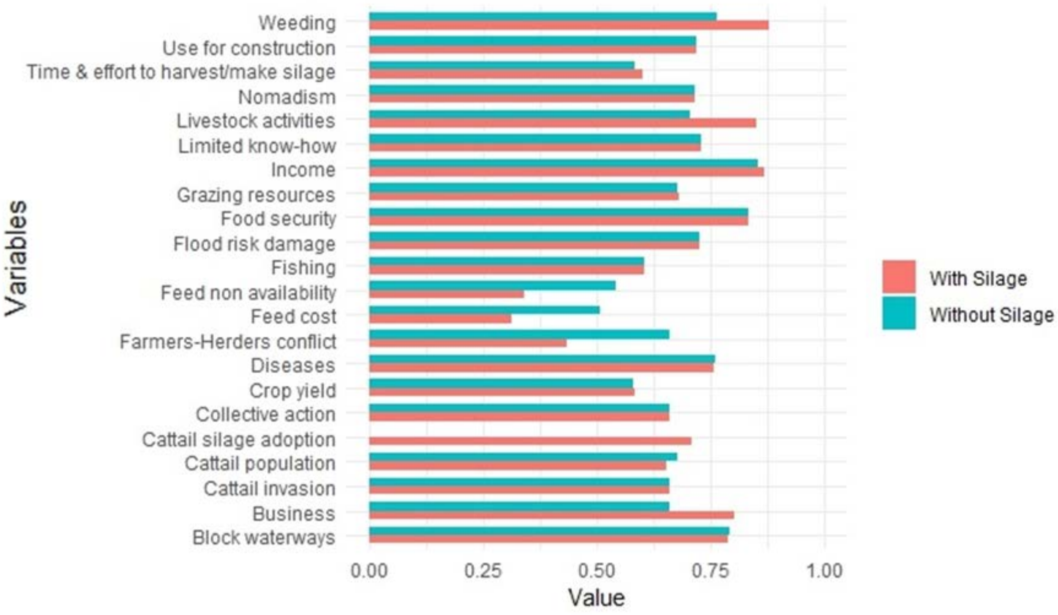

Figure 12. Steady state values of the system with and without cattail silage

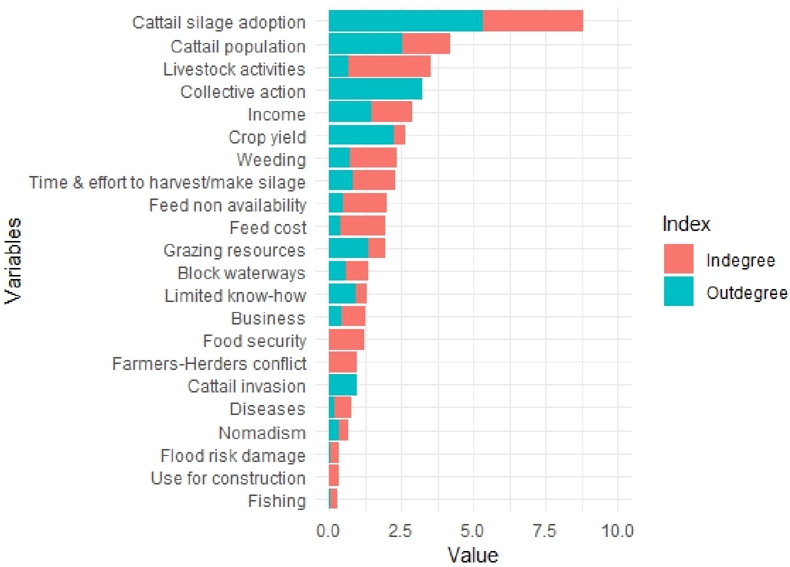

Figure 13. Outdegree and indegree values for each concept in the aggregated map

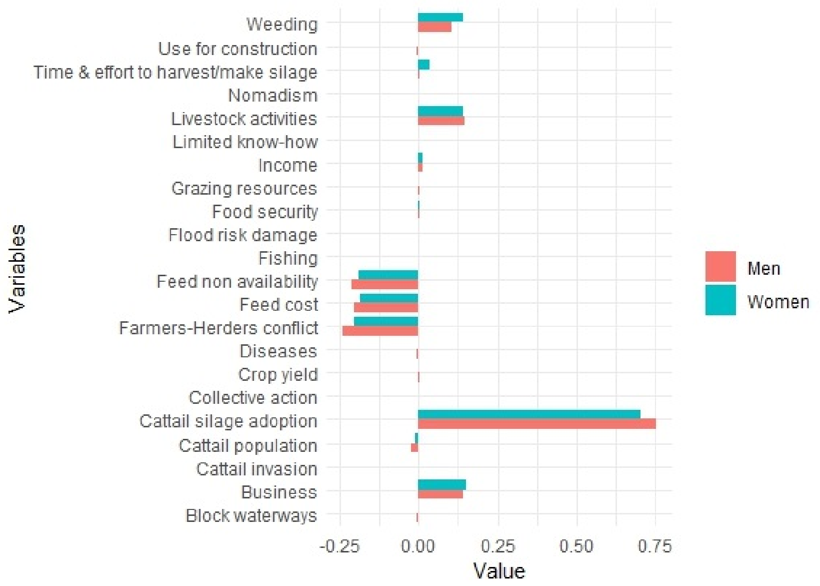

Figure 14. Differences in the steady state values of the gender-based FCMs with and without adoption

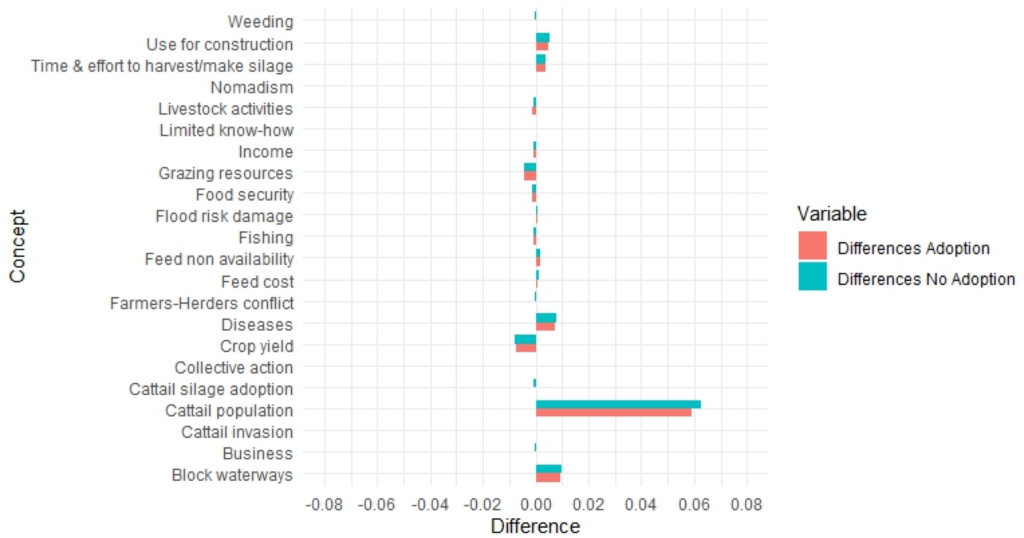

Figure 15. Differences between the negative scenario (Cattail invasion variable is set to 0.9) and the baseline scenario considering that it does exist adoption and it does not.

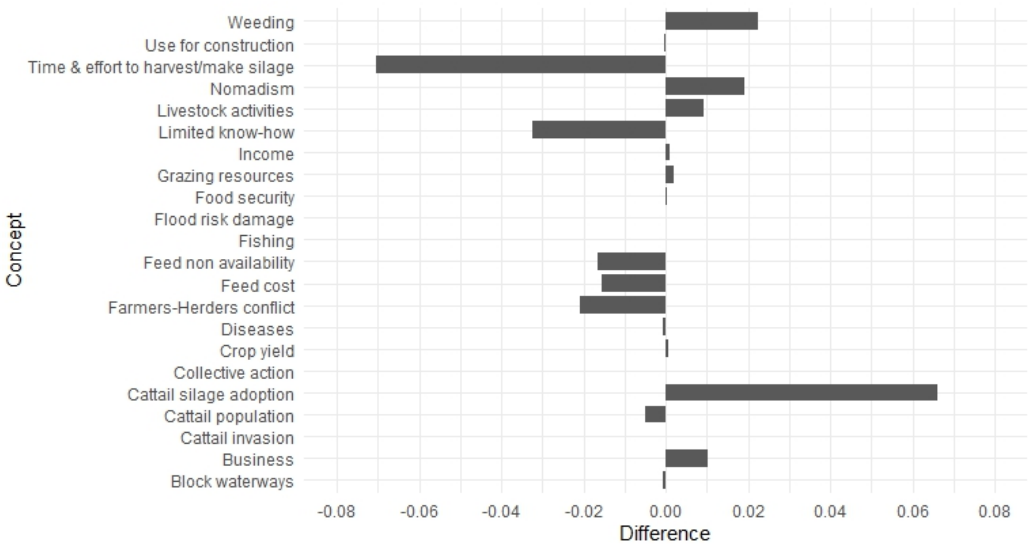

Figure 16. Differences between the positive scenario (Collective action is set to 0.9) and the neutral scenario in which adoption is not fostered by increasing collective action.

Table 1. Indices of the aggregated Fuzzy Cognitive Map

Index	**Value**
Connections	42
Concepts	22
Density	0.0868
Transmitter variables	2
Receiver variables	3
Ordinary variables	17

[i] *Typha* Project is an action research component of TRIMING (Transforming Irrigation Management in Nigeria), funded by the World Bank, 2017-2021

[ii] Silage is a way to preserve fodder for long periods and it is produced by fermenting forage in anaerobic conditions. To obtain silage, firstly, biomass must be left for 12 hours in the field to remove water content and then chop it into small pieces of about 2.5cm. Later, the chopped fodder must be introduced in a polythene bag and sprinkle a solution of urea and molasses to improve its quality. Finally, the biomass must be compressed and stored.