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Quantitative farming system typologies for targeted agricultural development: A review

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Abstract
The land holding size of marginal farmer in India had decreased from 0.40 ha in 1970-71 to 0.38 ha in 2010-11 and is expected to reduce further to 0.32 ha within this decade. By virtue of increased number of operational holdings, mainly due to fragmentation, land holding size is small. Agriculture in marginal farm holdings can be made profitable through integrated farming system which requires monetary and technical interventions. Characterization of farming systems is of utmost importance for identifying groups of farm holdings with fairly similar farming systems in a highly diverse and complex agro-ecological environment. Quantitative farming system typologies, based on multivariate analyses, allow identification of significant differences among farm holding types and use them as the basis for targeting agricultural interventions as well as design alternative farming systems for different types of farms. Farm Typology is a methodology for grouping farm households taking into account the agricultural heterogeneity within a region. Farm Typology can provide the basis for targeting appropriate agricultural technologies in farming system, ensuring their usefulness and adoption, thus contributing to success of agricultural projects.

Keywords: Farming system, integrated farming system, farm typology, multivariate statistical analysis

1. Introduction

During early history, humans survived as foragers or hunter gatherers. They hunted wild animals and gathered wild fruits and roots. The early foragers were knowledgeable about which plant are edible and which ones are poisonous. Their diet consisted of 2300 calories per day. Two third of it was plant based particularly fruits, roots and greenery. Later, human settlement started and agriculture began 10,000 years ago in several parts of the world. An area known as ‘fertile cresant’ of Mesopotamia where early human settlement started, plants domesticated include wheat, barley, pea and lentil while animals include goats, sheep and dogs. As settlements developed socio-economic situations lead to some of the household started focusing more on rearing of animals while others on crops. But they were mutually depend on each other. From here, started the emphasis of farming systems.

The holding sizes of marginal farms in India had decreased from 0.40 ha in 1970-71 to 0.38 ha in 2010-11 and is likely to reduce to the level of 0.32 ha with in this decade. By virtue of increased number of operational holdings (mainly due to fragmentation), their size is small but can be made profitable through interventions in farming system approach. In India, crop +livestock is the pre-dominant farming system in around 85 per cent of farm household. Understanding the constraints and temporal dynamics of the farming system is essential for optimization of resource utilization of farming system for which resource characterization and constraint analysis are done. A practical way of dealing with the complexity of farming systems variability and diversity is constructing typologies for distinguishing between farming systems. Quantitative typologies based on multivariate analyses allows to identify significant differences among farm types and use this as the basis for targeting interventions as well as design alternative farming systems for different types of farms [1].

Identification and characterization of farming systems is of utmost importance for identifying groups of farm holdings with fairly similar farming system in a highly diverse and complex agro-ecological environment. Heterogeneity in farming system is enormous due to the diverse agro-ecological, socio-economic and resource endowment conditions in which they develop. Transforming, increasing agricultural productivity or in general rural livelihoods improvement, must consider the small holders variability for several reasons. Rural families develop different livelihood strategies driven by the opportunities and constraints derived from such diversity.

Agroecology, markets and culture determine different land use patterns, but also within villages one may encounter differences in resources endowment, production orientation and objectives [2]. Even ethnicity, education, age, management skills and attitudes towards risks of the farmers, shape the diversity of strategies of natural resources exploitation [3].

2. Farming system

A farming system is the result of complex interactions among a number of interdependent enterprises/ components, where an individual farmer allocates certain quantities and qualities of four factors of production namely land, labour, capital and management to which he has access. Farming system approach is a powerful tool for natural and human resource management in developing countries such as India. It is a multidisciplinary whole-farm approach and can be effectively employed in solving the problems of small and marginal farmers.

A farming system is defined as a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate [4].

2.1 Three core characteristics of farming system

a. Farm family
b. Farm
c. Environment

When analysing a farming system, at least three sets of interacting factors need to be taken into account: farm, farmer and environment. That is the various members of the farm family, with their individual preferences, projects and history; the farm with its resources and assets; and the environment which is constituted by social networks, economic opportunities, political incentives and bio-physical context. This means that the farming system is understood as constructed by the farmer, while being dependent on material resources and structures. As such, a farming system is an emergent property of material conditions and social construction [5].

3. Integrated Farming System (IFS)

Integrated farming system can be defined as a set of agricultural activities organized into a functional unit to profitably harness the solar energy while preserving land productivity, environmental quality and maintaining the desirable level of biological diversity and ecological stability. Integration of different agricultural allied enterprises with crop activity as base would provide ways to reuse and recycle produce/ waste material of one component as input in the other linked component thus reduces the cost of production of the economic produce of the linked component and ultimately enhances the net income of the farm as a whole.

IFS is a system which comprises of inter-related set of enterprises with crop activity as base, will provide ways to recycle produces and "waste" from one component becomes an input for another part of the system, which reduces cost and improves soil health and production and/or income [6]. Integrated Farming System (IFS) is a whole farm management system which aims to deliver more sustainable agriculture and it refers to agricultural systems that integrate livestock and crop production [7].

4. Farming System Research (FSR)

FSR is an approach to agricultural research and development that views the whole farm as a system and focusses on (i) The interdependencies between the components under the control of members of the household and (ii) How these components interact with the physical, biological and socioeconomic factors not under the household's control [8]. Farming Systems Research (FSR) may be defined as a diagnostic process, providing a collection of methods for researchers to understand farm households and their decision-making. Its applications use this understanding to increase efficiency in the use of human and budgetary resources for agricultural development, including research, extension and policy formulation [9].

The term Farming System Research (FSR) in the broad sense refers to any research that views the farm in a holistic manner and considers interactions in a system [5]. Farming Systems Research is an intellectual way of life, a world view, a concept of the nature of reality and how to investigate it. How this 'worldview' is translated into conceptualising research and how it is translated into practical inquiry will depend on many factors. These include: the context of the research, the specific research question, the choice of spatial and temporal scale, the disciplinary back-ground of the researcher, institutional constraints of those participating in the inquiry, as well as the previous experiences and knowledge of systems thinking by the participants.

Initially, Farming Systems Research took the farm as a starting point for an analysis of a broad range of issues linked to agricultural production. Soon afterwards, it was recognised that to understand farming, the scale of analysis needed to be broadened, to capture the interactions between farms and their natural, social and economic context. Topics of research now range from on-farm issues such as interactions between crop production and animal husbandry, to farmer pluriactivity, civic food networks, and how cultural landscapes are shaped by farming activities [5].

4.1 Three core characteristics of FSR

They are system thinking, interdisciplinarity and participatory approach [5].

4.1.1 Systems thinking: Situations deemed 'problematic' are understood as emergent phenomena of systems, which cannot be comprehensively addressed by using only a reductionist, analytical approach. It requires thinking about the interconnections between a system's elements, its dynamics, and its relation with the environment. It studies boundaries, linkages, synergies and emergent properties. The aim is to understand and take into account interdependencies and dynamics. It means keeping the 'bigger picture' in mind, even when a study focuses on a specific aspect or sub-system.

4.1.2 Interdisciplinarity: Agronomic sciences (crop production, animal husbandry) are working closely with social sciences (sociology, economics, political sciences) and 'interdisciplinary' sciences (e.g. human geography, land-scape planning). This interdisciplinary approach is essential to understand farming in a systemic way. Farming Systems Research is thus distinct from disciplinary research, which can provide complementary insights (e.g. informing the development of new production methods).

4.1.3 Participatory approach: Integrating societal actors in research is critical to understand ‘real world’ situations, to include the goals of various actors, and to appreciate their perception of constraints and opportunities. A broad range of societal actors (farmers, extension agents, civil society organisations, associations, etc.) can be involved in research, and may actively shape the research process.

Farming Systems Research emerged to address a new set of questions that dominant approaches to agricultural research were poorly equipped to address [9]. This dominant approach was characterised by disciplinary specialisation in commodity-oriented research, taking place on experimental research stations and in laboratories, and with top down research-extension schemes. This research often emerged from a productivist orientation to agriculture, seeking optimization and striving for continuous productivity gains (measured through, for example, crop yields or return to labour). Capital intensive modernization was seen as the desirable model of development, and the orientation towards commodity markets was to be enabled by technological innovation, scale enlargement, and specialization of farms.

4.2 Challenges of FSR

Researchers from many different disciplinary backgrounds contribute to the development of Farming Systems Research, focusing on specific aspects and customising it to different contexts. As a result, a diversity of approaches and applications has been developed, a richness that comes at the cost of a simple, all-encompassing definition. This explains why Farming Systems Research cannot be neatly categorised and pinned down. At the same time it is a testimony to the vitality of the approach to inquiry and how it spurs creative research design, tailored to specific situation, rather than promoting a ‘one size fits all’ approach.

Interdisciplinary teamwork can still be problematic for some disciplinary trained scientists. They acknowledge that there are links to other disciplines, but tend to privilege their own discipline, expecting others to feed into their methods and approaches. Achieving inter-disciplinarity in which the interactions between the elements of the farming system – rather than any discipline – is the focus of attention, is an on-going challenge to achieve.

Based on Jiggins and Gibbon [10], a spider and its web is a suitable metaphor for an inter-disciplinary research team exploring an issue. The spider is the research team: it cannot move unless its legs (the disciplines) act together. The spider can move about its web, examine it from different angles. The web is connected to its environment, thus providing inputs. The web also catches new ideas. The spider might choose to redesign its web, thus breaking and remaking it, allowing it to catch different ideas.

5. Farm Typology

Factors contributing to heterogeneity between and within farming system are: heterogeneity in skill and ambition of farm household members and heterogeneity in biophysical, institutional, social and economic diversity of farming system. Farm typology is a tool to capture heterogeneity of farming system. It is a practical way of dealing with farming system complexity and diversity to artificially stratify smallholders into subsets or group that are homogenous according to specific criteria. Farm typology is an attempt to capture farming systems heterogeneity and are considered as a useful first step in the analysis of farm performance and rural livelihoods [11]. Farm typologies have been used for nearly 20 years now [12]. Farm typology is a methodology for grouping farm households taking into account the agricultural heterogeneity within a region [13].

Adoption and scaling of technologies in agricultural systems is of central interest for academics and policymakers, as higher levels of adoption results in higher return on investment in research and development, impacting the economy of rural livelihoods. But numerous examples have proved that technologies with great potential are not adopted because the complexity and heterogeneity of the smallholders is not addressed. Distinct group of farmers may need specific technologies as single “one size fits all” solutions do not exist [14].

Even more, reconfiguring farming systems to reach various productive and environmental objectives while meeting farm and policy constraints is challenging because of the large array of farm components and the multitude of interactions among them [15]. A practical way of dealing with farming system complexity and diversity is to artificially stratify smallholders into subsets or group that are homogenous according to specific criteria. The term typology designates both, the science of type delineation and the system of types resulting from this procedure. Farms typologies are an attempt to capture farming systems heterogeneity and are considered a useful first step in the analysis of farm performance and rural livelihoods. Farm typologies have been used for nearly 20 years now [11].

Farm typology study recognizes that farmers are not a monolithic group and face differential constraints in their farming decisions depending on the resources available to them and their lifestyle [16]. Moreover, typology studies are of paramount importance for understanding the factors that explain the adoption and/or rejection of new technologies [17].

The heterogeneity of farming systems is created by a host of biophysical (e.g. climate, soil fertility, slope etc.) and socio-economic (e.g. preferences, prices, production objectives etc.) factors [18].

Several approaches can be used for developing farm typologies, from participatory workshops where local knowledge and stakeholders perception of the main factors that explain local diversity is taken into account, to the use of surveys and the statistical multivariate analysis of data for typologies construction [19]. Quantitative typologies based on multivariate analyses allows to identify significant differences among farm types and use this as the basis for targeting interventions as well as design alternative farming systems for different types of farms.

5.1 Purpose of farm typology

Typologies respond to research questions that require taking into account the agricultural heterogeneity within a region. Ewert and coworkers [20] gave four main reasons to develop a typology:

1. Targeting: identifying appropriate interventions per farming system type
2. Scaling-out: how appropriate interventions can be disseminated at a large scale
3. Selection: selection of representative farms or the formulation of prototype farms for detailed analyses.
4. Scaling-up: extrapolation of ex-ante impact assessments to larger spatial or organizational scales

5.2 Methods used in farm typology

- Step by step comparison of farm functioning

- Expert knowledge
- Participatory rankings
- Typology- Multivariate analysis and clustering methods

5.2.1 Step by step comparison of farm functioning: for a delimited area, this classification method is based on extensive data about farm functioning (family, objectives, history, productions, management, techno-economic results, biophysical constraints, etc.), which can be obtained from surveys of a stratified sample of farms. The grouping into types is made using a "step by step" comparison of neighbouring farms [21].

5.2.2 Expert knowledge: the typology construction is based on aggregating farms in clusters defined by local experts, key informants, or farmers [22]. This approach leads to the establishment of a common reference base. Generally, the typology approach based on expert knowledge requires little time and costs.

5.2.3 Participatory rankings: the ranking of households, mostly according to wealth (wealth ranking), by experts and/or farmers themselves in a participatory process. Observable assets are important when ranking is based on wealth [23].

5.2.4 Multivariate analysis including ordination and clustering methods: this method can be seen as the quantitative equivalent of the 'Expert knowledge approach'. Statistical methods (e.g. Principal Components Analysis, Multiple Factorial Analysis) are used to classify objects (here farms). In the ideal case no hierarchy or preconceptions are projected on the objects [3]. This kind of methods are also called 'dimension reduction' or 'data-reduction' techniques [22] because they have the advantage of capturing the complexity of farming systems through taking into account, at the same time, numerous farm dimensions and then highlighting a few dimensions that are more explanatory of farm diversity [12].

5.3 Framework of farm typology
The structure of the typology construction framework is presented below. It comprises nine steps to go from a heterogeneous population of farms to the grouping of farms into coherent farm types. The steps are:

- Specify research objective
- Formulate hypothesis
- Data collection
- Exploratory data analysis
- Selection of key variables
- Multivariate analysis
- Clustering
- Cluster profiling
- Validating hypothesis

5.3.1 Specify research objective
Research objective should be specific to the study area. Eg: increase on-farm income of farm households in a locality.

5.3.2 Formulate hypothesis
Zonal stakeholders (farmers/ extension workers) can best describe the local farming system [12]. Participation of local stake holders results in ex-ante (forecast rather than actual result) of efficient farm types in the study area [19]. Effectiveness of farm typology could be improved by ensuring participation of local stakeholders in formulation of hypothesis.

5.3.3 Data collection
Zonal stakeholders should be part of designing questionnaire for survey [22]. Survey questionnaire should be designed to capture the heterogeneity in the farming system [3]. Random sampling method or stratified sampling method can be used to conduct survey. The farm sampling should cover the farm diversity of the studied area [22]. Thus the sampling should be elaborated based on the initial hypothesis, and notably on the expected farm types proportions. If the sampling is completely randomized, a large sampling size is necessary.
It is not recommended to ask to all farmers to come to a meeting place to make them fill the survey: the farm sample could be biased by the ability and/or motivation of farmers to come to the meeting place. Moreover, farm visits allow some additional checks, for instance on field area cultivated, crops grown, tools owned and livestock kept. Usually, for statistical reasons it advised to sample at least 50 farms [24]. In practice the sample of farms for typology studies ranges from 18 farms to 2746 farms, with a median of 138 farms surveyed.

5.3.4 Exploratory data analysis
Variables recorded in surveyed questionnaire can be grouped into specific categories to describe farming system. In order to ensure a systematic approach, variables related to main component of farming system and interaction of main component of farming system with outside environment must be used for analysis [19]. Crop-livestock farming systems are the back-bone of small holder agriculture in developing countries [25]. To check for zero and non-zero variance variables or possible outliers, histograms and boxplots are useful visualizations of our variables.

Table 1: Example of variables describing crop-livestock farming systems

Category	Variable
Household	Family size, Household head age, Family labour on farm activities, Labour hired, months food self sufficiency
Household- environment	Off- farm activities, Total gross margin of the household, Off- farm income, Food purchase, Production objectives
Cropping system	Area owned by household, area farmed, area with food crops/ fodder crops/ cash crops
Cropping system-Environment	Crop production sales, purchase of mineral/ organic fertilizers/ pesticide
Livestock system	Total no. of livestock, Nos. of local cattle/ improved bred-cattle, small ruminants/ small animals, milk production
Livestock system- Environment	Total animal product sales, manure sales, concentrate/ fodder purchases

5.3.5 Selection of key variables
Detect meaningful significant correlation among variables and select these variables for multivariate analysis. Correlation among variables helps in identifying linear dependencies or collinearities. That is, some variables might be constructs of another. The correlation among those variables would be one or very close to 1. If we find those correlated variables, we must only take one, of the correlated variables. Additional

important information that correlation analysis throws, is that, only by analyzing the correlation matrix we can begin to have an idea of what the factors (latent variables, PCs…) will be as a result of our factor analysis. Choosing variables for PCA from the correlation matrix has a thumb rule- you must have at least 5 times households than discriminant variables (variables for PCA).

By inspecting the matrix visualization of the significant correlations and the clustered variables along with the histograms and boxplots we can select variables for PCA.

5.3.6 Multivariate analysis

Key variables selected are used for Principal Component Analysis. PCA should be run to select the number of PCs to retain after inspecting the either eigenvalue criteria (choose the PCs that have eigenvalues >1) or the scree plot test (choose a break point in which variance change, slope, from one PC to another, flattens).

5.3.7 Clustering

The Cluster Analysis (CA) aims to group farms into classes/types that are as 'homogeneous' as possible. There are two main methods of CA commonly used [19]:

1. Non-hierarchical clustering: a separation of observations/farms space into disjoint groups/types where the number of groups (k) is fixed.
2. Hierarchical clustering- a stepwise aggregation of observations/farms space into disjoint groups/types. First each farm is a group all by itself, and then at each step, the two most similar groups are merged until only one group with all farms remains. The visual result of these steps (algorithm) is a dendrogram or classification tree.

5.3.8 Cluster profiling

Boxplot and Descriptive Statistics are used to summarize the characteristics of farm types resulting from a PCA-HC method by comparing the behavior of variables between farm types. In order to assess whether the differences in means observed in boxplot and descriptive statistics are statistically significant, non-parametric ANOVA- Kruskal-Wallis test is used. Once it is determined that significant differences exist between means, post hoc Boneformi test is used to perform pair wise comparison between means, so that we can know which farm type are different for each variable.

5.3.9 Validating hypothesis

Compare result of PCA-HC with hypothesis. Discuss with local stakeholders to better understand the differences between hypothesis and result of PCA-HC in case of unexpected results. Farm type should be selected based on their explanatory value- they have to be conceptually meaningful [26].

6. Studies on farm typology

Ridaura and coworkers [27] examined the food security status and livelihood activities of 269 smallholder farm households (HHs) in Bihar, India. Typologies can be developed using structural (farm assets and resources) or functional (livelihood pursuits) variables, or both. They selected and computed variables representing structural and functional features of farming systems, the latter related mainly to farmers' primary crop and livestock systems. Thirty-two variables were computed in total. Proceeding with a four-step analysis, they first applied a multivariate statistical methodology to differentiate five primary farming system types. An indicator of food security in the form of HH potential food availability (PFA) is used and examined the contribution of crop, livestock, and on- and off-farm income generation to PFA within each farm HH type. Lastly, they applied scenario analysis to examine the potential impact of the adoption of 'climate smart' agricultural (CSA) practices in the form of conservation agriculture (CA) and improved livestock husbandry, and environmental shocks on HH PFA. Result depicted hierarchical clustering analysis indicated five main types of farm HHs across the three districts examined.

Kuivanan and coworkers [11] compared quantitative, statistical typology based on a survey dataset and multivariate analysis, with a qualitative participatory typology based on informal group sessions and activities with local stakeholders from three communities in Northern Ghana. The Africa RISING survey for the Northern Region comprised information from80 randomly sampled farm households across the three case study communities, capturing the diversity in local farming system From the pool of farm household-level information, 12 variables describing household, labour, land use, livestock ownership and income dimensions were distilled. The choice of variables was informed by the findings of previous studies, project objectives and data availability. Two multivariate statistical techniques were employed sequentially: principal component analysis (PCA) to reduce the dataset into non-correlated principal components (PC's) and cluster analysis for partitioning the PCA output into clusters. For the latter, a two-step approach was followed. The PCA extracted the first five PC's explaining about 66% of the variability in the dataset. Six farm types were identified; contrasted by their structural (resource endowment)- and functional (production objectives/livelihood strategies) characteristics. The participatory typology identified five farm types, based primarily on endowment (farm size, income investment), gender and age-related criteria.

7. Conclusion

Farming System is a collection of farm enterprises and its interaction with environment. Integrated Farming System is a management strategy aimed at efficient resource recycling within Farming System. Farming System Research is a diagnostic method to understand farm household and their decision making process. Farm Typology is a methodology for grouping farm households taking into account the agricultural heterogeneity within a region. Farm Typology can provide the basis for targeting appropriate agricultural technologies in farming system, ensuring their usefulness and adoption, thus contributing to success of agricultural projects.

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