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Research article

Data driven analysis of social capital in Farmer Producer Companies

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A B S T R A C T

The Farmer Producer Company (FPC), a subset of the Farmer Producer Organization (FPO), is an important institutional form designed to organize farmer groups towards better coordinated farming and marketing. In the Indian context, as FPCs have emerged as new forms of members-led agribusiness, their ability to identify prevailing social ties and tap them effectively towards business growth needs to be better understood. Although social capital is studied broadly for its potential to drive organizational performance, it has been poorly researched in farmer collectives such as FPCs. The current work examines the effect of social capital on benefits and business performance at the level of member groups in FPCs. An empirical analysis was conducted in which two FPCs, which differed significantly in their mobilization strategies, farming methods, and supply chain linkages, were surveyed. Data collected from the surveys were visualized and clustering analysis was carried out using Self Organizing Maps (SOM), an unsupervised Artificial Neural Network (ANN) tool. Insights from clustering reveal the importance of pre-existing social ties, leadership, participation in group activities and the geographical affinity of groups in benefits realization and business performance of FPCs. The importance of bottom-up approaches in establishing robust supply chain linkages in emerging FPCs was keyed out through this work. The inferences through SOM, distilled strategies for FPCs' stakeholders in prioritizing interventions for member groups and in generating broader implications for policy makers accounting social capital in new institutional models.

1. Introduction

In order for small and marginal farmers to derive benefits at economies of scale, various institutional forms such as cooperatives, societies and Self-Help Groups (SHGs) have been promoted by government and non- governmental organizations in developing economies [1]. Each of those models improved outreach and rendered benefits of cooperation to their members. Still, there was limited success in ensuring participation and minimal improvement in the economic welfare of small and marginal farmers, leading to the search for new institutional forms [2]. Apart from ensuring the active participation of farmer members, these new institutional models are targeted towards making rural producers follow organized marketing of their products themselves instead of continuing to rely on exploitative transactions managed by brokers and other intermediaries [3]. The focus of this paper is on one such institutional model implemented in India, known as the Farmer Producer Company (FPC(s)), which preserves the cooperative framework but is managed on the basis of a corporate organizational structure.

FPCs are mobilized from SHGs, producer groups and small clusters organized by their earlier collective form or in the form of new Farmer Interest Groups (FIGs). The foundations of FPCs are thus embedded in local customs, though initially structured as formal

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organizations based on economic principles [4]. As FPCs emerge as new institutional forms for members-led agribusiness, their ability to recognize the pre-existing social ties and utilize them effectively towards business growth needs to be understood better [5]. Their inclusiveness of small and marginal farmers and the extent of their ability to tap social networks to aid the performance and growth of FPCs remain unexplored in national and regional contexts [6]. The social networks and affiliations of individuals to a collective [7] are used to explain the concept of 'Social Capital'. While Burt (2000) [8] and Bourdieu (1986) [9] conveyed social networks as the causative factor for the aggregation of resources and social capital, the definitions of Nahapiet & Ghoshal (1998) [10] and Coleman (1988) [11] explained social capital as a constituent of both networks and resources. FPC as an organization, mobilized from clusters and farmer groups, needs to manage the social networks of members, so as to enhance their collective abilities and render unbiased benefits. Thus, FPC makes a converging case of these divergent views of social capital. 'Social capital' and 'member satisfaction' have emerged as essential characteristics [12] of farmer collectives, be it to ensure farmers' access to innovation [13], technology adoption [14], farm risk and resilience [15] or for sustainable livelihoods amidst uncertainties [16]. FPC, as an institutional innovation [17] cutting across all these elements, is yet to be researched in establishing the role of social capital towards organizational performance. This paper, therefore, aims to fill this gap by exploring the nexus of social capital and the performance of FPCs in a comparative case study from South India.

The importance of FPCs and similar institutional forms such as agricultural cooperatives, producer organizations, farmer groups, and associations in promoting farm production and marketing performance has received great attention of scholars and government makers. A growing number of studies have found that these farmer-based institutions have significant and positive impacts on farm productivity and production efficiency [18–20], marketing channel choice and product quality improvement [21,22], household welfare and rural development [23,24], cropland abandonment reduction and climate change mitigation [25], technology adoption [26,27], and women empowerment [28]. However, to date, no previous studies have discussed how social capital in FPCs drives the realization of benefits for its members and business performance of FPCs.

Analyses of social capital in local social structures have mostly deployed multilevel linear regressions, hypothesis testing [29,30] and econometric techniques, such as propensity score matching [31]. Only a few studies have explored Social Network Analysis (SNA), hypothesis testing, structural equation modeling and participatory surveys to explain the association of social capital with innovation facilitation, entrepreneurship and network dynamism of cooperatives [32–34]. While the association of social capital with the performance of rural cooperatives has contributed to theoretical development [35–37], researchers have increasingly called for tools and models that can provide decision support for stakeholders themselves in a more straightforward manner [38,39]. Among methods that enable less supervised decision making capabilities to stakeholders, visualization tools contribute substantially and are yet less applied in social capital research. Apart from SNA based visualization [32,40], other forms of data visualization have not been tapped in the social context of agricultural cooperatives. While SNA renders strategic insights for researchers and policy makers, its interpretation by stakeholders themselves for decision making is not straightforward. A valuable visualization tool that enables automated data analytic capability for social contexts is 'Self Organizing Maps (SOM)' [41]. SOM renders a two-dimensional visualization of multidimensional data, ensuring simplified interpretation of social context [42,43]. In the current work, we propose using SOM for its potential in providing stakeholders with self-explanatory visualization patterns and in understanding social capital attributes and performance of FPCs using clustering led insights.

The current study attempts firstly to perform an empirical analysis of social capital by stakeholders' perceptions of its various attributes; second to analyze their connections with the FPC's performance in its benefits outreach and procurement activities. Until now, the impact of FPCs was assessed on the basis of member's income, participation and overall profit [44–46]. The uniqueness in the current study is in understanding the members' perceptions on various dimensions of FPC through social capital lenses and in aligning it to the performance in terms of benefits derived by the membership and the FPC's capability in enabling the business of members' produce. The study proceeds through the following steps. (i) selection of representative FPCs and social capital surveys at the level of Farmer Interest Groups (FIGs) in the chosen FPCs (ii) visualization of social capital attributes through SOM (iii) application of clustering of SOM towards detecting new groupings associated with social capital attributes (iv) the position of identified clusters with respect to benefits and procurement activities in the surveyed FPCs and (v) validation of clustering by SOM. The visualization generated by SOM captured variations in FIGs across input and output attributes in two-dimensional space. Insights gained from the clustering include the importance of pre-existing social ties, leadership, participation in group activities and geographical affinity of groups in benefits realization and procurement activities at FPCs. Inferences based on observations from SOM distilled strategies for FPCs' stakeholders in the array of operations, from mobilization and group activities to business outreach.

The rest of the paper is organized as follows. The study area and sampling details are discussed in section 2. The data surveyed and the categorization of input and output attributes are stated in section 3. Description of SOM and the algorithm are explained in section 4; the results from SOM for each of the FPCs and validation of SOM led clustering is presented in section 5; Section 6 summarizes the inferences drawn from SOM led observations and section 7 presents the conclusions.

2. Study area and survey instrument

2.1. Selection of FPCs

In India, some of the leading states in the formation and establishment of FPCs include Maharashtra, Madhya Pradesh, Gujarat, Rajasthan, Goa in the northern zone and Tamil Nadu, Kerala, Andhra Pradesh and Karnataka in the south zone. [4]. The proliferation of FPCs was dependent on the specific state's agriculture and marketing policies and the supporting institutions in the region. Nearly 7374 FPCs are registered in India [47] and the aforementioned states had promoted nearly 50% of these FPCs. Still, there is no

equitable spread of literature on FPC across these states. Among southern states, Andhra Pradesh and Karnataka gained sufficient attention by profound research on FPCs [48,49]. FPCs in Tamil Nadu have got the least attention so far, be it in empirical studies, reviews or policy research. They appeared with narrow details in baseline analyses [4] and researched little, except for a few mentions in conceptual analysis and case references. Also, FPCs across states seek a tailored policy agenda for nurturing their ecosystem and for synthesizing guiding tools for their practitioners. Therefore, two FPCs have been chosen from Tamil Nadu for this study. While the two FPCs may not be representative of the whole FPC ecosystem, they still encompass critical categories of FPCs in the region such as government funded FPCs versus self-promoted ones, FPCs based on natural farming versus chemical inputs based farming and also varied levels of supply chain relationships in FPC, as defined through the scope further in this section.

More than 600 FPCs are functioning in Tamil Nadu, of which at least 75% of FPCs [50] were established with the support of government-led funding entities such as the National Bank for Agriculture and Rural Development (NABARD) and Tamil Nadu Small Farmers' Agribusiness Consortium (TNSFAC). Apart from them, there are many self-funded FPCs in Tamil Nadu, formed through mobilization and shareholding by farmers themselves without deriving any support from the aforementioned government-led funding sources. The latter FPCs are formed by 'bottom-up' approaches of mobilization by bringing their pre-existing social ties and informal business activities under the formalized FPC model. The former FPCs constituted through the support of government-led incubators fall under FPCs mobilized through top-down approaches. In any community-led governance mechanism, the bottom-up model is highly advocated [51,52] and FPC is not an exception in this. However, FPCs were treated as startups in their early years and an extended period of promotion through Non-Governmental Organizations (NGOs), NABARD and TNSFAC was anticipated. A shift of focus is insisted from implementation to facilitation role, be that played by governments and NGOs in such top-down approaches [39]. The role of regional and state representation of the government in framing rural development policies that encourage stakeholder mobilization in a bottom-up manner [51,53] were implied in social capital literature. Hence, mobilization was taken as the first and primary scope for this study and thereby FPCs, one each on bottom-up mobilization and top-down approach were selected.

Second is the farming methods followed by these FPCs. The representative FPC for bottom-up mobilization was formed through its clusters of farmers practicing natural farming from surrounding villages and districts. The top-down model encompassed FIGs with producers in it practicing farming dependent on chemical inputs. Apart from mobilization and farming practices, the supply chain relationships of these FPCs with the respective members make the third scope of this study. FPC I formed through a top-down approach lacked the supplier-buyer relationship with its members except for crop inputs sales, whereas FPC II engaged actively in collective marketing of its members' produce, right from the establishment phase by tapping the informal ties with its natural farming clusters.

2.2. FPC I and II

FPCs are formed by mobilizing a set of member groups termed 'Farmer Interest Groups (FIG), each having a membership count from 5 to 20. These members were grouped, be it by the farm produce they cultivate or the activities, they are aligned to. The term FIGs were introduced for mapping membership and to enable smoother management of FPCs by promoting agencies and funding institutions. 20 FIGs were surveyed for this study, in each of the FPC. Given the distinctive characteristics of the two FPCs in Table 1, the membership size is far larger in FPC I and to capture the sample in uniform proportions, 400 members were covered in FPC I and 100 members were covered in FPC II thus covering 40% of the membership in each of the FPC. FIGs were chosen by strategic sampling based on their geographic location (encompassing FIGs in all the 3 blocks in case of FPC I and 4 districts in FPC II) and the cropping details. FPC I is located in Kallakurichi district covering 3 blocks and FPC II is located in Villupuram covering members from Villupuram, Pondicherry, Kallakurichi, Cuddalore and Tiruvannamalai districts. Since FPC II is based on its natural farming principles and the farmers following natural farming are scattered across the districts, the FPC needs to include membership even from its nearby districts and hence the reason for its extended geographic footprint. Thus, the soil types, agro-climatic characteristics and groundwater availability differ highly between these FPCs. Though both the FPCs are dependent on groundwater availability majorly, some clusters in FPC II had the privilege of perennial availability of groundwater due to their proximity to the coast.

Table 1
Operational details of FPC I and II.

	FPC I	FPC II
Year of registration	2014	2015
Promoting Organization	National Agro Foundation	Self-Promoted (Trust)
Funding support	Tamil Nadu Small Farmers Agribusiness Consortium	Self-funded
Membership size	1000	250
Group Constitution	Farmer Interest Groups	Clusters
Farming method	Chemical inputs	Natural farming
Geographic coverage	3 administrative blocks of a district	4 districts
Cropping details	Oilseeds, pulses, paddy and fodder crops	Paddy, millets, pulses and horticultural crops

3. Data

3.1. Survey instrument

Data collection in the two FPCs was conducted through surveys, using the World Bank's 'Social Capital Assessment Tool (SOCAT)' developed by Grootaert and Bastelaer (2002) [54]. SOCAT is designed to gather data on individuals and groups, focusing on their social assets and networks. The 'member interview guide' of the tool was utilized, with each question serving as an attribute to capture the FPC's social capital. Data collection took place between August and September 2018 in FPC I, and January to February 2019 in FPC II across representative member groups (20 in each of the FPC) through focus group discussions. On average, it took around 2 hours to complete the survey for each identified member group, herein referred as FIGs. The member interview guide generated qualitative data. Responses were recorded on a Likert scale ranging from 1 to 4, where 1 indicated a lower average opinion and 4 represented a very positive opinion on survey variables related to group/organizational characteristics. The scales were adapted from Grootaert and Bastelaer (2002) [54] and tailored to the attributes relevant to FPCs. The selection of FPCs was based on their differences in mobilization and downstream farming practices as detailed in Section 2. The FPCs were approached through capacity-building initiatives at the research institute where the study was conducted.

3.2. Input and output attributes

As mentioned earlier, the objective of the current study is to analyze the role of social capital in benefits outreach and procurement of members' produce by FPCs. Hence, 'procurement by FPC' and 'benefits being part of FPC' were taken as performance benchmarks to be analyzed across member groups. These benchmarks were also strongly implied in policy briefs and technical reports [5,55] for empirical research on FPCs. The attributes surveyed are categorized as (i) Group history and structure, (ii) Leadership, (iii) Participation in group activities, (iv) Board of Directors' activities and (v) Business Operations. The survey encompasses an overall of 30 attributes as listed in Table 2 and also detailed in Table S1. 28 attributes characterizing membership, participation and trust in leadership were categorized as 'input attributes'. Two attributes viz., 'Benefits' and 'Group Procurement' surveyed alongside other attributes were considered as 'output attributes'.

Table 2
Questionnaire for social capital assessment.

	Attribute	Attribute explanation	Conceptual details
	Group History and Structure		
1	Group Initiation	Whether FIG/Cluster mobilized for FPC or existed before?	Origin of group (FPC/Other Purpose)
2	**Benefits**	Benefits derived out of your association with FPC	Services and Resources access
3	Expressing Concerns	To what extent, FPC expresses your concerns to the outside world?	Functional scope of FPC (Responses
4	Substituting Government	To what extent, FPC complement/replaces govt institutions in your locale?	derived through case references)
5	Substituting NGOs	To what extent, FPC complement/replaces NGOs in your locale?	
	Leadership	How would you characterize FPC leadership in terms of	
6	Stability		Organizational Capacities (ranking the
7	Availability		BoD by each attribute
8	Diversity	Heterogeneity of 'Board of Directors (BoD)'	
9	Skills Leaders	Relationship of BoD with the community through FIG heads	
10	Relationship Community	Quality and skills in handling situations	
	Participation		
11	Group Meetings	How frequent the meetings are organized by FIGs?	Active participation (to set the group
12	Attendance	Attendance at FIG led meetings	visibility)
13	Decision Making	Active participation during meetings	Decision making
14	Dissemination	Dissemination about meetings and various decisions taken to members	Communication& Coordination
15	Consultation FIGs	How well are you satisfied by consultation from BoD with FIGs?	
16	Broad Debate	Broad debates, including constructive opinions and oppositions?	
17	Women Ratio	Number of women in FIGs	Gender & Social Inclusivity
18	Social Inclusion	Relationship of BoD with the community through FIG heads	
19	Big Farmers	Whether big farmers are supportive or influencing negative?	
	Board of Directors' activities		
20	Knowledge Levels	Level of knowledge of procedures and policies of FPC	Organizational Culture (Following
21	Procedures	Whether procedures are carried out? Any issues in following up?	norms & compliances of FPC)
22	BoD Meeting Attendance	Attendance in meetings led by BoD	
	Business Operations		
23	Conflicts Resolution	Conflicts resolution mechanism within clusters and by BoD?	Organizational Capacities
24	Credit Facilities	Any credit facilities maintained by FIGs or led by BoD?	Organizing the supply chain (Generating
25	**Group Procurement**	Whether members' produce procured by FIG head or BoD of FPC?	working capital, negotiation power and
26	Contracting Dealers	How good is the BoD in contracting input and market dealers?	selling the produce through FPC)
27	Financial Reports	Whether financial reports for banks/donors prepared by procedures?	
28	Reacting Fluctuations	Does the FPC able to react to changing circumstances (Price rise, climate, etc.,)	Organizational sustainability (during
29	Planning	Does the FPC develop specific plans for the future instead of reacting?	uncertainties)
30	Reflecting Experience	How well you are reflecting your earlier experience in FPC led business?	Indigenous Knowledge and Experience

In FPC II, only 29 attributes were surveyed as Social Inclusion was recorded with uniform responses and responses for Women Ratio were not absolute. There was an additional attribute in FPC II, *Mobilization* capturing the details for the slow increase in membership at each cluster. This was not applicable in FPC I, as 50 FIGs were formed through the supporting NGO with 20 members each, making the total membership count to 1000.

4. Methods

The qualitative data collected from FPC members is considered the data space with 20 sample points and 30 dimensions. That is, the 20 FIGs correspond to the sample points and the 30 attributes for each FIG are the dimensions. It is to be noted that each FIG has a maximum of 20 members and the data accrued is an average of these members' perspective on the respective attribute. Of the 30 attributes, 28 of them characterize the input and 2, the output. The underlying goal is to use such a multidimensional data space for social capital analysis that can help stakeholders and policy makers towards governance and operational guidelines for the FPC. In order to be able to do that, one needs to understand the relationship, such as correlations and patterns between the input space and the performance space. While Spearman correlation showed correlations between attributes, it couldn't highlight the differences in such correlations across the FIG groups (Appendix Figures S1a and S1b). Since the stakeholders and policymakers could have different backgrounds and varying levels of exposure to technology, knowledge and literacy, it is desirable to present the data in a visually intuitive and interpretive manner. Analyses of data through plots such as nested axes plots, tile plots and parallel axes plots [56] exist. However, all these methods fix a particular variable and vary the other variables and hence do not capture the simultaneous variation of all variables. In addition, with the increase in dimensions, the computational load is higher and visual interpretation is cumbersome. Dimensionality reduction methods, such as Principal Component Analysis or Active Subspace [57] work on the principle of identifying the crucial factors and recasting the function in terms of these variables. While the dimensions for analysis get reduced, remapping the reduced dimensions to the original dimension is a challenge. Multiple Correspondence Analysis (MCA), a generalization of 'Principal components analysis' though highlighted key dimensions, couldn't render details on associations, that are interpretable by stakeholders (Appendix Figure S2). Hence, in order to preserve the details of design space in higher dimensions and to ensure interpretable visualization, we use the SOM [41].

SOM belongs to a class of unsupervised neural networks [41] that enable visual interpretation of multidimensional data by their ability to map non-linear relations. SOM maps could be generated without the knowledge of complexities and associations in the system that created the data [58]. Thus, it is used to explore datasets even when quantification of associations remains difficult. Unified distance matrix (U-matrix) and component planes are the two forms of visualization rendered by SOM. The former provides valuable insights into the topology of SOM and aids in identifying clusters, whereas the latter depicts the associations between the attributes mapped in 2D space. SOM-based visualization and clustering have been reported in agriculture for disease detection, plant species detection [59], biodiversity [60], water resources utilization [42] and land use [61] among other applications. The application of SOM is limited in the social and economic context of agriculture [62] and to the best of our knowledge, this is the first attempt to use SOM in the research of farmers-led organizations and social capital assessment.

The data collected from the two FPCs were normalized before applying SOM algorithm so that all the attributes would be in comparable units for analysis. In SOM, the inputs are processed as vectors and every neuron is assigned a weight vector whose dimension is that of input space. After normalizing by range, the input vectors were transformed into a two-dimensional map by the SOM algorithm (Appendix Figure S3). The weight vectors are either randomly or linearly initiated, and each neuron is examined to identify which neuron's weight is closest to the input vector. Based on Euclidean distance criteria, the neuron that is closest to a chosen data point is assigned as the Best Matching Unit (BMU). The weights of neighboring neurons are updated such that the neighborhood function and the learning rate decrease to a minimum over multiple iterations. The training phase of SOM proceeds until convergence criteria are met. Finally, 2D plots of the input and output are obtained, which are essentially the weights of the respective components. Apart from these component planes generated for inputs and outputs, the U-matrix is generated by assigning each neuron a value that represents the distance to its neighboring neurons. These values are then visualized as a grid of colors, where each color represents a different level of distance. Clusters are identified in the color grid by uniform areas of low values, whereas high values indicate the border of clusters. The two-dimensional map rendered qualitative details on how the input variables, here the social capital attributes are associated with each other. SOM's potential in visualization, as well as clustering, is tapped in this study to draw inferences on the FPCs surveyed. The platform used for developing SOM is MATLAB [63].

5. Results

A SOM with 24 nodes is trained on the data that is collected. The component planes for the inputs and output of the data space are provided in Fig. 1. It is to be noted that the plots presented are the weights of the respective attributes at the end of the SOM training. The color bar beside each component plane provides the weights. Blue color corresponds to lower weight range and brown color for higher weights, whereas yellow and pale red colors denote the ranges in between of the attribute weights. Component planes enable understanding the correlations among variables by observing the color patterns. For instance, similar patterns were observed between *Credit Facilities* and *Group Procurement*. From these component planes, one can infer that the FIGs that had credit facilities were able to procure goods. That is, the ones that had more credit facilities (left top of the component plane with high weights) had better procurement capabilities (left top of the component plane with high weights). Similarly, *Reflecting Experience* and *Benefits* were inversely correlated. That is, the FIGs with low *Reflecting Experience* (right half of the component plane) had better perception on *Benefits* (right half of the respective component plane).

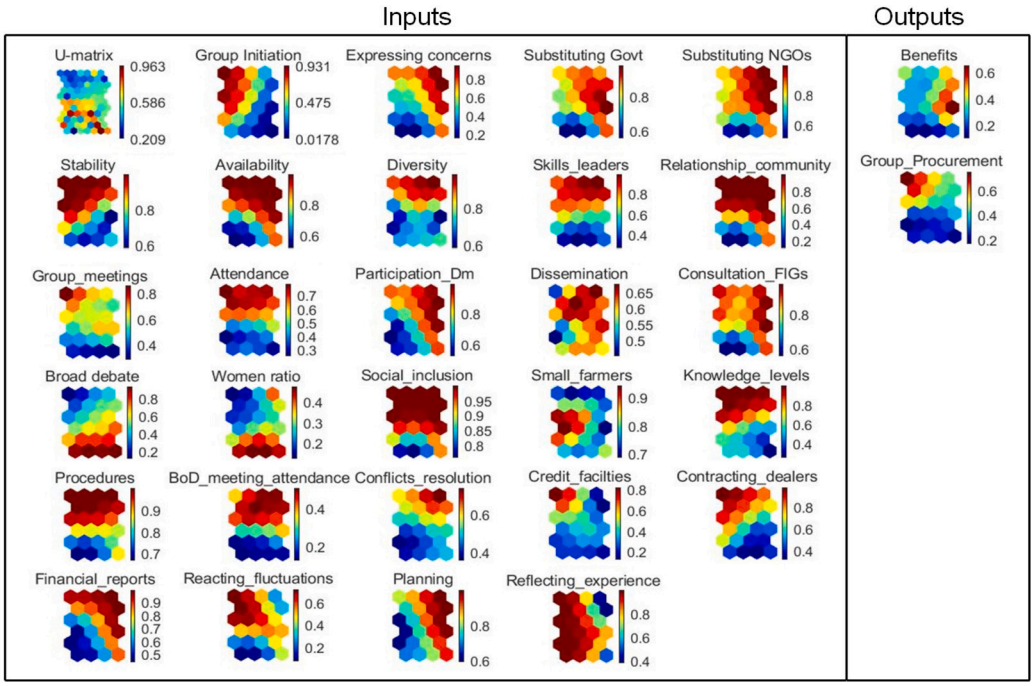


Fig. 1. U-matrix and Component planes segregated by inputs and outputs of the data space - FPC I.

By analyzing SOM, the following can be inferred:

i. Groups (FIGs) that existed earlier had better perceptions on FPC's ability in *Contracting Dealers*. Some of these groups which maintained credit sections, were able to engage in procurement activities.
ii. In FIGs that were formed alongside FPC, *Women Ratio* is comparatively higher and in these groups, *Broad Debates* on resource distribution were reported.
iii. *Benefits* was perceived low across many FIGs and still, these FIGs were able to reflect well their earlier experience in collective farming.
iv. FIGs with a better representation of small and marginal farmers exhibited lower perceptions on *Credit Facilities*, *Conflicts Resolution*, *Planning* and *Benefits*.
v. *Social Inclusion* and the relationship of BoD with FIGs were rated similarly by the FIGs. FIGs that are distantly located from core operations exhibited less than average perceptions in many of the attributes, as inferred from the blue patches of neurons in the lower rows of component planes.

It is worth noting that the 30 dimensional data reduced to 30 2D plots allow one to visually observe the relationships and make inferences. Apart from visualizations through component planes, the U-matrix of SOM rendered substantive details by capturing the distance between data points in space. The partitions derived through U-matrix (Fig. 2a) could be analyzed as explicit clusters by combining SOM with a suitable clustering algorithm. SOM based clustering has been explored in this work to expose the inter-cluster variations of attributes specifically towards their influence in benefits outreach and procurement.

5.1. SOM led clustering – FPC I

The U matrix is created by inserting a cell between every pair of node. Each cell is assigned the Euclidean distance between the pair of nodes that it connects. These values are then visualized as color contours which are essentially the difference in the values of the adjacent nodes. Thus, U-matrix provides information on the distribution or groups of data for a given SOM and is usually used for clustering purpose. It is to be noted that the clustering is performed on the weights of the U-matrix. Here, we use a K-means clustering approach. This approach divides the samples into a pre-chosen number (K) of groups, based on the features that are provided. The points are clustered such that the squared error between the centroid and the data points in each cluster is minimized. By examining these clusters which represent unique feature vectors within themselves, unknown groupings in the dataset can be detected. Upon detecting the clusters, a new sample can be easily assigned to the appropriate cluster [64].

The U-matrix for FPC I is presented in Fig. 2a. Wherever the neuron color is darker compared to a group of neurons of similar shades, it means that the distance between the neighboring nodes is large and hence can be considered the boundary of a cluster. Alternately, nodes of similar shades will be clustered and separated by dark color nodes. The resulting clusters and the respective

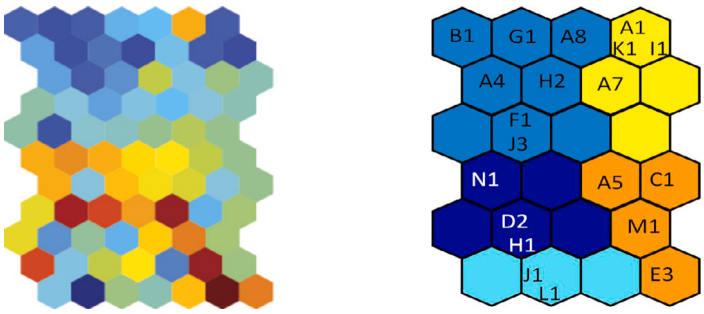


Fig. 2. (a) U-matrix of SOM – FPC I; (b) Clustered SOM.

labels of FIGs for FPC I are presented in Fig. 2b. For each component plane, the codebook vectors corresponding to the clusters identified in Fig. 2b were retrieved. The average, minimum and maximum of code book vector values were calculated for each cluster and by every component plane. The circular bar chart derived through these values is presented in Appendix Figure S4. A sharper view of the clusters variations are presented in Fig. 3 using the same color legend from Fig. 2b.

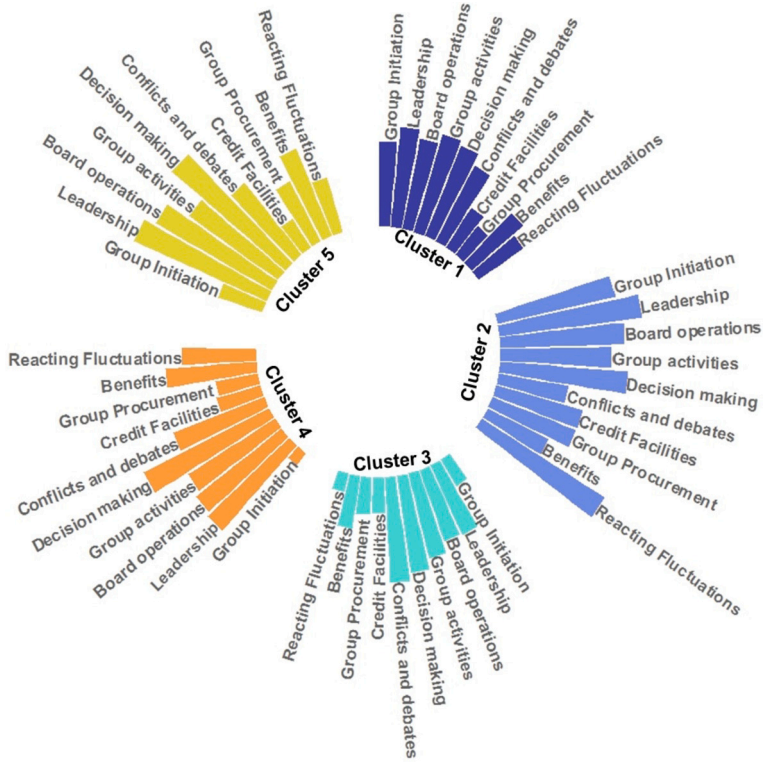


Fig. 3. Circular bar chart of cluster average values- FPC I.

In Fig. 3, the social capital attributes were grouped under Group activities, Leadership, Board operations, Decision making and Conflicts and debates by averaging the codebook values in each cluster. *Stability*, *Availability*, *Diversity*, *Skills Leaders* and *Relationship Community* were grouped under Leadership. *Knowledge levels*, *Procedures*, *BoD Meeting Attendance*, *Contracting Dealers*, *Financial Reports*, *Planning*, *Substituting Government*, *Substituting NGOs* and *Expressing Concerns* were grouped under Board Functions. *Group Meetings*, *Attendance*, *Dissemination*, *Consultation FIGs*, *Women Ratio*, *Social Inclusion* were grouped under Group activities. *Conflicts Resolution* and *Broad Debates* were put together as Conflicts and debates. *Group Initiation*, *Decision Making*, *Credit Facilities*, *Reacting Fluctuations*, *Benefits* and *Group Procurement* were mapped as such in Fig. 3. While the data analyzed by SOM enabled establishing clusters of FIGs based on their opinions on FPC operations, additional information on attribute values by each cluster (Fig. 3) derived inferences specific to the cluster.

FIGs belonging to clusters 1 and 2 are representative of FIGs which existed before the formation of FPCs. These clusters performed well in most of the attributes. However, realization of *Benefits* was less than average. This can be attributed to the fact that the members couldn't make use of resources and exposures from FPC due to consecutive years of drought in the region. In the case of procurement activities, at the most, FIGs in cluster 2 were only able to make progress while the other clusters were still in planning for procurement and collective marketing. The attributes differentiating clusters 1 and 2 are those of leadership, participation in decision making and *Credit Facilities*.

Cluster 3 is composed of newly formed FIGs with the least perceptions on leadership, intra-group activities and their participation in decision making. Conflicts and debates on impartial resource access constrained by their remoteness from the core operations of FPC were reported in this cluster. Cluster 4 and 5 represent newly formed FIGs with comparably better perceptions than cluster 3 on group activities and leadership. The realization of *Benefits* in these clusters is proportional to their perceptions on participation in group activities, leadership, conflicts resolution and debates. Across all the clusters, the presence of *Credit Facilities* is less associated with the realization of *Benefits*.

5.2. SOM led visualization- FPC II

FPC II differed from FPC I, by its mobilization strategies and farming methods, and the surveys captured variations in the responses for respective attributes. To account for the bottom-up approaches of FPC II in the mobilization of members, *Mobilization* is included as an attribute to be surveyed.

Similar to FPC I, SOM maps were created for FPC II as well and presented in Fig. 4. It can be inferred that,

i. The lower rank for *Mobilization* in most of the groups was associated with the expectations of new members towards incentivisation for membership and faster payments for their produce
ii. The inverse patterns of *Mobilization* and *Group Procurement* indicate that though the mobilization is slow across many groups, the existing members were satisfied with the procurement strategies
iii. The groups corresponding to the top right nodes in *Mobilization*, though were able to aggregate more members in FPC, many members were in a phase of conversion to natural farming practices. This delay in conversion was reflected in getting certification for their organic produce, due to which they were less satisfied with FPC's differential procurement mechanisms for uncertified produce
iv. The blue nodes in the top right of the component planes of *Benefits* and *Reflecting Experience* point that the groups which did not have earlier experience on collective farming did not express better realization of *Benefits*
v. The frequency of meetings at group level and participation in decision making were less linked to *Group Procurement* and *Benefits* respectively, as inferred from their inverse patterns

Similar to FPC I, the U-matrix of FPC II data also was established to understand additional details.

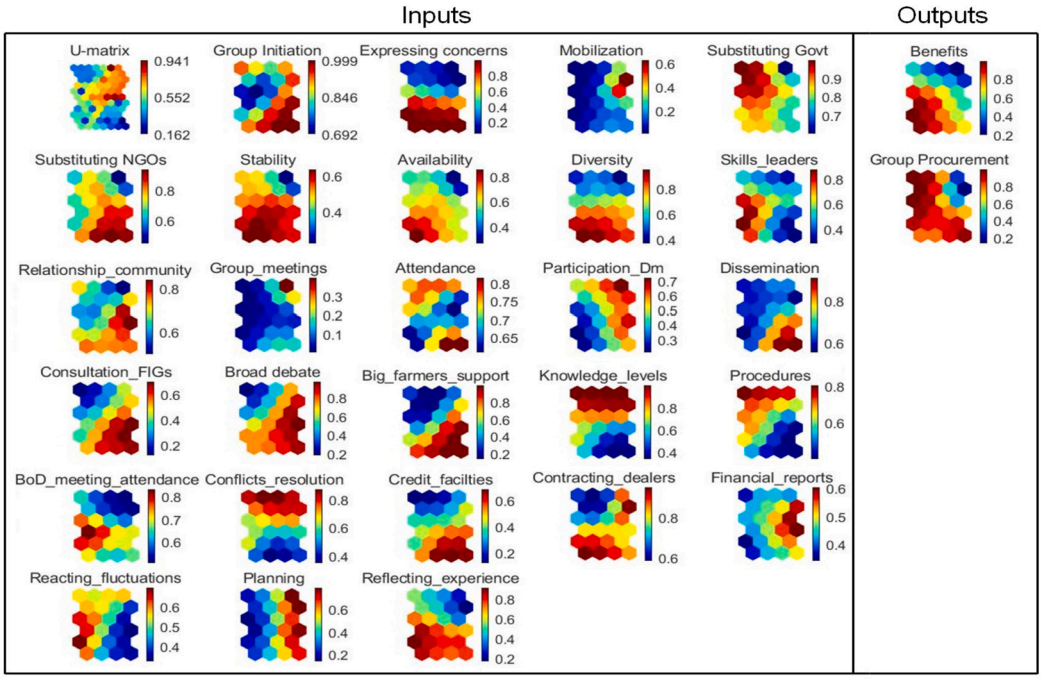


Fig. 4. U-matrix and Component planes segregated by inputs and outputs of the data space - FPC II.

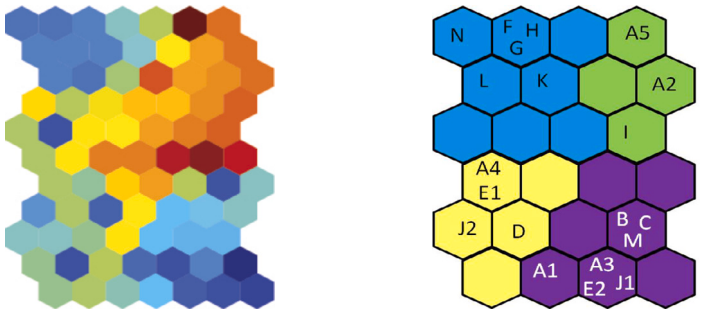


Fig. 5. (a) U-matrix of SOM – FPC II; (b) Clustered SOM.

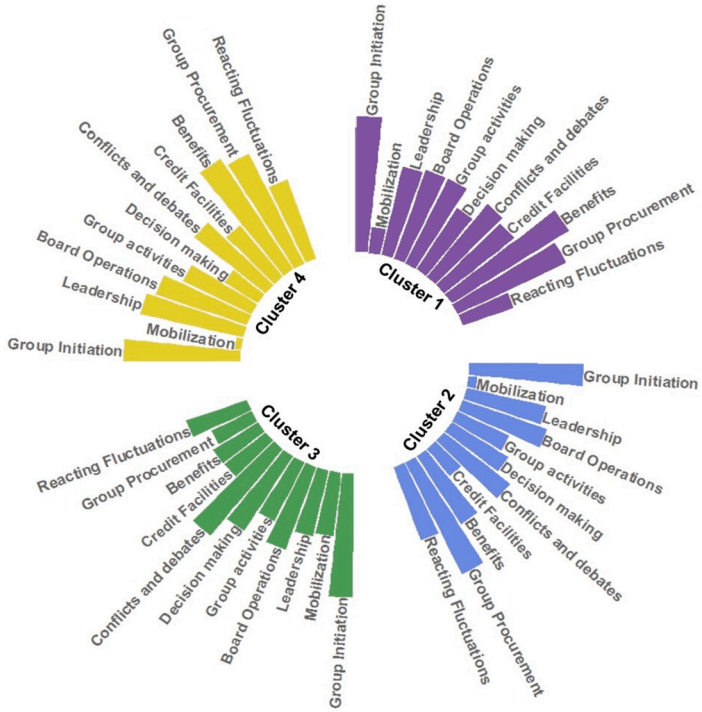


Fig. 6. Circular bar chart of cluster average values- FPC II.

5.3. SOM led clustering- FPC II

The U-matrix of FPC II Fig. 5a showed four different groupings, and they were marked explicitly through k-means clustering along with the labels for 20 FIGs, as seen in Fig. 5b. The code book vectors of component planes were retrieved by their clusters, similar to FPC I and they are averaged for each cluster. The circular bar plots made for each cluster by grouped attributes are shown in Fig. 6. The grouping was done similar to that of FPC I and *Mobilization* was the only additional attribute, thus making 11 attributes per cluster in the circular bar chart.

The following can be observed from Fig. 6:

i. The lower rank for *Mobilization* in most of the groups was associated with the expectations of new members towards incentivisation for membership and faster payments for their produce
ii. Cluster 1 captured well many of the social capital attributes and it exhibited lower weights only on the FPC's ability to react to price volatility in the market
iii. Cluster 2 had average weights on leadership and less than average weights on group activities and participation in decision making, which were reflected in their average realization of *Benefits*

iv. Cluster 3 had lower weights on leadership and group activities. Also, *Broad Debates* were recorded in the cluster pertaining to payment delays and certification requirements for their farm produce. Since many members in the cluster were yet to get approved of organic certification, there were lags in the procurement of their produce also
v. *Credit Facilities* are managed majorly by the 'Board of Directors'. Clusters 2 and 3 had less awareness of the deployment of credit facilities
vi. Cluster 4, though had minimal participation in group activities and decision making, their trust in leadership was proportional to the realization of *Benefits* and procurement process of the FPC.

Except for Cluster 3, the attribute *Group Procurement* received good weights across the clusters. Observation of minimum, average and maximum values by each attribute has been presented in the Appendix Figure S5.

5.4. Comparison of FPC I and II

Apart from analyzing the effects of social capital on the two outputs viz., benefits and procurement, one needs to understand the association between them. Benefits include inputs supply, seeds distribution, credit linkages, exposure visits, soil testing and agro-advisories through extension officials. Based on various such services availed through FPCs, FIGs/clusters ranked 'benefits' from '1' to '4'. These services constitute institutional support by FPC. Business performance characterized by marketing and sales of members' produce is captured through the attribute 'procurement' in this study. The scope of FPC in its supply chain activities is determined by its procurement process. Benefits can be perceived as institutional support and procurement as supply chain linkages.

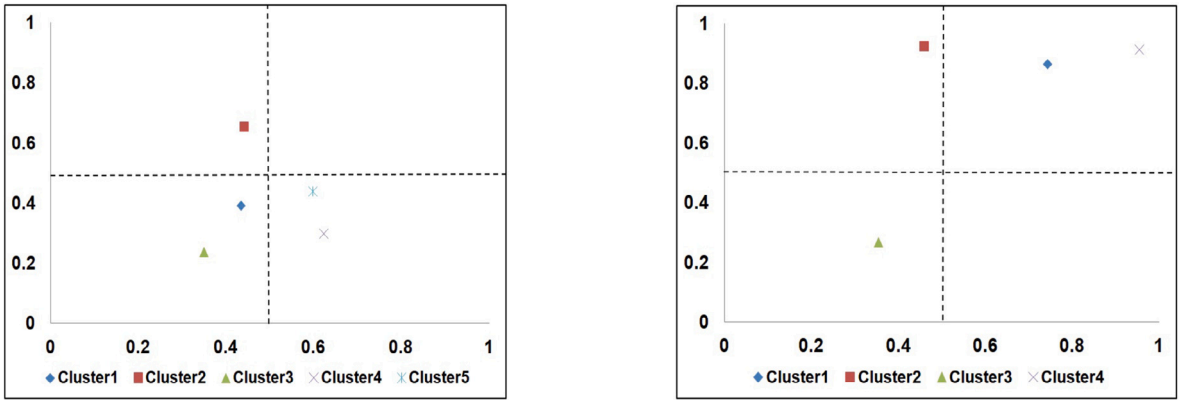


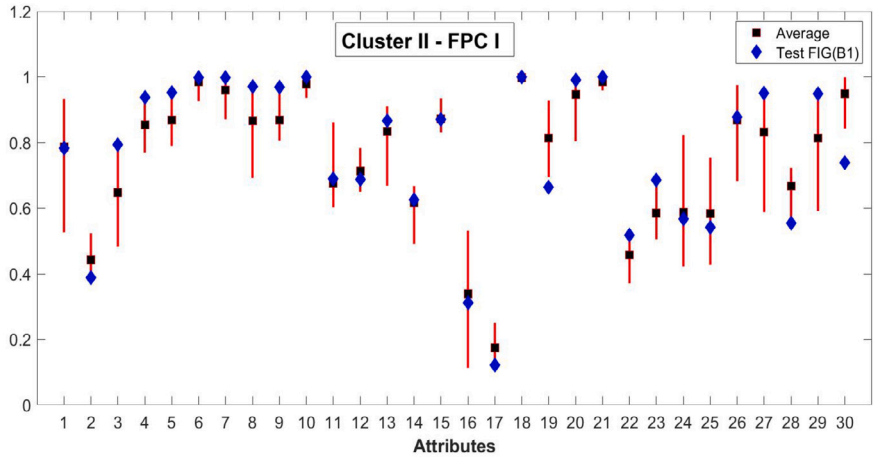
Fig. 7. Institutional Support vs Supply chain linkages (a) FPC I (b) FPC II.

A scatter plot between the two is presented in Fig. 7, by averaging the attribute values in each cluster. In Fig. 7a, no cluster occupied the first quadrant and only Cluster 2 was in the second quadrant. This implies that the institutional support led by FPC I to its members has not facilitated an environment for supply chain linkages and missed to facilitate strategies for procurement from member farmers. The plot for FPC II (Fig. 7b) placed three out of four clusters in upper quadrants and 2 clusters in first quadrant. It uttered the potential of FPC II in translating effectively its support to members, as an institution to supply chain linkages effectively. Also, these two plots of FPCs appear inverse of each other, underscoring the effects of their contraries in mobilization, farming methods and supply chain mechanisms.

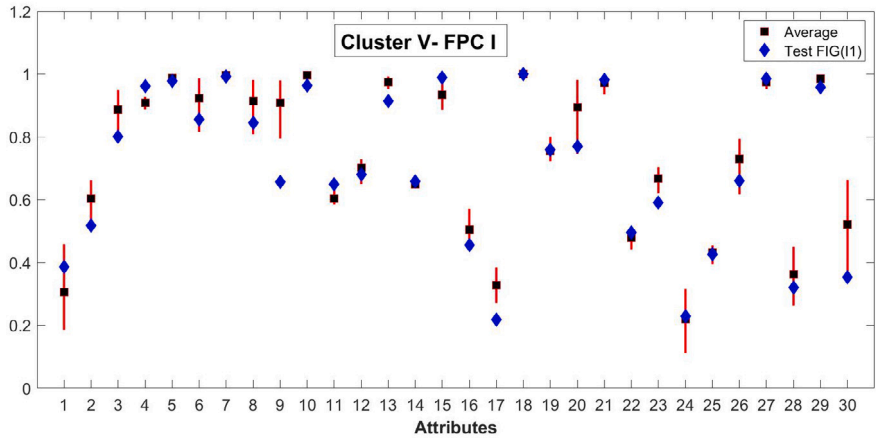
5.5. Validation- SOM led clustering

To this end, we have analyzed the data using SOM to understand the relationships and based on clustering. In order to validate the clustering, we propose to use 90% of the whole data (100%) for training and use the remaining 10% data for testing. By testing, we attempt to predict which cluster would each of the tested FIG belong, based on the clustering obtained from the 90% training data. This cluster prediction can then be compared to clustering obtained from the 100% whole data. To execute the same, the SOM was applied to training data (18 FIGs) and clustered. It was then examined whether the test data (2 FIGs) were classified into clusters that they would have been classified, if the clustering was performed with 20 FIGs.

The testing carried out on both the FPCs are shown in Fig. 8a and 8b for FPC I and Fig. 9a and 9b for FPC II. In the clustering performed with 100% whole data, the bounds and average values for a particular cluster in which the test FIG was classified is presented, along with the code book value of the test FIG with the 90% training data. It can be observed that in the cases shown, the test FIG is always classified into the correct cluster. Such validation done for a set of samples in FPC I and II is presented here and similar testing done with a few other sample combinations are given in the Appendix Figures S6a, S6b and Figures S7a, S7b.

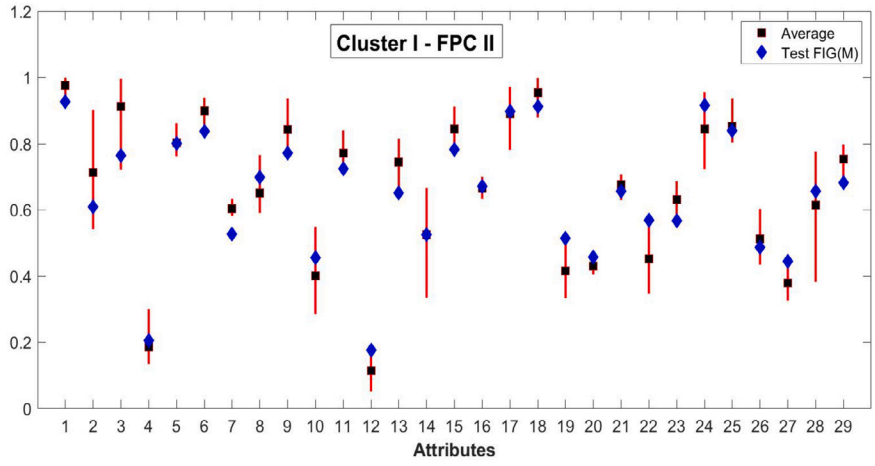


(a)

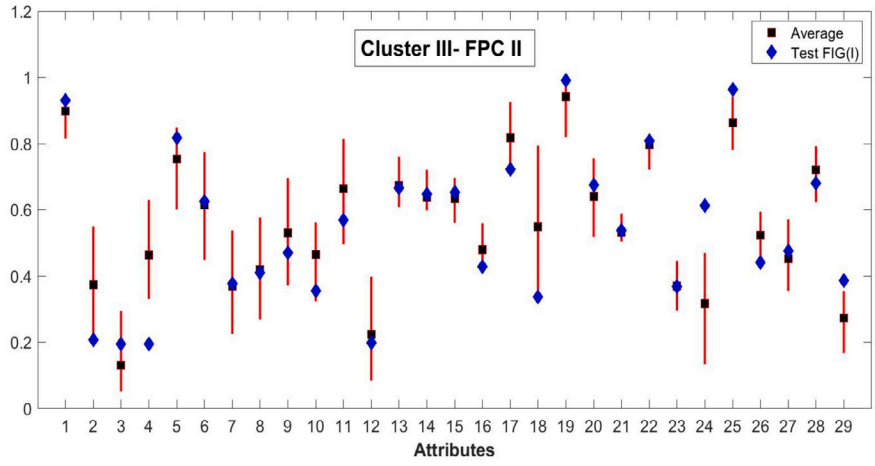


(b)

Fig. 8. Validation of clustering by SOM - FPC I (a) Test FIG - B1 (b) Test FIG - I1.



(a)



(b)

Fig. 9. Validation of clustering by SOM - FPC II (a) Test FIG - M (b) Test FIG - I.

This verification allows us to conclude that if a particular FIG aspires to belong to a cluster than the one that it belongs to currently, then one needs to compare the attributes of the corresponding cluster with that of the FIG and the comparison will provide the information which attributes one need to address for the FIG to be classified into the aspiring cluster. Since the clustering need to be validated on empirical survey data on groups, this type of validation has been followed.

6. Discussions

The research interest is in examining the importance of social capital in facilitating benefits and procurement through FPCs. FPCs were taken as the context since they were promoted as promising strategies to organize agricultural production and marketing [65]. They were also postulated as network organizations with a higher dependence on social capital [66]. FPCs I and II that were identified for the study were institutionally similar but functionally different. While FPC I was an outcome of externally initiated collective action, FPC II emerged through an indigenous institution-building process. The explanation for the observations derived through SOM analysis and the inferences for each of the FPCs in addressing the shortcomings on benefits and procurement are listed in Table 3. The attributes were filtered based on their associations with 'Benefits' and 'Procurement' derived through SOM led visualization (Fig. 1 and Fig. 4) and clustering (Fig. 3 and Fig. 6).

It is inferred from Table 3 that leadership remains a key construct in determining the perceptions on benefits in both the FPCs and also on procurement strategies in FPC II. This observation is similar to the observations made on the impact of active leadership in generating and sustaining the social capital [67,68]. The dissociation between some of the social capital attributes with benefits and procurement have been brought out for both the FPCs. The role of FPC in linking various strategies and the social capital gained through them to benefits and procurement is essential and failing to do so would bring down FPC's identity to a mere extension

Table 3
Observations and suggested strategies – FPC I & II.

FPC I			
SC attributes	B	P	Observation (O), Explanation (E), Inference (I)
Group Initiation		↑	O: FIGs that were initiated before the formation of FPC demonstrated increased procurement compared to the FIGs that were initiated during FPC formation E: Pre-existing FIGs had a better understanding of collective farming and logistics I: Recognizing the existing clusters and social affinity of farmers are essential in the process of formation of FPC
	↓		O: *Benefits* (inputs supply, trainings) rendered by FPC weren't useful to pre-existing groups as compared to newly formed FIGs E: Pre-existing FIGs followed adapted cropping patterns to combat droughts I: Interventions required in addressing challenges at downstream production, be it through droughts or any erratic climate situations
Small Farmers	↓		O: FIGs with more small and marginal farmers had lower perceptions on *Benefits*. These FIGs were also dissatisfied with *Planning*, *Conflicts Resolution* and *Diversity* of BoD E: FIGs with more small and marginal farmers reported unfair distribution of seeds and access to information on trainings I: Ensuring equitable access to benefits and prioritizing concerns of FIGs with more small and marginal farmers; Capacity building of BoD to address concerns pertaining to *Conflicts Resolution* and *Diversity*
Credit Facilities	↓		O: Initial intention of credit sections was to align them to overarching beneficial services planned by FPC. The credit sections were tapped highly for decisions at group levels such as members' loans, labor charges and logistics of produce E: Lack of awareness of FIGs on using credit facilities for activities linked to FPC's business services I: FPC needs to sensitize the utilization of credit facilities for the overall business objective and enhance awareness on the returns out of the process at the level of individual members
Leadership and Participation in Decision Making	↑		O: Trust in leadership and participation of FIGs in decision making reflected in increased benefits realization E: *Availability* of BoD to FIGs is essential for continued access to resources and information by FIGs I: Ensuring unbiased outreach to FIGs for enhancing the realization of benefits and in mounting the collective strengths of FIGs
FPC II			
SC attributes	B	P	Observation (O), Explanation (E), Inference (I)
Mobilization		↓	O: FIGs which made good mobilization showed lesser perceptions on procurement E: The newly joining members expect faster payments for the produce and hence had lower perceptions on procurement I: Need to target grants and working capital to enhance outreach and to ensure immediate payments for produce
Group meetings		↓	O: Few groups are from nearby districts and coordinating group meetings were difficult in these FIGs E: FPC did not have supporting grants/funds and couldn't invest to conduct group activities frequently I: To avoid a decrease in ownership in the future due to reduced group activities, FPC needs to strengthen procurement based transactions and periodic communications on the same through groups
Participation in decision making	↓		O: Groups which made increased participation in decision making had lower perceptions on *Benefits* E: Participation in decision making was reported on procurement based transactions and processes and hence less inclined to *Benefits*
Leadership	↑	↑	O: Leadership is perceived well across all groups except that of Cluster III. E: Lower perceptions in cluster III were reasoned for payment delays and certification requirements mandated by BoD I: BoD needs to educate members on the certification process and facilitate sales of produce until certification by identifying relevant markets
Procurement	Perceived well across many FIGs except for the groups that reported certification led delays		

SC- Social capital: B-Benefits: P- Procurement.

service rather than the purposed form of members-led agribusiness organization. The emphasis on strategic mobilization to ensure benefits and supply chain linkages, though had been made earlier in the cooperative context [6], this study generates evidence for emerging FPCs by extracting social capital as a mechanism to explain it.

The study showed that gaining social capital is essential in ensuring the realization of benefits and procurement of members produce to make business through FPC. Benefits and business of members' produce through FPC were stated as performance benchmarks [55,5] in various forms of literature. Though FPC I mobilized 1000 members through top-down facilitation by support from government and an NGO, it missed translating effectively the social capital gained through FIGs to benefits realization and procurement activities. This was evidenced also from Fig. 7a and Fig. 7b. In the former, only one cluster was able to fill the top quadrant whereas, in the latter, three clusters were able to make it and two of which were visibly positioned in the first quadrant. As stated earlier, by perceiving benefits as institutional support and procurement as supply chain linkages, this depiction in Fig. 7 highlighted the disconnection between institutional support and supply chain linkages in the FPC formed by the top-down approach. FPC, being an emerging organizational model, has always been argued for its sustainability through bottom-up approaches [69] and the findings stated here make strong empirical evidence to imply this construct.

Pertaining to methodological contributions, this study adds to the literature on the applications of SOCAT tool for social capital analysis in FPCs. While the tool has been applied in exploring social capital and natural resources utilization in India, also as an indicator of rural development in many countries [70,54], its application in the performance of agribusiness entities such as FPCs is the first of its kind. Another methodological contribution comes through SOM, the visualization based inferences through which are interpretative by stakeholders themselves. Also it's clustering capability can help one to understand the attributes that they must focus on to ensure targeted outreach of benefits and processes, leading to the procurement of members' produce. Hence, this can be used as a decision support tool by the board of directors of FPCs.

It is important to consider the limitations of our study when interpreting our findings. The study was based solely on the reported perceptions of informants and was not independently corroborated by other empirical research. With regard to sample selection, it

is based on the broad groupings of FPCs with reference to the study scope and one each on the classifications of FPCs, recognized by key stakeholders. More strategized sampling is needed to explain the role of social capital in the business performance of FPCs. While SOM is chosen for rendering intuitive visualization of multidimensional data, visualization and clustering were derived based on the first two principal components generated through the SOM algorithm (Appendix 3). This is under the assumption that maximum variation is captured in the direction of the first two eigen values. Though this is largely true, that's not necessarily the case always. Hence, a more detailed analysis of eigen values before performing a 2D SOM is a more robust method and a possible extension.

7. Conclusions

In the context of FPCs, the objective of the study was to understand the relationship between social capital and the benefits and procurement of members produce. The study assessed the importance of social capital in driving FPC's performance right from downstream production to supply chain linkages. The analysis was carried out through empirical data collected through surveys on social capital. The survey was based on a 'World Bank repository' and the observations were subjected to SOM. SOM was able to explain the varied perceptions of FPC operations in geographical and social space through explanatory two-dimensional maps. SOM based clustering and validation established the potential of SOM in guiding leadership of FPCs through the attributes, characterizing member groups.

FPC I was formed through top-down interventions by assembling 1000 members in a single agribusiness entity. The members were organized into distinctive groups with varied expectations and resource access. Although FPC I was able to derive the threshold support from the government to commence the business, it could not translate this external support from the government to its internal member networks. The reasons for the failure in transforming the institutional support for shareholders to sustain thriving supply chain linkages were identified from the analysis. The prime requirement of shaping the existing social infrastructure for institutional benefit was emphasized through the findings. This study contributes to the argument that membership alone in FPCs couldn't fetch negotiation power and marketing linkages. The policies facilitating grants for FPCs should be able to enhance ownership and member-centric business activities through bottom-up mobilization approaches.

The strengthened focus of FPC II on downstream production activities and strategic mobilization based on farmer's adherence to natural farming enabled it to progress well on upstream supply chain linkages too. Its inability to incentivize group level activities was attributed to the lack of any support through grants or working capital from government agencies. The geographic coverage of FPC II also added a burden to the leadership by stipulating awareness of demand-supply gaps and market situations in all the districts that the FPC covers. Still, FPC II, by its consistent engagement with its members through the buyer-seller relationship, was able to maintain the ownership structure and social capital of members. Incentivizing FPCs that enable business of members' agricultural produce should become a policy focus so that the member engagement becomes priority and also business led interactions can ensure social capital and trust of members, as deduced from this study.

FPCs are regarded as emerging institutional forms to improve the economic situations of farmers and for inclusive agribusiness. Since they are regarded as vehicles to deliver various reforms by government, their performance from the lenses of social capital is worth exploring. National and regional promoting organizations of FPCs would derive an interest in tapping this tool to render targeted capacities for FPCs. Also for FPCs, the tool could facilitate in resource management among clusters. Such a cluster based analysis is strongly insisted in large FPCs constrained in coordination of heterogeneous member preferences in farming and marketing. Still this study has been focused much on the internal member networks of FPCs and hence future research on calibrating the dynamics of stakeholders, both internal and external to the FPC ecosystem could generate a guiding blueprint that would fine-tune operations of these new institutional models in broader context.

CRediT authorship contribution statement

Aishwarya Jayaraman: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Palaniappan Ramu: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Sudhir Chella Rajan:Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Sidhant Pravinkumar Thole: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e17489.

References

[1] O.M. Ashtankar, Cooperative farming & Indian agriculture sector, Int. J. Appl. Res. 1 (11) (2015) 557–561, https://doi.org/10.9780/22315063.
[2] Chandrasekhara Rao Nu, et al., Organised retailing and agri-business: implications of new supply chains on the Indian farm economy, https://doi.org/10.1007/978-81-322-2476-1, 2016, ISBN: 978–81-322-2475–978-81-322-4.
[3] Sukhpal Singh, Producer companies as new cooperatives, Econ. Polit. Wkly 43 (20) (2008) 22–24.
[4] Anika Trebbin, Linking small farmers to modern retail through producer organizations - experiences with producer companies in India, Food Policy 45 (2014) 35–44, https://doi.org/10.1016/j.foodpol.2013.12.007.
[5] K.V. Raju, et al., Farmer producer organization in Andhra Pradesh: a scoping study. 2017, ISBN 9789290665922, https://doi.org/10.13140/RG.2.2.32657.22883.
[6] Andre Nickow, Growing in value: NGOs, social movements and the cultivation of developmental value chains in Uttarakhand, India, Glob. Netw. 15.s1 (2015) S45–S64, https://doi.org/10.1111/glob.12087.
[7] Maura A. Belliveau, Charles A. O'Reilly, James B. Wade, Social capital at the top: effects of social similarity and status on CEO compensation, Acad. Manag. J. (ISSN 0001-4273) 39 (6) (1996) 1568–1593, https://doi.org/10.2307/257069.
[8] Ronald S. Burt, The network structure of social capital, Res. Organ. Behav. 22 (2000) 345–423, https://doi.org/10.1016/S0191-3085(00)22009-1, issn: 0191–3085.
[9] Bourdieu, The forms of capital, in: J.G. Richardson (Ed.), Handbook of Theory and Research for the Sociology of Education, Greenwood Press, New York, 1986, pp. 241–258.
[10] Janine Nahapiet, Sumantra Ghoshal, Social capital, intellectual capital, and the organizational advantage, vol. 23, https://doi.org/10.2307/259373, Apr. 1998.
[11] James S. Coleman, Social capital in the creation of human capital, Am. J. Sociol. 94 (1988) S95–S120, issn: 00029602, 15375390.
[12] Wendong Deng, George Hendrikse, Cooperative social capital - towards a lifecycle perspective, in: 2014 International Congress, Ljubljana, Slovenia, August 26–29, 2014, European Association of Agricultural Economists, Aug. 2014, p. 182922.
[13] Gabriela Cofre-Bravo, Laurens Klerkx, Alejandra Engler, Combinations of bonding, bridging, and linking social capital for farm innovation: how farmers configure different support networks, J. Rural Stud. 69 (2019) 53–64, https://doi.org/10.1016/j.jrurstud.2019.04.004, issn: 0743-0167.
[14] Claudia Hunecke, et al., Understanding the role of social capital in adoption decisions: an application to irrigation technology, Agric. Syst. 153 (2017) 221–231, https://doi.org/10.1016/j.agsy.2017.02.002.
[15] Daniel C. Kenny, Modeling of natural and social capital on farms: toward useable integration, Ecol. Model. (ISSN 0304-3800) 356 (2017) 1–13, https://doi.org/10.1016/j.ecolmodel.2017.04.010, www.sciencedirect.com/science/article/pii/S0304380016304082.
[16] Darmawan Salman, et al., Combination of bonding, bridging and linking social capital in a livelihood system: nomadic duck herders amid the Covid-19 pandemic in south Sulawesi, Indonesia, For. Soc. 5 (1 Mar. 2021) 136–158, https://doi.org/10.24259/fs.v5i1.11813, https://journal.unhas.ac.id/index.php/fs/article/view/11813.
[17] Saswat Kumar Pani, Sanjaya Kumar Satapathy, Agricultural sustainability through institutional innovation: a study on farmer producers company in rainfed region of odisha, in: Ramesh Anbanandam, Santosh Rangnekar (Eds.), Springer Nature, Singapore, ISBN 978-981-19-1697-7, 2022, pp. 77–88.
[18] Stanley Kojo Dary, Jasper Grashuis, Characterization of farmer-based cooperative societies in the upper West region of Ghana, Ann. Public Coop. Econ. 92 (4) (Dec. 2021) 669–687, https://doi.org/10.1111/apce.12305.
[19] Benyam Tadesse, et al., Factors influencing organic honey production level and marketing: evidence from southwest Ethiopia, Heliyon (ISSN 2405-8440) 7 (9) (2021), https://doi.org/10.1016/j.heliyon.2021.e07975, e07975, https://www.sciencedirect.com/science/article/pii/S2405844021020788.
[20] Salimata Traore, Farmer organizations and maize productivity in rural Burkina Faso: the effects of the diversion strategy on cotton input loans, Rev. Dev. Econ. 24 (3) (2020) 1150–1166, https://doi.org/10.1111/rode.12674, https://onlinelibrary.wiley.com/doi/abs/10.1111/rode.12674.
[21] Jinghui Hao, et al., Cooperative membership and farmers' choice of marketing channels - evidence from apple farmers in Shaanxi and Shandong provinces, China, English, Food Policy 74 (Jan. 2018) 53–64, https://doi.org/10.1016/j.foodpol.2017.11.004, issn: 0306–9192.
[22] Yuying Liu, Alan Renwick, Xinhong Fu, The role of agricultural cooperatives in serving as a marketing channel: evidence from low-income regions of Sichuan province in China, Int. Food Agribus. Manag. Rev. 22 (2019) 2, https://doi.org/10.22004/ag.econ.284937, https://ideas.repec.org/a/ags/ifaamr/284937.html.
[23] Mercy Mwambi, Jos Bijman, Patience Mshenga, Which type of producer organization is (more) inclusive? Dynamics of farmers' membership and participation in the decision-making process, English, Ann. Public Coop. Econ. (ISSN 1370-4788) 91 (2) (June 2020) 213–236, https://doi.org/10.1111/apce.12269.
[24] Wanglin Ma, Awudu Abdulai, Does cooperative membership improve household welfare? Evidence from apple farmers in China, Food Policy (ISSN 0306-9192) 58 (2016) 94–102, https://doi.org/10.1016/j.foodpol.2015.12.002, https://www.sciencedirect.com/science/article/pii/S0306919215001396.
[25] Elizabeth Hobson, Michael Avery, Timothy Wright, An analytical framework for quantifying and testing patterns of temporal dynamics in social networks, Anim. Behav. 85 (2013) 83–96, https://doi.org/10.1016/j.anbehav.2012.10.010.
[26] Shemei Zhang, et al., The effect of cooperative membership on agricultural technology adoption in Sichuan, China, China Econ. Rev. 62.C (2020), https://doi.org/10.1016/j,chieco.2019.101, https://ideas.repec.org/a/eee/chieco/v62y2020ics1043951x19300951.html.
[27] Richa Kandpal, Izuru Saizen, Self-help group participation towards sustainable solid waste management in peri-urban villages: evidence from Mumbai metropolitan region, India, Environ. Dev. Sustain. 24 (3 2022) 3791–3814, https://doi.org/10.1007/s10668-021-01588-6, issn: 1573–2975.
[28] Carla Dohmwirth, Ziming Liu, Does cooperative membership matter for women's empowerment? Evidence from South Indian dairy producers, J. Dev. Eff. 12 (2) (Apr. 2020) 133–150, https://doi.org/10.1080/19439342.2020.175, https://ideas.repec.org/aZtaf/jdevef/v12y2020i2p133-150.html.
[29] Li Feng, Anna Friis, Jerker Nilsson, Social capital among members in grain marketing cooperatives of different sizes, Agribus. 32 (2015), https://doi.org/10.1002/agr.21427.
[30] Ayodeji Ogunleye, et al., Impacts of farmers' participation in social capital networks on climate change adaptation strategies adoption in Nigeria, Heliyon (ISSN 2405-8440) 7 (12) (2021), https://doi.org/10.1016/j.heliyon.2021.e08624, e08624, https://www.sciencedirect.com/science/article/pii/S2405844021027274.
[31] Dagne Mojo, Christian Fischer, Terefe Degefa, Social and environmental impacts of agricultural cooperatives: evidence from Ethiopia, Int. J. Sustain. Dev. World Ecol. 22 (5) (2015) 388–400, https://doi.org/10.1080/13504509.2015.1052860.
[32] Graeme Reed, Gordon M. Hickey, Contrasting innovation networks in smallholder agricultural producer cooperatives: insights from the niayes region of Senegal, J. Co-op. Organ. Manag. 4 (2) (2016) 97–107, https://doi.org/10.1016/j.jcom.2016.09.001.
[33] Jens F.L. Sorensen, Testing the hypothesis of higher social capital in rural areas: the case of Denmark, Reg. Stud. 46 (7) (2012) 873–891, https://doi.org/10.1080/00343404.2012.669471.
[34] Richard Brereton, Self organising maps for visualising and modelling, Chem. Cent. J. 6 (Suppl 2) (2012) S1, https://doi.org/10.1186/1752-153X-6-S2-S1.
[35] Clarietta Chagwiza, Roldan Muradian, Ruerd Ruben, Cooperative membership and dairy performance among smallholders in Ethiopia, Food Policy (ISSN 0306-9192) 59 (2016) 165–173, https://doi.org/10.1016/j.foodpol.2016.01.008.
[36] Liyan Yu, Jerker Nilsson, Social capital and the financing performance of farmer cooperatives in Fujian province, China, Agribus. 34 (4) (2018) 847–864, https://doi.org/10.1002/agr.21560.

[37] Q. Liang, et al., Social capital, member participation, and cooperative performance: evidence from China's Zhejiang, Int. Food Agribus. Manag. Rev. 12 (3) (2009) 1–22.
[38] Nikola Milojevic-Dupont, Felix Creutzig, Machine learning for geographically differentiated climate change mitigation in urban areas, Sustain. Cities Soc. 64 (2021) 102526, https://doi.org/10.1016/j.scs.2020.102526.
[39] Denis Herbel, Mariagrazia Rocchigiani, Christine Ferrier, The role of the social and organisational capital in agricultural co-operatives' development practical lessons from the CUMA movement, J. Co-op. Organ. Manag. 3 (1) (2015) 24–31, https://doi.org/10.1016/j.jcom.2015.02.003.
[40] Yupadee Methamontri, et al., Factors influencing participation in collective marketing through organic rice farmer groups in northeast Thailand, Heliyon (ISSN 2405-8440) 8 (11) (2022), https://doi.org/10.1016/j.heliyon.2022.e11421, e11421, https://www.sciencedirect.com/science/article/pii/S2405844022027098.
[41] Teuvo Kohonen, The Basic SOM, Self-Organizing Maps, Springer Berlin Heidelberg, Berlin, Heidelberg, 1997, p. 85144.
[42] Aman Mohammad Kalteh, Peder Hjorth, R. Berndtsson, Review of the Self-Organizing Map (SOM) approach in water resources: analysis, modelling and application, Environ. Model. Softw. 23 (2008) 835–845, https://doi.org/10.1016/j.envsoft.2007.10.001.
[43] Jimin Qian, et al., Introducing self-organized maps (SOM) as a visualization tool for materials research and education, Results Mater. (ISSN 2590-048X) 4 (2019), https://doi.org/10.1016/j.rinma.2019.100020, p. 100020.
[44] Raj M. Desai, Shareen Joshi, Can producer associations improve rural livelihoods? Evidence from farmer centres in India, J. Dev. Stud. 50 (1) (2014) 64–80, https://doi.org/10.1080/00220388.2013.849339.
[45] M.J. Chandre Gowda, Sreenath Dixit, H.L. Megha, Women's participation in Karnataka's FPOs, Econ. Polit. Wkly (ISSN 2349-8846) 53 (45) (2018) 20–22.
[46] Swati Chauhan, Luvkush crop producer company: a farmer's organization, Decis. 43 (1) (2016) 93–103, https://doi.org/10.1007/s40622-015-0121-1, issn 0304–0941.
[47] Annapurna Neti, Richa Govil, Madhushree Rao, Farmer producer companies in India: demystifying the numbers, Rev. Agrar. Stud. 9 (2) (2019).
[48] R. Venkattakumar, et al., Performance of farmers producers organizations (FPOs) and associated factors in Karnataka: producers' perspectives, Indian Res. J. Ext. Educ. 19.July (2019) 7–12.
[49] D.A. Rajini Devi, et al., FPOs in telangana - status and strategies, Curr. J. Appl. Sci. Technol. 39 (19) (2020) 86–90, https://doi.org/10.9734/cjast/2020/v39i1930795.
[50] NABARD, Farmer Producers' Organizations (FPOs): Status, Issues & Suggested Policy Reforms, Tech. Rep., 2018, p. 10.
[51] Kushankur Dey, Farmer producer companies in maharastra, Econ. Polit. Wkly 53 (35) (2018) 44–52.
[52] Yuheng Li, et al., Bottom-up initiatives and revival in the face of rural decline: case studies from China and Sweden, J. Rural Stud. (ISSN 0743-0167) 47 (2016) 506–513.
[53] Stavriani Koutsou, Maria Partalidou, Athanasios Ragkos, Young farmers' social capital in Greece: trust levels and collective actions, J. Rural Stud. 34 (2014) 204–211.
[54] Christiaan Grootaert, Thierry Van Bastelaer Bastelaer, Understanding and Measuring Social Capital - a Multidisciplinary Tool for Practitioners, World Bank, Washington, DC, ISBN 0-8213-5068-4, June 2002.
[55] Anshul (Development Alternatives) Bhamra, Farmer Producer Organisations in India, March 2017.
[56] Sulaymon Eshkabilov, Plots and data visualization BT - beginning Matlab and simulink: from novice to professional, in: Sulaymon Eshkabilov (Ed.), Apress, Berkeley, CA, ISBN 978-1-4842-5061-7, 2019, pp. 343–396.
[57] Zhongming Jiang, Jie Li, High dimensional structural reliability with dimension reduction, Struct. Saf. 69 (2017) 35–46, https://doi.org/10.1016/j.strusafe.2017.07.007.
[58] Stephanie Clark, Scott.A. Sisson, Ashish Sharma, Tools for enhancing the application of self-organizing maps in water resources research and engineering, Adv. Water Resour. 143 (2020) 103676, https://doi.org/10.1016/j.advwatres.2020.103676.
[59] Esa Tyystjarvi, et al., The kautsky curve is a built-in barcode, Biophys. J. 77 (2) (1999) 1159–1167, https://doi.org/10.1016/S0006-3495(99)76967-5, issn 0006–3495.
[60] R. Cereghino, et al., Biodiversity and distribution patterns of freshwater invertebrates in farm ponds of a south-western French agricultural landscape, Hydrobiologia 597 (1) (2008) 43–51, https://doi.org/10.1007/s10750-007-9219-6.
[61] Yufeng Li, et al., Land use pattern, irrigation, and fertilization effects of rice-wheat rotation on water quality of ponds by using self-organizing map in agricultural watersheds, Agric. Ecosyst. Environ. 272 (2019) 155–164, https://doi.org/10.1016/j.agee.2018.11.021.
[62] Mika Sulkava, et al., Clustering of the self-organizing map reveals profiles of farm profitability and upscaling weights, Neurocomputing 147 (2015) 197–206, https://doi.org/10.1016/j.neucom.2013.09.063.
[63] Matlab version 9.4.0.813654 (R2018a), The Mathworks, Inc. Natick, Massachusetts, 2018.
[64] Anil K. Jain, Data clustering: 50 years beyond K-means, Pattern Recognit. Lett. 31 (8) (2010) 651–666, issn: 01678655.
[65] FAO, Institutional and policy environment for nutrition, in: Annual flagship publication of FAO, Food and Agriculture Organization of the United Nations, Rome, Italy, 2013.
[66] Chrysoula Morfi, et al., Social networks and member participation in cooperative governance, Agribus. 37 (2) (2021) 264–285, https://doi.org/10.1002/agr.21660.
[67] Beatrice Crona, Stefan Gelcich, Orjan Bodin, The importance of interplay between leadership and social capital in shaping outcomes of rights-based fisheries governance, World Dev. 91 (2017) 70–83, https://doi.org/10.1016/j.worlddev.2016.10.006.
[68] Daniel Kyalo Willy, Karin Holm-Muller, Social influence and collective action effects on farm level soil conservation effort in rural Kenya, Ecol. Econ. 90 (2013) 94–103, https://doi.org/10.1016/j.ecolecon.2013.03.008.
[69] Elena Gorriz-Mifsud, Laura Secco, Elena Pisani, Exploring the interlinkages between governance and social capital: a dynamic model for forestry, For. Policy Econ. 65 (2016) 25–36, https://doi.org/10.1016/j.forpol.2016.01.006.
[70] Surjono, Yourike Prasisca, Fauzul Rizal Sutikno, Gender equality and social capital as rural development indicators in Indonesia (case: malang regency, Indonesia), in: Procedia - Social and Behavioral Sciences, vol. 211, 2015, pp. 370–374.