



Farming system typology construction for the adoption of new technologies in north-west India

KARTIK SHARMA^{1*}, SOHAN SINGH WALIA², JASHANJOT KAUR³,
RAKSHIT BHAGAT² and JAYANTA LAYEK¹

Punjab Agricultural University, Ludhiana, Punjab 141 004, India

Received: 24 December 2024; Accepted: 21 January 2025

ABSTRACT

The modern agricultural sector is facing significant challenges, viz. productivity, sustainability and profitability due to shrinking landholdings and limited resource base. Therefore, a study was carried in 2020 and 2021 at Punjab Agricultural University, Ludhiana, Punjab, to investigate farm typologies in the north-west part of India using multivariate techniques [Principal Component Analysis (PCA) and cluster analysis (CA) (small diversified farms (Cluster I), larger crop-dominated farms (Cluster II), moderate-sized mixed farms (Cluster III), and large commercial farms (Cluster IV)] surveying 95 farm households in two districts (Tarn Taran and Patiala) of Punjab. By examining socio-economic factors and enterprise contributions, it identifies farm diversity to enhance technology adoption, improve incomes and recommend targeted policy interventions to the farmers. Using multivariate statistical techniques, structural and functional farm characteristics were analysed to construct specific farm typologies. The sequential application of PCA and CA revealed that the surveyed farmers had an average landholding of 17 acres, with a pre-dominant focus on cereal cultivation (cropping intensity: 163.7%) and crop income accounted for 94.1% of total earnings, with dairy and other agricultural allied enterprises contributing minimally. The PCA identified three principal components that explained 51.5% of the variance, emphasizing cropping intensity, income distribution, and livestock dynamics. Cluster analysis grouped households into four typologies i.e. (small diversified farms (Cluster I), larger crop-dominated farms (Cluster II), moderate-sized mixed farms (Cluster III), and large commercial farms (Cluster IV)] surveying 95 farm households in two districts (Tarn Taran and Patiala) of Punjab, each cluster exhibited variations in landholding size, labour utilization, crop-livestock integration, and income composition. Cluster-specific recommendations include technical support, diversification strategies and market-oriented interventions to enhance productivity and sustainability. This typology-based classification integrates socioeconomic and resource characteristics, offering a sustainable framework for targeted agricultural policies and interventions.

Keywords: Cluster analysis, Farm clusters, Farming system, Farm typology, Principal component analysis

The modern agriculture is facing critical challenges, including food security, sustainability, productivity, and profitability, driven by inadequate land-use allocation that fails to meet growing food demands for burgeoning population (Bhagat *et al.* 2024). In this regard, the integrated farming systems (IFS) model offer a sustainable pathway to ensure food and nutritional security while improving farmers' livelihoods (Paramesh *et al.* 2022). However, farming systems research advancement is hindered by global-scale assessments that overlook local complexities and diversity, leading to rigid and ineffective policy frameworks (Sarker

et al. 2021). Therefore, identifying and characterizing farming systems model can simplify the diversity of farm types within complex agroecosystems, enabling precise technological interventions and informed policy support (Behera and France 2023). Farming system typology is influenced by various factors, viz. resource availability, landholdings, topography, and farmer-specific needs, which are important for evaluating constraints, identifying opportunities and providing tailored solutions to the farming community (Kaur *et al.* 2021).

Moreover, there is a need to reduce and understands the diversity existing among agricultural households in Punjab, which can be done by identifying the major variables that affect variability and classifying those variables into homogenous groups. While many studies examine the technology adoption process and its impacts on farming households, few analyse the factors influencing its adoption. Therefore, this study categorizes farms based on

¹ICAR-Indian Institute of Agricultural Biotechnology, Ranchi, Jharkhand; ²Punjab Agricultural University, Ludhiana, Punjab; ³Regional Research Station, Kapurthala, Punjab Agricultural University, Ludhiana, Punjab. *Corresponding author email: kartik.icar@gmail.com

enterprise contributions and socio-economic factors to offer insights into farm types and facilitate targeted technological interventions to improve incomes of small and marginal farmers. By exploring farming system heterogeneity across north-western India, the study aims to better define farm diversity and improve the targeting of interventions. Using multivariate statistical techniques, including Principal Component Analysis (PCA) and Cluster Analysis (CA), the research identifies the socio-economic factors influencing technology adoption, building on methodologies from prior studies (Innazent *et al.* 2022). Moreover, the farming system typologies in North-Western India, identified through PCA and cluster analysis, can be useful for targeted technological interventions to enhance productivity, sustainability and profitability.

MATERIALS AND METHODS

Study area: The present study was carried in 2020 and 2021 at Punjab Agricultural University, Ludhiana, Punjab, in Tarn Taran ($31^{\circ}72'$ and $32^{\circ}32'$ North and $74^{\circ}29'$ and $75^{\circ}23'$ East, at an elevation of 230 m asl) and Patiala ($30^{\circ}19'$ N, $76^{\circ}24'$ E; 247 m amsl) districts of Punjab. The district Tarn Taran is located between in the subtropical region. The climate of Tarn Taran district exhibits the characteristics of a tropical steppe, semi-arid, and hot region. It is predominantly arid, except for a brief period during the south-west monsoon season. The summer months (April–June) are hot and dry, followed by humid and cloudy conditions from July–September during the monsoon. Early winter (October–November) is relatively mild, while cold winters dominate from December–February. The district

receives an average annual rainfall of 482.9 mm, with approximately 74% of the total precipitation occurring during the south-west monsoon, which begins in the last week of June and withdraws by mid-September. July and August are the rainiest months of the year. Patiala district of Punjab experiences a subtropical climate, characterized by hot and dry summers (April–June), hot and humid monsoons (July–September), mild winters (October–November), and cold winters (December–February). Temperature variations throughout the year are significant, with maximum temperatures occasionally reaching 40 – 45°C and minimum temperatures dropping as low as 0.5°C during winter. The region receives an average annual rainfall of 650 mm, with approximately three-fourths of the precipitation occurring during the southwest monsoon season from July–September.

Data collection and survey: The survey for farm typology construction was done in 2020 and 2021 by surveying 95 households in Patiala and Tarn Taran districts of Punjab (Fig. 1). The identification and characterization of farming systems simplify huge diversity of farm types in complex agro-ecosystems, enabling the formulation of precise technological interventions and evidence-based policy recommendations as there is necessity to analyze and classify the diversity among agricultural households in Punjab by identifying key variables influencing variability and grouping them into homogeneous categories. The methodology involved an initial assessment of the farming situation and hypothesis formulation, followed by a survey of 95 farm households to collect data on crop component, livestock component and other household characteristics using a structured questionnaire to collect information

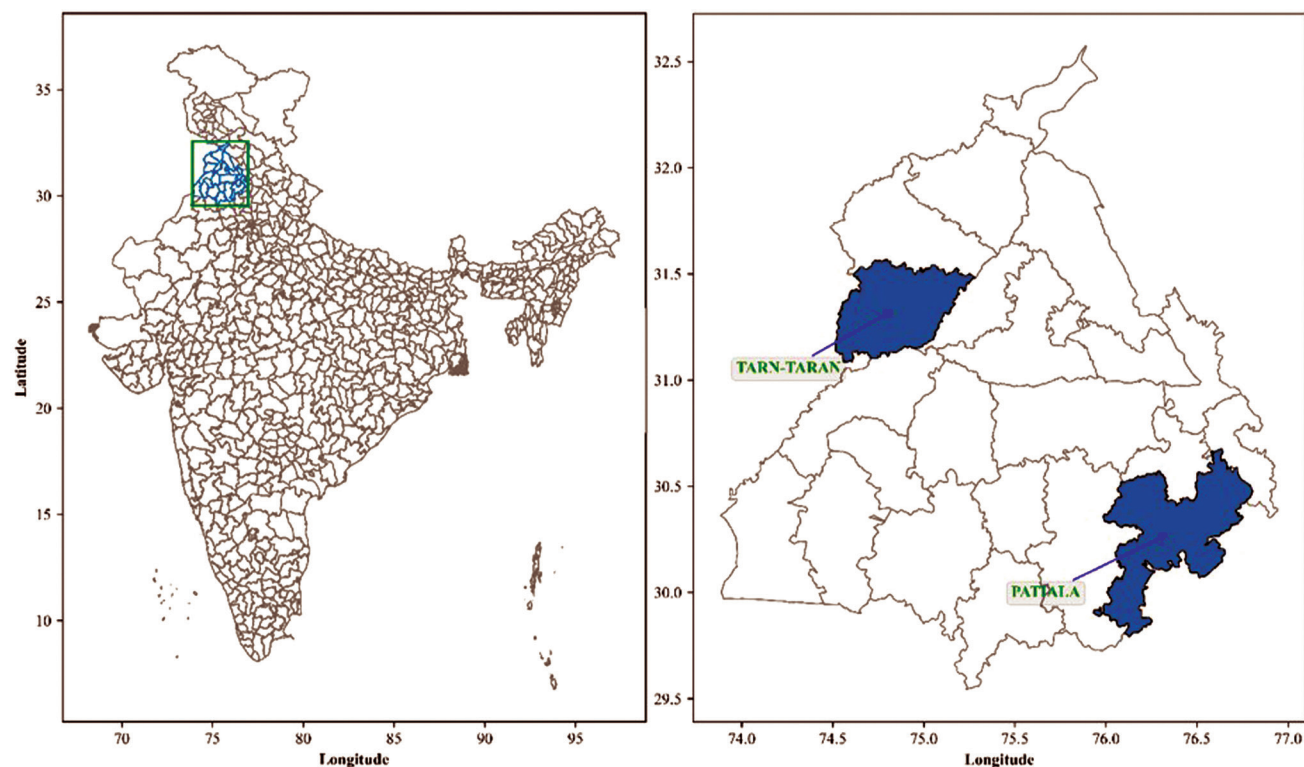


Fig. 1 Map of study area with selected districts of Punjab, India

pertaining to structural and functional characteristics of farm and farming systems. The multivariate techniques, viz. PCA and hierarchical clustering, were applied for data analysis, and the proposed hypothesis was subsequently verified. A 15-variable survey questionnaire, approved under All India Coordinated Research Project on Integrated Farming Systems, captured structural, cropping, livestock, and income-related characteristics. Moreover, the survey was performed in accordance with their relevant guidelines and regulations approved by the technical programme review committee of AICRP on Integrated Farming System headed by Programme Coordinator. The Code of Ethics of the International Sociological Association (ISA) for the formulation and execution of the questionnaire was followed. The questionnaire was also approved by the institutional committee at ICAR-Indian Institute of Farming Systems Research and pre-tested in the field before the final collection of data. Since the survey was interview-based with humans, before conducting the survey, we informed the participant about the purpose and the utilization of the survey, informed consent was obtained from each of the participants. The surveyed data was subjected to principal component analysis (PCA) and cluster analysis (CA) for typology construction.

Typology construction: The diversity of farm households in the Punjab region was explored for typology construction. For this purpose, the structural (structural characteristics and livestock-related) and functional (cropping system and income-related) variables were computed. To avoid the effects of collinearity, the fifteen variables were then subjected to correlation analysis and the variables which were significantly correlated were identified. From the inter-related variables, the variables which explain more diversity of data were selected. Two multivariate statistical techniques, viz. PCA and CA were employed sequentially for generating a typology of the surveyed farm households. The PCA was applied to reduce the dataset into non-correlated components followed by Hierarchical Cluster Analysis (CA)

for partitioning the PCA output into clusters. This approach has been previously used by Kaur *et al.* (2021) to categorize farming systems. Based on correlation analysis, out of 28 variables (Table 1) 15 variables were selected for further analysis (Fig. 2).

The PCA was applied to reduce the multivariate farm household dataset into uncorrelated principal components (PCs), with the number of PCs retained based on three criteria: (1) Kaiser's criterion, retaining PCs with eigenvalues >1.00, (2) the scree plot test combined with a minimum cumulative percentage of explained variance, and (3) interpretability, ensuring the retained PCs aligned conceptually with the hypothesis. The reduced PCA dataset was then subjected to Cluster Analysis (CA) using

Table 1 Respondents profile characteristics

Characteristic	Mean	Range
Age (year)	45.6	18–69
No. of allied enterprises (other than crops)	1.1	1–2
Total land (acre)	17.4	3–72
Own land (acre)	14.5	3–72
Leased in (acre)	2.9	0–44
Cereal intensity (%)	163.7	88.9–196
Fodder crop intensity (%)	19.1	0–66.7
Industrial crop intensity (%)	1.2	0–59.6
Oilseed crop intensity (%)	2.5	0–22.2
Other cereal crop intensity (%)	9.5	0–85
Other crop intensity (vegetables) (%)	2.1	0–33.3
Total labour for farming system (man-days)	579.7	212.7–1673
Percent family labour	60.9	18.2–100
Percent hired labour	40.5	0–229.8
Percent labour engaged in broiler	0.8	0–50
Percent labour engaged in crops	75.1	42.9–92.3
Percent labour engaged in dairy	23.6	0–42.9
Total mushroom produced (kg)	37.9	0–2000
Total no. of buffalo	4.3	0–18
Total no. of cow	2.3	0–13
No. of broilers/cycle (Nos.)	42.1	0–3500
Total cost of crop production (₹)	465,616	69,000–2,163,000
Total gross returns from crops (₹)	3,985,674	334,118–21,543,335
Total income from farming system (₹)	3,716,683	671,914–19,544,675
Percent income from broiler (%)	1	0–85.3
Percent income from crops (%)	94.1	14.7–122.5
Percent income from dairy (%)	4.8	-22.5–37.2
Percent income from mushroom (%)	0.1	0–6.2

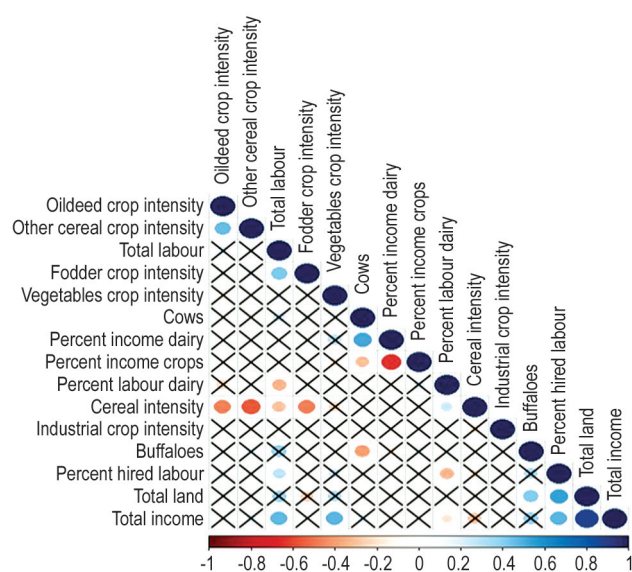


Fig. 2 Variables chosen for typology construction (15).

a two-step approach; hierarchical clustering via Ward's method (Ward 1963), and maximum average silhouette width (Rousseeuw 1987) to determine the optimal number of clusters, followed by k-means clustering to partition the dataset into the identified clusters (Rousseeuw 1987). Ward's method grouped observations based on similarity, visualized through a dendrogram, which was cut at the point maximizing the average silhouette width. The Kruskal-Wallis test was applied to evaluate significant differences among variables across the identified farm typologies, ensuring robust cluster validation.

Statistical analysis: All statistical analyses were performed using R software (R version 4.3.3).

RESULTS AND DISCUSSION

Farming system characterization

Principal component analysis: The survey of 95 farmers household (HH) revealed that farmers had an average of 17-acre of land holding with ranges vary from 3–72 acres, higher number of buffalo (4.3 per HH) than cows (2.3 HH) (Table 1). The farmers have higher proportion of income from crops (94.1%), 4.8 % income from livestock and very less from other sources. Furthermore, cereal crop intensity per household ranked one and varies from 88.9–196% with an average of 163.7%, which is followed by fodder crop intensity (19.1%), other cereals crop intensity (9.5%), oil seed crop intensity (2.5%), vegetable crop intensity (2.1%) and other industrial crop intensity of 1.2% only (Table 1). Almost 60% labour on the farm HH was family labour and 40% labour were hired from outside the farm. Moreover, 75.1% of the total labours was engaged in raising crops, followed by dairy component (23.6%) and broiler production (0.8 %). Total gross returns of from the crops have an average value of ₹39,85,674/- with cost incurred on crop production was ₹4,65,616/-. There were small enterprises like mushroom was also adopted by few farmers.

After correlation studies of the surveyed data, 15 variables were chosen as depicted in Fig. 2 for the principal component analysis (PCA) studies. The PCA resulted in extraction of ten principal components, out of which 3 principal components were retained with eigenvalue more than one (Fig. 3a). The correlation plot (Fig. 3b) presents the loading of different variable on the principal components and the variables were related to cropping activities like cereal crop intensity, fodder crop intensity, vegetable crop intensity, other cereal crop intensity, cows, buffalos, total income, total labour, percent income from crops and dairy. Negative correlations in PCA don't cause any concern. Component one explained 22.7% of variance and

showed correlation with percent area under different crops (cereal intensity = -0.58; fodder crop intensity = 0.26; oilseed crop intensity = 0.42; vegetables crop intensity = 0.43 and other cereal crop intensity = 0.4), livestock components (cows = 0.15 and buffalo = 0.46), share of labour (total labour = 0.68 and labour percentage from dairy = -0.36), but the higher discriminating variables total income (0.84) and total land (0.71) and total labour (0.68). Likewise, component 2 explained 15.5% of variance and showed correlation with income share (percent income from dairy = -0.78 and percent income from crops = 0.71), livestock component (cows = -0.66) and total area (total land = 0.37) and it also discriminated based on income components and livestock components. Component 3 explained loading of different crop intensities (cereal intensity = -0.55; fodder crop intensity = 0.52; vegetable crop intensity = -0.43 and other cereal crop intensity = 0.55), total cultivable area (total land = -0.48) and total income share (total income = -0.32; percent income from crops = 0.26 and percent income from dairy = -0.27). These initial three components together explained 51.5% of total variance. We can also state this as these three components represented the crop intensity related components and income related components explaining 51.5% of variance in data.

Cluster analysis: The three principal components generated for the 95 farmer HH were used as input data for cluster analysis. Hierarchical clustering indicated 4 cluster cut off points grouped by structural and functional characteristics of the farm such as land and livestock resources as well as their main farming activities and income generated characteristics. The dendrogram was generated from agglomerative hierarchical clustering, suggested 4 clusters and the scree plot also supported 4 clusters (Supplementary Fig. 1 a and b).

Farm cluster characterization: The characteristics of clusters in terms of background variables such as crop intensity and livestock components and economic performance indicators of the farming system have been

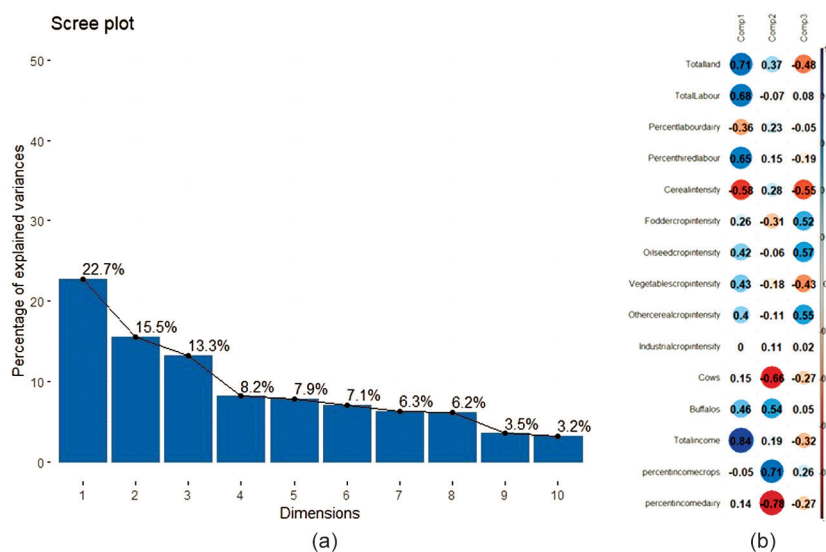


Fig. 3 PCA result output: (3a) Scree plot (3b) Correlation plot of PCs with variables.

summarized in Table 2. Cluster I account for 8.4% of total farm households. This cluster is characterized by 10 acre of land, 159.2% cereal intensity, 15.8% fodder intensity, 5.2% vegetable crop intensity, 1.0% of other industrial crop intensity and none of the farmer of this cluster raising oilseeds crops. Additionally, total labour (man-days) available on the farm were 574 and out of this 32.6% was the hired labour. Also 18.8% of the total labour was engaged in dairy enterprise and mainly responsible for production of dairy products. The farmers of this cluster were majorly reared cow. Moreover, average total income per household in this cluster was around ₹23,01,218/- and crop component and livestock components shared 68.4% and 20.9% of this total gross income of farm HH respectively. Thus, these HH, on an average secured higher income from crop components in comparison to other enterprises. These farms may be supported for technically sound intensification of agriculture with assured input and advisory services. Since these groups pursue a capital-intensive diversified farming, access to credit is important for them. The farmers may be assisted in commercial production techniques with provision for building requisite capacity in farm and non-farm-based entrepreneurship (Folmer *et al.* 2010). Export-oriented crops may be tried with these farmers with suitable incentive (Goswami *et al.* 2014). Cluster II comprised of 62.1% of the farm households. The cluster members have relatively larger land holdings, viz. 14.3 acre. This cluster is mainly characterized by higher cereal crop intensity (175.8%), 16.5% fodder crop intensity, 1.8% industrial crop intensity, 0.9% of vegetable crop intensity and 0.5% cereal crop intensity. Farmers of this cluster also grow minor cereals with an intensity of 4.1%. Furthermore, total labour (man-days) available on the farm were 485 and out of this 33.1% was hired labour. Out of total labour engaged on the farm, 26.2% were utilized in dairy component. The farmers of

this cluster raised both cow as well as buffalos. Average total income per household in this cluster was around ₹26,33,227/- and crop component shares 97.3% of total farm income. Dairy component contributes only 2.5% share of the total income. As these farms are also depended on crop component for higher income of the farm, technical support for sound intensification of agriculture with assured input and advisory services may further enhance the total income of the farm (Goswami *et al.* 2014).

Cluster III comprised of 20.0% of total farm household. Farmers are relatively smaller as they have 13.8 acres of land per household. This cluster was characterized by 132.5% of cereal crop intensity followed by fodder crop intensity (29.4%), minor cereals crop intensity (29.1%), oilseeds crop intensity (9.4%) and vegetable crop intensity (0.9%). Total labour engaged on the farm households were 727.7, and out of which 48.9% were hired labour. Also 19.6% of the labour was associated with dairy component as the farmers of this cluster reared both buffalos and cows. The share of total income from the crop component was 94.8% and from dairy was 4.9% and total income of the farm household were around ₹38,71,072/-. As farmers of this clusters raised fair number of minor cereals, their efficient management, availability of elite varieties, and adopting diversification approaches may enhance the overall farm income. Also, integration of livestock component with agriculture crops enhances the productivity of the farm and enhanced the soil fertility levels and thus, sustains the food and livelihood security (Bhagat *et al.* 2024). For this, specialized extension supports with farming system approach, and institutional convergence for sound planning is required (Nabi 2008). Furthermore, cluster IV comprises 9.5% of total households. The cluster members had relatively larger land holdings (51.9 acre), higher total labour in man-days (894) and higher total income of the household (₹1,17,51,595/-). Out of total labour engaged on the farm, 79% share was of hired labour.

Table 2 Derived farm clusters along with their major characteristics

Attribute	Cluster 1 (8.4%)	Cluster 2 (62.1%)	Cluster 3 (20.0%)	Cluster 4 (9.5%)
Total land (acres)	10.1	14.3	13.8	51.9
Total labour (man-days)	574.1	484.9	727.7	894.4
Percent labour dairy	18.8	26.2	19.6	19.4
Percent hired labour	32.6	33.1	48.9	79.0
Buffalos (Nos.)	0	4	5	7
Cows (Nos.)	8	1	2	5
Cereal intensity (%)	159.2	175.8	132.5	153.9
Fodder crop intensity (%)	15.8	16.5	29.4	17.4
Vegetables crop intensity (%)	5.2	0.9	0.9	9.7
Industrial crop intensity (%)	1.0	1.8	0.0	0.0
Oilseed crop intensity (%)	0.0	0.5	9.4	3.9
Other cereal crop intensity (%)	0.0	4.1	29.1	11.4
Total income (₹)	2,301,218	2,633,227	3,871,072	11,751,595
Percent income crops (%)	68.4	97.3	94.8	94.5
Percent income dairy (%)	20.9	2.5	4.9	5.5

Also 19.4% of the labour percentage was associated with the dairy component. The farmers of this clusters reared both buffalos as well as cow as livestock components. The other characteristics of this cluster was higher cereal crop intensity (153.9%), followed by fodder crop intensity (17.4%), other cereal crop intensity (11.4%), vegetable crop intensity (9.7%) and other cereal crop intensity (11.4%). Agricultural crops were the major component responsible for the income generation as it contributes about 94.5% of the total income, followed by the dairy component giving only 5.5% of the total income of the farm household. These farms are capital intensive, developed to meet the growing food demand at the nearest town markets. These may be supported for intensive farming with improved technology. Since they specialize in food grain production, assured marketing support and crop insurance are critical for such farms.

Conventionally, the farm households were classified majorly on the basis of the size of land holding in possession i.e. marginal, small, semi-medium, upper-medium, and large farmer. In this study, the typologies are developed based on the possession of assets, viz. crop, livestock and decisions made by them related to the crops and livestock rearing. Our analysis has clustered the farm households into four clusters based on structural characteristics, cropping system, livestock possessed, source of income and heterogeneity among different farm households. This farm typology classification offers clear advantages over classifications based on farm size or agroecological characteristics. The farm types delineated are manageable in number and represent both socio-economic, resource ownership and management orientation of the farms. Farm size-based classifications undermine the huge diversity among size classes and agroecological classification and ignore socio-economic realities of the farms. At the same time, the farm classes are based on sound statistical procedures instead of size-based classifications and, hence, more acceptable to policymakers. Based on the cluster characteristics, possible interventions, viz. diversification strategies, better marketing structures and technical support should be prioritized to ensure the livelihood security of farmers.

REFERENCES

- Behera U K and France J. 2023. Farming systems research: Concepts, design and methodology. *Advances in Agronomy* **177**: 1–49.
- Bhagat R, Walia S S, Sharma K, Singh R, Singh G and Hossain A. 2024. The integrated farming system is an environmentally friendly and cost-effective approach to the sustainability of agri-food systems in the modern era of the changing climate: A comprehensive review. *Food and Energy Security* **13**: e534.
- Folmer H, Dutta S and Oud H. 2010. Determinants of rural industrial entrepreneurship of farmers in West Bengal: A structural equations approach. *International Regional Science Review* **33**: 367–96.
- Goswami R, Chatterjee S and Prasad B. 2014. Farm types and their economic characterization in complex agro-ecosystems for informed extension intervention: study from coastal West Bengal, India. *Agricultural and Food Economics* **2**: 1–24.
- Innazent A, Jacob D, Bindhu J S, Joseph B, Anith K N, Ravisankar N, Prusty, A K, Paramesh V and Panwar A S. 2022. Farm typology of smallholders integrated farming systems in Southern Coastal Plains of Kerala, India. *Scientific Reports* **12**: 333.
- Kaur J, Prusty A K, Ravisankar N, Panwar A S, Shamim M, Walia S S, Chatterjee S, Pasha M L, Babu S, Jat M L and López-Ridaura S. 2021. Farm typology for planning targeted farming systems interventions for smallholders in Indo-Gangetic Plains of India. *Scientific reports* **11**: 20978.
- Nabi R. 2008. Constraints to the adoption of rice-fish farming by smallholders in Bangladesh: A farming systems analysis. *Aquaculture Economics and Management* **12**: 145–53.
- Paramesh V, Ravisankar N, Behera U, Arunachalam V, Kumar P, Solomon Rajkumar R, Dhar Misra S, Mohan Kumar R, Prusty A K, Jacob D and Panwar A S. 2022. Integrated farming system approaches to achieve food and nutritional security for enhancing profitability, employment, and climate resilience in India. *Food and Energy Security* **11**: e321.
- Rousseeuw P J. 1987. Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. *Journal of Computational and Applied Mathematics* **20**: 53–65.
- Sarker M R, Galdos M V, Challinor A J and Hossain A. 2021. A farming system typology for the adoption of new technology in Bangladesh. *Food and Energy Security* **10**: e287.
- Ward J J H. 1963. Hierarchical grouping to optimize an objective function. *Journal of American Statistical Association* **58**: 236–44.