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ORIGINAL ARTICLE

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Farmer Producer Organizations and Agricultural Sustainability in Uttarakhand's Hills: A Cross-Sectional Analysis of Conservation Practices and Economic Outcomes

Rajinder Singh Bisht[1]* | **Pradeep Mamgain[1]**

[1]Department of Business Management, HNB Garhwal University, Srinagar Garhwal, Uttarakhand, India

Corresponding Author:
E-mail: rajendrre.bist.official@gmail.com

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ABSTRACT

Hill agriculture in Uttarakhand is bottlenecked with multiple overlapping challenges. Fragmented landholdings, weak market linkages, severe soil erosion and growing climate variability are some of the major ones. Farmer Producer Organizations (FPOs) have been promoted as an institutional response to these constraints. But, the link between FPO membership and improved outcomes in ecological and economic domains has not been studied systematically in mountain agriculture. To address this gap, we studied 300 farm households (150 FPO members, 150 non-members) across three districts in Uttarakhand's Garhwal region. It was a cross-sectional survey using multistage random sampling. Key outcomes measured were: (1) a composite Resource Conservation Index (RCI; range 0-5) constructed from ten soil and water management practices, (2) agricultural income per *nali* (local land unit ≈ 0.02 ha) and (3) price realization ratio. Data was analysed for group differences and OLS Regression models controlling for farmer age, education, landholding size, market distance and district-level variations. FPO members demonstrated substantially higher conservation adoption (mean RCI: 3.25 vs. 2.15; 51% difference; $p < 0.001$), agricultural income (₹4,850 vs. ₹3,520 per *nali*; 38% difference; $p < 0.001$) and price realization (0.88 vs. 0.75; 13% difference; $p < 0.001$) compared to non-members. These associations persisted after multivariate adjustment (RCI: $\beta = 1.25$, $p < 0.001$; Income: β = ₹1,156, $p < 0.001$). The study found meaningful associations between FPO membership and improved performance in natural resource management and farm income. Interestingly, marginal (<3 *nali*) and less educated farmers showed stronger associations. These findings reinforce the role of FPO model for hill agriculture particularly when targeting marginalized farmers. The mechanism underlying these associations – whether through training, credit access, market linkage or other pathways – remains topic of future studies.

1 | INTRODUCTION

Nearly 70% of rural population in the Indian Himalayan Region (IHR) depends on hill farming system for its food and livelihood security (Sati, 2024). Notwithstanding the importance, this system operates under multiple pressures to its sustainability and economic viability (Singh *et al*., 2019). The challenges come from multiple directions. Landholdings are small and highly fragmented that resist mechanization (Tayang *et al*., 2024). Soil erosion steadily depletes fertility (Meena and Maikhuri, 2024), while increasingly erratic weather disrupts cropping calendars farmers have relied on for generations (Goel and Singh, 2024). Uttarakhand, our area of study, faces additional complications. Here the biophysical challenges are further complicated by the region's peculiar socio-economic dynamics. High rates of out-migration reduces labor pool and indigenous knowledge transfer (Balusamy *et al*., 2024; Mamgain and Reddy, 2017). Weak institutional support leaves farmers with reduced capacity to adapt as agro-ecological conditions grow more volatile (Joshi et al., 2023). These problems reinforce each other: small-sized farms restrict conservation investment thereby accelerating erosion and reducing productivity (Meena *et al*., 2022). Conventional solutions like improved seeds and irrigation often fall short where farmers lack awareness and bargaining power (Dinesh *et al*., 2022). What may be needed instead are institutional innovations that work at higher systemic level by reshaping how actors interact, how risk and rewards are shared and how decision are made (Schut *et al*., 2016).

Collective action programs in rural India include traditional cooperatives, Self-Help Groups (SHGs), watershed committees and NGOs. The Farmer Producer Organizations (FPOs) or Farmer Producer Companies

(FPCs) are a new addition to this list. FPOs enjoy greater statutory autonomy and less political interference compared to traditional cooperatives (Khiangte & Malsawmsanga, 2025). FPOs tend to adopt a more professional approach with salaried CEO and marketing team (Prabhavathi *et al*., 2023). FPOs integrate multiple services such as input supply, technical advice, credit facilitation and output marketing within a single institutional framework (Murugananthi *et al*., 2025). FPOs are selected for this study as they are built specifically around production aggregation and value chain participation. This design enables them to be of direct help in addressing the scale and market access constraints typical of hill agriculture (Bisht, 2021). The Indian government aimed to establish 10,000 FPOs by 2020 (Surendran-Padmaja & Ojha, 2025) supported by NABARD and various other government programs (Yazhini *et al*., 2025). However, empirical literature on FPO effectiveness shows geographic and thematic biases. Most studies concentrate on lowland regions and specific value chains (Kumar *et al*., 2023; Lalitha *et al*., 2024). Other studies highlight the FPOs importance in social capital especially for women and marginalized groups (Harrington *et al*., 2024; Prabhavathi *et al*., 2023). Much of the existing evidence focuses primarily on economic outcomes and market integration, with limited attention to ecological dimensions such as soil and water conservation. Empirical research on FPOs in hill agriculture is limited. Some studies from the Eastern Himalayas and Northeast India document the FPOs impact on farmers participation and economic welfare (Gurung & Choubey, 2023; Sharma *et al*., 2023), but systematic analysis of their dual resource conservation and income effect is rare. In Uttarakhand, most existing studies have focussed mainly on socio-economic impacts (Harrington *et al*., 2024; Prasad *et al.*, 2023) or specific commodity (Choudhary *et al*., 2015; Kumar *et al*., 2021). Studies have not explored FPOs as a distinct institutional form. As a result, little is known if FPOs in Uttarakhand contribute to conservation and economic goals.

This study examines association between FPO membership and agricultural outcomes in Garhwal region of Uttarakhand. It makes three major contributions to hill agricultural literature. First, it provides one of the few quantitative household-level comparison of FPO members and non-members in Indian Himalayan Region thereby filling a critical gap. Next, it develops a composite Resource Conservation Index (RCI) that captures adoption of ten soil and water conservation practices. Third, it records heterogeneity in FPO benefits across farm size and education levels.

Guided by the above discussion, we derived two hypotheses for the study:

1. **H1:** FPO membership is positively associated with higher adoption of resource conservation practices among farmers in Uttarakhand, after controlling for farmers age, education, landholding size, market distance and district-level differences.
2. **H2:** FPO members demonstrate higher average agricultural income and better price realization for their produce compared to non-members in Uttarakhand, after controlling for farmers age, education, landholding size, market distance and district-level differences.

HIGHLIGHTS

- FPO membership is associated with better outcomes on both fronts: 51.2% higher resource conservation score, with 37.8% higher agricultural income per *nali* and 13 percentage points better price realization.
- Marginal farmers (< 3 *nali*) and less educated farmers show disproportionately larger differences, suggesting equity benefits of FPO membership.
- Cross-sectional design stops us from drawing causal inferences, though the associations we recorded are strong enough to encourage longitudinal research on FPO effectiveness.

Cross-sectional design we adopted cannot establish causality or rule out self-selection into FPOs. Farmers who join FPOs may differ from non-joiners in ways our data do not capture. Unobservable differences such as entrepreneurial orientation or social capital may influence both membership and outcomes. We therefore present our findings as association, rather than definite evidence of FPOs impact.

2 | MATERIALS AND METHOD

2.1 | Study Area

Our fieldwork focussed on three districts in the Garhwal region of Uttarakhand: Pauri, Chamoli, and Tehri Garhwal (Fig. 1). These districts were selected as – (i) they fall in the mid-Himalayan agro-ecological zone where 70% of the state's hill agriculture is practiced (Bisht, 2021) and (ii) each has at least two operationally active FPOs with minimum two years of establishment (Small Farmers' Agribusiness Consortium, 2022). The study region is characterized by fragmented landholdings and multi-crop hill farming systems described as *Baranaaja* system (Ghosh and Dhyani, 2004). Agricultural markets are typically 5 to 15 kilometres distant from villages making transport both time consuming and costly (Sati, 2012).

2.2 | Research Design and Sampling Procedure

We adopted a cross-sectional comparative research design to examine the associations difference between FPO membership, resource conservation practices and economic outcomes. The target population comprised smallholder farmers engaged in multi-crop hill agriculture in the three selected districts. The sampling procedure followed a multi-stage procedure:

Stage 1 (Block selection): From each of the three selected districts, we identified all blocks containing operational FPOs and randomly selected two blocks per district yielding six blocks: Pokhara and Yamkeshwar (Pauri), arayanbagar and Tharali (Chamoli) and Devprayag and Bhilangna (Tehri Garhwal).

Stage 2 (Village selection): We constructed a sampling frame of all villages within selected blocks that contained at least one active FPO member. From this frame, 25 villages were randomly selected (approximately 4 villages per block), stratified to ensure proportional representation across districts.

Stage 3 (Farmer selection): Within each selected village, we randomly selected 6 FPO members from membership lists obtained from FPO offices. An equal number of non-member farmers were selected from the same village with similar landholding size (± 3 *nali*) and primary crop cultivation practices. This three-stage procedure produced a final sample of 150 FPO members and 150 non-members (total $N = 300$).

An a priori power analysis in G*Power 3.1 for an independent-samples t-test (two-tailed, $\alpha = 0.05$) assuming a small-to-medium effect size ($d = 0.35$)indicated that a minimum of 130 FPO members and 130 non-members (total $N = 260$) would be required to achieve 80% power. We therefore targeted a slightly larger sample and surveyed 150 members and 150 non-members (total $N = 300$)to provide a margin for non-response and data quality issues. FPO members and non-members may differ in unobservable characteristics (motivation, social networks, entrepreneurial capacity, risk averseness etc.) that influence both FPO participation and outcomes. Our analytical strategy controls for observable differences but cannot eliminate selection bias inherent in the cross-sectional comparative design.

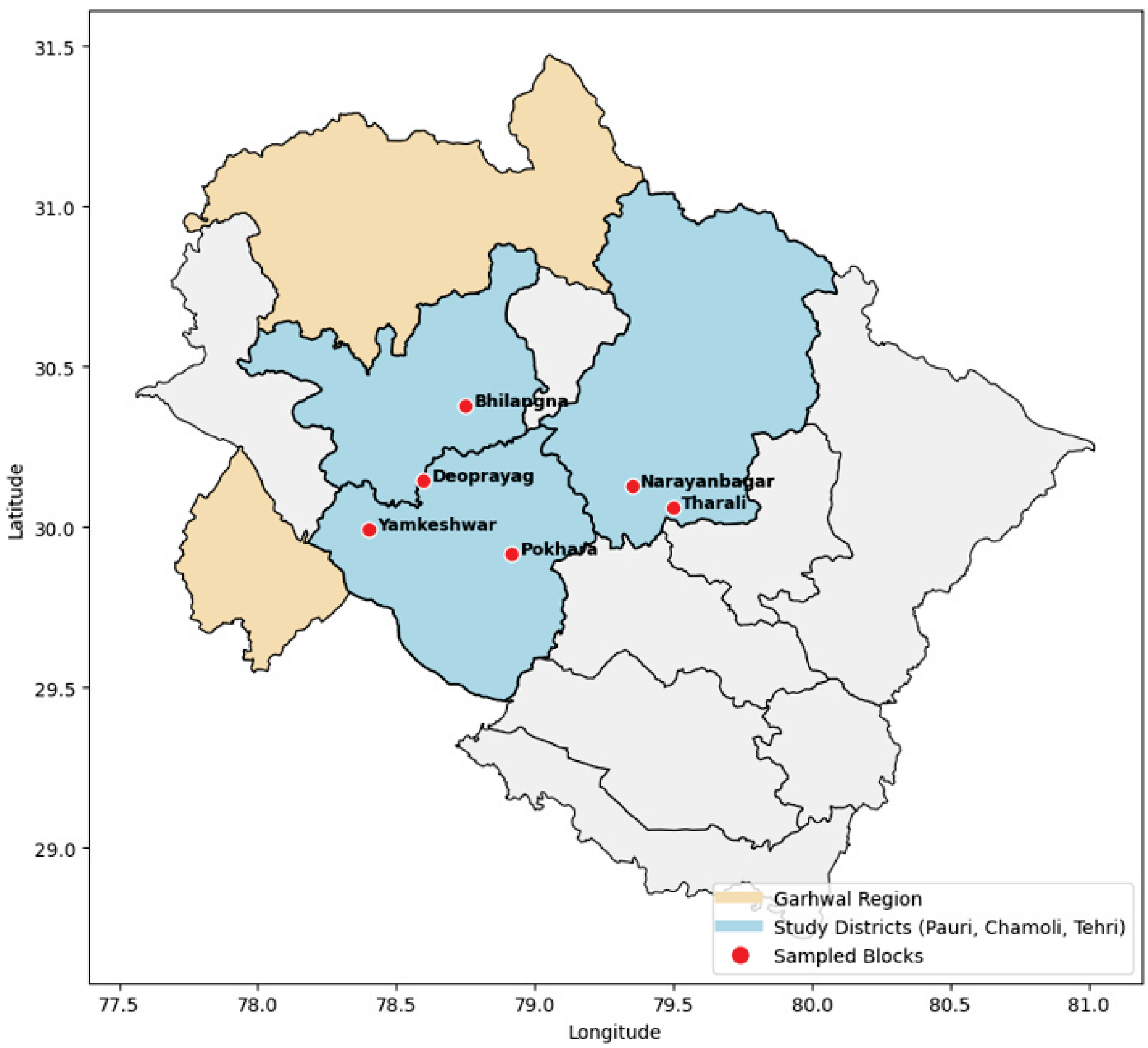

FIGURE 1 Study Area Map of Uttarakhand (Sampled FPO Blocks)

2.3 | Data Collection

Primary data were collected between October and December 2024 using a structured questionnaire administered in Hindi. The survey instrument captured household demographics, farming practices, income indicators, FPO participation details and resource conservation outcomes. The instrument was pilot tested with 30 farmers in a non-sample village in Pauri district (September 2024). Question phrasing was simplified based on pilot test feedback. The study relies exclusively on quantitative survey data. The absence of qualitative triangulation (FGDs or key informant interviews) is noted as a limitation. We addressed this limitation partially through interpretation of statistical patterns based on prior qualitative research.

2.4 | Variable Specifications

2.4.1 | Dependent Variables

- Resource Conservation Index (RCI, range: 0 – 5): explained in section 2.5
- Gross agricultural income per *nali* (traditional land measurement unit in Uttarakhand): 1 *nali* ≈ 0.02 hectare (Tiwari and Bhatt, 2021). Income was based on famers' reports of sale values and prices for 2023-24 (expressed in ₹).
- Price realisation ratio (actual farm-gate price ÷ prevailing mandi price): compares farm-gate prices to mandi prices for each crop. The ratio is typically between 0 and 1 when mandi prices are used as the reference benchmark for comparable crop/grade and period. Mandi prices were sourced from AGMARKNET (Agricultural Marketing Information Network) portal maintained by the Directorate of Marketing & Inspection, Ministry of Agriculture & Farmers Welfare, Government of India.

2.4.2 | Independent Variable

- FPO membership status: It is a binary variable (1 = member, 0 = non-member). Membership verification was conducted using FPO membership lists. Members were specifically defined as farmers who had joined at least 12 months before the survey date to ensure adequate exposure time.

2.4.3 | Control Variables

Control variables included age of the farmer (years), education (years of formal schooling), operational landholding size (*nali*), distance to nearest market town (km). District fixed effects were included using two dummy variables (Chamoli and Tehri; Pauri as reference).

2.5 | Resource Conservation Index (RCI)

The RCI was constructed as a composite measure capturing farmers' adoption breadth and intensity of 10 key sustainable agricultural practices. These ten practices were selected based on their relevance to hill agriculture as identified in prior agronomic research and in consultation with three field agronomists from Uttarakhand.

2.5.1 | Practices Included

The ten practices are divided into three domains:

- Soil conservation (3 practices): terracing, contour farming, farmyard manure (FYM) application. The three Soil Conservation practices include terracing (building and maintaining bench terraces or contour bunds); contour farming (ploughing and planting along contours instead of up and down the slope) and farmyard manure (FYM) application, which involves regularly incorporating composted animal waste.
- Water management (4 practices): mulching, rainwater harvesting, drip irrigation, on-farm water storage structures. The four Water Management practices are mulching (covering the soil surface with organic materials to conserve moisture); rainwater harvesting (collecting and storing roof or surface runoff); drip irrigation (using drip systems for water efficient watering) and on-farm water storage structures (building farm ponds, tanks or check dams).
- Integrated farming (3 practices): crop rotation, intercropping, agroforestry. The three Integrated Farming practices comprise crop rotation (systematic changing of crops in planned sequences); intercropping (growing two or more crops simultaneously on the same plot); and agroforestry (combining trees with crops and/or livestock).

2.5.2 | Scoring and Weighting

Each practice was scored on a three-point adoption intensity scale: 2 = regularly adopted (used every season), 1 = occasionally adopted (used irregularly or on some plots only), 0 = not adopted. All ten practices were assigned equal weight in the composite index. This choice reflects the study's conceptual focus on adoption breadth and intensity rather than on estimating the relative impact of individual practice. Also, no widely accepted empirical basis from Himalayan hill agriculture exists to justify differential weighting of soil, water and integrated farming practices.

For each household, the ten practice scores (each 0 – 2) were summed to obtain a raw conservation score ranging from 0 to 20. To express this on a 0 – 5 scale, the raw score was rescaled using:

$$\mathrm{RCI}_i = \left(\frac{\sum_{j=1}^{10} \mathrm{Score}_{ij}}{20} \right) \times 5$$

where Score_{ij} is the 0/1/2 value for practice *j* for household *i*. The resulting RCI therefore ranges from 0 (no conservation practice adopted) to 5 (all ten practices adopted regularly). Higher scores indicate broader and more intensive adoption of conservation practices. Although the index does not apply explicit domain weights, domain-specific adoption patterns (soil, water, integrated farming) are analysed separately in the Results to ensure that domain differences are not obscured by aggregation.

2.5.3 | Index Validation

Internal consistency of the 10-items scale was assessed using Cronbach's alpha ($\alpha = 0.76$). Face validity was established through review by three agronomists with field experience in the study region. As a convergent validity check, we computed bivariate correlations between RCI and selected farmer characteristics. RCI scores correlated positively with education ($r = 0.34$, $p < 0.001$) and operational landholding size ($r = 0.28$, $p < 0.001$), while showing a negative correlation with distance to the nearest market ($r = -0.22$, $p < 0.001$). At the same time, the index relies on self-reported adoption and we did not perform on-site verification. We therefore cannot confirm the implementation quality on ground and measurable environmental benefits. Future research should complement survey-based adoption methods with direct observation and biophysical measurements.

2.6 | Analytical Framework

Data analysis was conducted in four stages: (i) descriptive comparison between members and non-members, (ii) multivariate OLS regressions with controls, (iii) heterogeneity checks by farm size and education, and (iv) robustness checks, including outlier sensitivity. All analyses were performed using IBM SPSS 26.

Differences between FPO member and non-members groups were tested using independent sample t-tests for continuous variables (viz. RCI, income per *nali* and price realization ratio) and chi-square tests for categorical variables (viz. adoption of each conservation practice). Effect sizes were calculated using Cohen's d.

Three OLS regression models were estimated to test hypotheses H1 and H2 while controlling for confounders:

- Model 1: Resource_Conservation_Index = β_0 + β_1(FPO_Membership) + β_2(Age) + β_3(Education) + β_4(Landholding) + β_5(Market_Distance) + β_6(District_Chamoli) + β_7(District_Tehri) + ε
- Model 2: Income_per_*Nali* = β_0 + β_1(FPO_Membership) + β_2(Age) + β_3(Education) + β_4(Landholding) + β_5(Market_Distance) + β_6(District_Chamoli) + β_7(District_Tehri) + ε
- Model 3: Price_Realization_Ratio = β_0 + β_1(FPO_Membership) + β_2(Age) + β_3(Education) + β_4(Landholding) + β_5(Market_Distance) + β_6(District_Chamoli) + β_7(District_Tehri) + ε

Heterogeneity in associations was examined using (i) stratified comparisons by farm size (marginal: < 3 *nali*; small: 3 – 6 *nali*; medium: > 6 *nali*) and education (low: ≤7 years; high: >7 years), and (ii) interaction models that added FPO × Landholding and FPO × Education terms to the baseline regressions.

Robustness checks and regression diagnostics were conducted to verify that the main inferences are not driven by modelling choices, aggregation decisions or influential observations. Multicollinearity was assessed using Variance Inflation Factors (VIF < 3 for all predictors) Heteroskedasticity was tested using Breusch-Pagan test ($\chi^2 = 18.4$, $p = 0.03$) and standard errors (HC3) were used where evidence of heteroskedasticity was found. Outliers were identified using Cook's distance (4 observations with D > 0.5; no major change in results after exclusion). Residual normality was confirmed via Q-Q plots.

3 | RESULTS AND DISCUSSION

3.1 | Sample Profile and Baseline Comparisons

Table 1 presents a comparison of key demographic and farm-level characteristics between FPO members (n=150) and non-members (n=150).

TABLE 1 Sample Profile and Baseline Comparison

Characteristics	FPO Members (n=150)	Non-members (n=150)	Test Statistic	*p*-value
Age (years)	43.1 ± 8.5	46.2 ± 9.8	*t* = -3.11	0.002**
Operational landholding (*nali*)	18.2 ± 5.4	17.8 ± 5.1	*t* = 0.68	0.497
Market distance (km)	7.1 ± 2.3	7.4 ± 2.6	*t* = -1.12	0.264
Education level			$\chi^2 = 11.45$	0.010**
• Illiterate	18 (12.0%)	31 (20.7%)		
• Primary (1-5 years)	42 (28.0%)	55 (36.7%)		
• Secondary (6-10 years)	65 (43.3%)	48 (32.0%)		
• Higher secondary and above (>10 years)	25 (16.7%)	16 (10.6%)		
District			$\chi^2 = 0.42$	0.811
• Pauri Garhwal	51 (34.0%)	48 (32.0%)		
• Chamoli	50 (33.3%)	52 (34.7%)		
• Tehri Garhwal	49 (32.7%)	50 (33.3%)		

Notes: Values for continuous variables are mean ± standard deviation. Comparisons use independent-samples t-tests (continuous) and Pearson's χ^2 tests (categorical). **$p < 0.01$, ***$p < 0.001$.

As detailed in Table 1, the two groups are broadly similar in mean operational landholding size (18.2 vs. 17.8 *nali*, $p = 0.497$) or the average distance to the nearest market town (7.1 vs. 7.4 km, $p = 0.264$). We did, however, find statistically significant differences in age and education level. On average, FPO members were slightly younger (43.1 vs. 46.2 years, $p = 0.002$) and more educated (higher proportion with secondary or above education, $p = 0.010$) compared to non-members. These differences underline the need to control for age and education in multivariate analyses.

3.2 | Resource Conservation Practice Adoption (H1)

3.2.1 | Overall Conservation Index Comparison

To test the hypothesis that FPO membership increases the adoption of resource conservation practices (H1), we compared the mean Resource Conservation Index (RCI) between groups. Fig. 2 shows the contrast very clearly. FPO members reported markedly higher mean RCI score (3.25 ± 0.85) than non-members (2.15 ± 0.92). The gap of 1.10 points on the 0-5 scale was statistically meaningful and substantively large ($t(298) = 11.4$, $p < 0.001$; Cohen's $d = 1.26$). Put simply, members' conservation adoption scores were 51.2% higher than non-members.

Inspection of the full RCI score distribution (Table 2) points to group differences in adoption patterns.

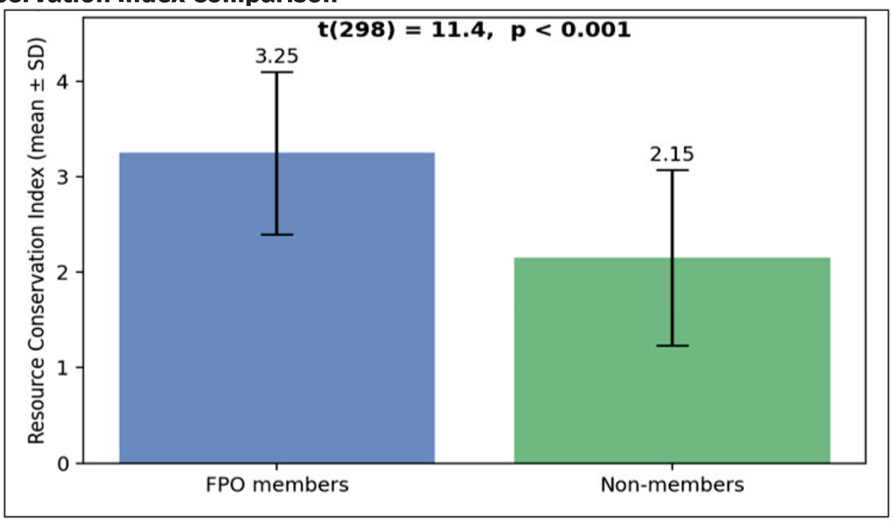

FIGURE 2 Mean Resource Conservation Index (RCI) for FPO members vs. Non-Members

TABLE 2 Distribution of Farmers by Resource Conservation Index Categories

RCI Category	Score Range	FPO Members	Non-Members	χ^2	p-value
Very Low	0.0-1.0	4 (2.7%)	28 (18.7%)	82.4	< 0.001***
Low	1.1-2.0	18 (12.0%)	52 (34.7%)		
Moderate	2.1-3.0	45 (30%)	47 (31.3%)		
High	3.1-4.0	62 (41.3%)	21 (14.0%)		
Very High	4.1-5.0	21 (14.0%)	2 (1.3%)		

Among FPO members, 55.3% scored in the "High" or "Very High" adoption categories (RCI > 3.0), while only 15.3% of non-members reach these levels. The pattern is reversed at the lower end of the scale: 53.4% of non-members are classified in the "Low" or "Very Low" categories, compared with just 14.7% of FPO members. The distribution difference was highly significant ($\chi^2 = 82.4$, $p < 0.001$).

3.2.2 | Domain-Specific Conservation Adoption

We grouped the ten conservation practices into three domains to see where the aggregate RCI difference was coming from. The three domains were: soil conservation (3 practices), water management (4 practices) and integrated farming (3 practices). Table 3 presents adoption rates for individual practices within each domain.

FPO members showed higher adoption rate than non-members for the ten conservation practices ($p < 0.001$ for all comparisons). The largest adoption gap was observed in mulching (27.3 pp), contour farming (26.6 pp). Even widely adopted traditional practices such as FYM application showed higher rate of adoption among FPO farmers (94.7% vs. 81.3%). At the domain level, mean adoption was highest for integrated farming practices (75.1% vs. 56.7%; 18.4 pp), followed by soil conservation (86.2% vs. 67.3%; 18.9 pp) and water management (44.0% vs. 20.7%; 23.3 pp).

3.2.3 | Multivariate Analysis - RCI Regression Model

To isolate the association between FPO membership and conservation adoption while controlling for confounding factors, a multiple regression model was estimated with the Resource Conservation Index (RCI) as the dependent variable. Results appear in Table 4.

After controlling for demographic and locational characteristics, FPO membership remained a highly significant predictor of RCI ($\beta = 1.251$, $p < 0.001$). FPO members scored, on average, about 1.25 points higher on the 0 – 5 RCI scale than comparable non-members. Education ($\beta = 0.052$, $p = 0.004$) and operational landholding size ($\beta = 0.028$, $p = 0.002$) were also positively and significantly associated with conservation adoption, while market distance was negatively and significantly associated with RCI ($\beta = -0.045$, $p = 0.003$). Each additional kilometre from the market was linked to a 0.045-point decrease in RCI. Age was not statistically related to RCI. District dummy variables for Chamoli and Tehri Garhwal showed no significant effects, suggesting that the positive association between FPO membership and RCI was consistent across districts. Overall, the model accounted for 48.2% of the variance in RCI scores ($R^2 = 0.482$; Adjusted $R^2 = 0.473$), indicating substantial explanatory power.

TABLE 3 Adoption Rates of Specific Conservation Practices by Domains

S. No	Domain & Practice	FPO Members Adopters (%)	Non- FPO Members Adopters (%)	Difference (pp)	χ^2 value	*p*-value
A. Soil Conservation						
1	Terracing	88.7	72.0	16.7	13.7	<0.001***
2	Contour Farming	75.3	48.7	26.6	22.1	<0.001***
3	FYM Application	94.7	81.3	13.4	12.3	<0.001***
Mean soil conservation adoption		86.2	67.3	18.9		
B. Water Management						
1	Mulching	62.0	34.7	27.3	22.0	<0.001***
2	Rainwater Harvesting	51.3	28.0	23.3	16.7	<0.001***
3	Drip Irrigation	24.7	5.3	19.4	24.1	<0.001***
4	On-farm Water Storage Structures	38.0	14.7	23.3	20.9	<0.001***
Mean water management adoption		44.0	20.7	23.3		
C. Integrated Farming						
1	Crop Rotation	92.0	78.0	14.0	11.6	<0.001***
2	Intercropping	85.3	66.7	18.6	13.8	<0.001***
3	Agroforestry	48.0	25.3	22.7	16.6	<0.001***
Mean integrated farming adoption		75.1	56.7	18.4		

Notes: "pp = percentage points". ***p < 0.001 (Pearson's chi-square test).

TABLE 4 Multiple Regression Results – Resource Conservation Index (Model 1)

Variable	Coefficient (β)	Robust SE	*t*-value	*p*-value
Constant	1.854***	0.215	8.62	<0.001
Age (years)	-0.008	0.006	-1.33	0.185
Education (years)	0.052**	0.018	2.89	0.004
Landholding (*nali*)	0.028**	0.009	3.11	0.002
Market distance (km)	-0.045**	0.015	-3.00	0.003
FPO Membership (1=Yes)	1.251***	0.102	12.26	<0.001
District: Chamoli	0.150	0.121	1.24	0.216
District: Tehri	-0.098	0.120	-0.82	0.414

Model diagnostics: $R^2 = 0.482$, Adjusted $R^2 = 0.473$, $F(7, 292) = 54.67$, $p < 0.001$, N = 300.
Notes: Dependent Variable = RCI (0-5 scale). Robust standard errors (HC3) used to address heteroskedasticity. Reference category for district = Pauri Garhwal. **p < 0.01, ***p < 0.001.

3.3 | Economic Outcomes : Income and Price Realization (H2)

3.3.1 | Descriptive Comparison

Table 5 compares gross agricultural income per *nali* and price realization ratio between FPO members and non-members.

FPO members reported mean gross agricultural income of ₹ 4,850 per *nali* which is 37.8% higher than that of non-members (₹ 3,520 per *nali*). This difference was statistically significant ($t(298) = 11.25$, $p < 0.001$) with a large effect size (Cohen's d = 1.29). Price realization ratio also differs. FPO members achieved a mean price realization ratio of 0.88, indicating they captured 88% of the prevailing mandi price at the farm gate (Table 5). In contrast, non-members realized only 75% of mandi prices (mean ratio = 0.75). The difference of 0.13 (13 percentage points) was statistically significant ($t(298) = 8.41$, $p < 0.001$, Cohen's d = 0.97).

TABLE 5 Comparison of Economic Outcomes by FPO Membership Status

Outcome Indicator	FPO Members	Non-FPO Members	*t*-value	*p*-value	Cohen's *d*
Gross agricultural income (₹ per *nali*)	4,850 ± 1,120	3,520 ± 980	11.25	<0.001***	1.29
Price realization ratio	0.88 ± 0.12	0.75 ± 0.15	8.41	<0.001***	0.97

Notes: Values are mean ± standard deviation. Independent-samples t-tests. ***p < 0.001. Cohen's d > 0.8 indicates large effect size.

3.3.2 | Multivariate Analysis - Economic Outcome Regression

Two regression models were estimated to test whether FPO membership effects on economic outcomes persisted after controlling for confounding variables. Results are presented in Table 6.

In model 2 (Income per *nali*), FPO membership showed a highly significant positive association with income. FPO members earn ₹1,156 more per *nali* than non-members after controlling for demographic and farm characteristics (β = 1,155.8, $p < 0.001$). Education and operational landholding size were also positively associated with income (β = 58.4, p = 0.016; β = 45.2, $p < 0.001$, respectively). On the other hand, greater market distance was associated with significantly lower income, with each additional kilometer from the market town reducing income by about ₹28.5 per *nali* (β = −28.5, p = 0.040). No strong income differences across districts were shown once other variables are held constant. Overall, Model 2 explains a substantial share of the variation in income per *nali* (R^2 = 0.455, Adjusted R^2 = 0.446, $F(7, 292) = 49.12$, $p < 0.001$).

In model 3 (Price realization ratio), FPO membership remained a strong predictor of price realization (β = 0.121, $p < 0.001$). Education, landholding size, and market distance again displayed smaller but significant effects. Additional schooling and larger operational area were associated with modest improvements in price realization (β = 0.006, p = 0.028; β = 0.002, p = 0.009 respectively), whereas greater distance from the market was linked to lower realized prices (β = −0.005, p = 0.024). Neither age nor district indicators were found to be significant for predicting price realization ratio. Model 3 explains a substantial share of the variance in the price realization ratio (R^2 = 0.389, Adjusted R^2 = 0.378, $F(7, 292) = 37.45$, $p < 0.001$), underscoring that FPO membership is not a peripheral covariate but a central lever shaping both what farmers earn and the prices they are able to command.

TABLE 6 Multiple Regression Results – Economic Outcomes (Models 2 & 3)

Variable	Model 2: Income per *nali* (₹)				Model 3: Price Realization Ratio			
	Coef. (β)	Robust SE	*t*-value	*p*-value	Coef. (β)	Robust SE	*t*-value	*p*-value
Constant	2,650.4***	185.2	14.31	< 0.001	0.650***	0.021	30.95	< 0.001
Age (years)	-12.3	8.2	-1.50	0.135	-0.001	0.001	-1.0	0.317
Education (years)	58.4*	24.1	2.42	0.016	0.006*	0.003	2.2	0.028
Landholding (nali)	45.2***	10.1	4.48	< 0.001	0.002**	0.001	2.61	0.009
Market distance (km)	-28.5*	12.8	-2.23	0.04	-0.005*	0.002	-2.27	0.024
FPO Membership (1=Yes)	1,155.8***	95.5	12.11	< 0.001	0.121***	0.014	8.64	< 0.001
District : Chamoli	120.5	105.1	1.15	0.251	0.015	0.015	1.03	0.318
District : Tehri	88.2	104.5	0.84	0.400	0.011	0.015	0.73	0.465

Model 2 diagnostics: R^2 = 0.455, Adjusted R^2 = 0.446, $F(7, 292) = 49.12$, $p < 0.001$; N = 300. Model 3 diagnostics: R^2 = 0.389, Adjusted R^2 = 0.378, $F(7, 292) = 37.45$, $p < 0.001$; N = 300.

Notes: Dependent Variable in Model 2 = Gross agricultural income per *nali* (₹) and in Model 3 = Price realization ratio. Robust standard errors (HC3) used to address heteroskedasticity. Reference category for district: Pauri. *p < 0.05, **p < 0.01, ***p < 0.001.

3.4 | Heterogeneity in FPO Association

3.4.1 | Differential Effects by Farm Size

To probe if FPO association differ across farmers type, we classified the sample by the conventional landholding size: marginal farmers (< 3 *nali*), small farmers (3 – 6 *nali*), and medium farmers (> 6 *nali*). Table 7 places mean outcomes across these strata by FPO membership status.

There was a clear pattern that the marginal farmers gained the most. Among marginal farmers, FPO membership correlated with 64.4% increase in RCI scores and a 45.1% boost in income. The corresponding gains for medium farmers (> 6 *nali*), though still sizable, fall to 38.0% and 28.1%. Absolute differences also favor marginal farmers (RCI: 1.34 vs. 0.82 points; income: ₹ 1,600 vs. ₹ 970). Whether these differences were statistically meaningful required testing interaction effects. So, the regression model was extended by adding interaction terms between FPO membership and landholding size (FPO × Landholding). The interaction term for RCI was negative and statistically significant (β = -0.158, p = 0.022), confirming that FPO impacts on conservation adoption decrease as farm size increases. Similarly, the income model interaction term was significant (β = -124.3, p = 0.038).

TABLE 7 Heterogeneity Analysis – Outcomes by Farm Size Category

Farm Size Category	n	Mean RCI		Mean Income per *Nali* (₹)	
		FPO Members	Non Members	FPO Members	Non Members
Marginal (< 3 *nali*)	102	3.42 ± 0.81	2.08 ± 0.88	5,150 ± 1,180	3,550 ± 1,090
Difference		1.34***		1,600***	
% Difference		64.4%		45.1%	
Small (3-6 nali)	138	3.28 ± 0.84	2.18 ± 0.93	4,820 ± 1,210	3,580 ± 1,140
Difference		1.10***		1,240***	
% Difference		50.5%		34.6%	
Medium (> 6 *nali*)	60	2.98 ± 0.89	2.16 ± 0.96	4,420 ± 1,320	3,450 ± 1,210
Difference		0.82***		970***	
% Difference		38.0%		28.1%	

Notes: Values are mean ± SD. All within-category differences significant at ***p < 0.001 (independent *t*-tests).

3.4.2 | Differential Impacts by Education Level

The sample was divided at the median education level (7 years of schooling) into low education (≤7 years, n=162) and high education (>7 years, n=138) subgroups. Table 8 presents mean outcomes by education level and FPO membership status. FPO impacts on conservation were larger among low-education farmers (+60.6% vs. +40.8%), while income impacts were relatively similar across education levels. Regression interaction tests confirmed that the differential conservation effect by education was statistically significant (β = -0.185, p = 0.031), but the income effect interaction was not (β = -68.4, p = 0.412).

TABLE 8 Heterogeneity Analysis – Outcomes by Education Level

Education Level	n	Mean RCI		Mean Income per *Nali* (₹)	
		FPO Members	Non Members	FPO Members	Non Members
Low (≤ 7 *years*)	162	3.18 ± 0.87	1.98 ± 0.85	4,680 ± 1,280	3,320 ± 1,110
Difference		1.20***		1,360***	
% Difference		60.60%		41.0%	
High (> 7 years)	138	3.35 ± 0.82	2.38 ± 0.95	5,080 ± 1,150	3,780 ± 1,160
Difference		0.97***		1,300***	
% Difference		40.8%		34.4%	

Note: All within-category differences significant at ***p < 0.001 (independent t-tests).

3.4.3 | Geographic Variation in Outcomes

While district dummy variables in the main regression models (Tables 4 and 6) showed no statistically significant effects, descriptive comparisons reveal some geographic variation in absolute outcome levels (Table 9). Tehri Garhwal showed the highest absolute RCI scores (3.45 for FPO members, 2.23 for non-members), while Chamoli showed the lowest (3.02 and 2.04 respectively). However, the FPO membership effect (difference between FPO and non-FPO groups) remained consistently large and significant across all three districts, ranging from 0.98 to 1.22 points on the RCI scale.

TABLE 9 Mean Outcomes by District and FPO Membership

District	n	Mean RCI		Mean Income per *Nali* (₹)	
		FPO Members	Non Members	FPO Members	Non Members
Pauri	99	3.28 ± 0.83	2.18 ± 0.91	4,920 ± 1,210	3,580 ± 1,140
Chamoli	102	3.02 ± 0.89	2.04 ± 0.94	4,650 ± 1,310	3,420 ± 1,180
Tehri Garhwal	99	3.45 ± 0.80	2.23 ± 0.90	4,980 ± 1,190	3,560 ± 1,130

3.5 | Robustness Checks

We ran sensitivity analyses to test our findings robustness. Cook's distance identified 4 observations with D > 0.5 (about 1.3% of the sample). Re-estimating Models 1–3 after excluding these cases produced essentially similar outcomes for the FPO membership coefficients. This confirmed that the results are not driven by a small number of extreme observations. Because the RCI combines practices across three domains viz. soil conservation (3 practices), water management (4 practices), and integrated farming (3 practices), we examined domain-wise patterns to ensure that the composite index does not obscure domain-specific effects. The membership advantage remained present across domains. Water management shows the largest gap (1.17 points), consistent with Table 3. We tested for potential non-linearities in the relationship between landholding size and outcomes by adding a quadratic landholding term to the regression specifications. This did not indicate meaningful non-linear effects. Finally, we implemented Coarsened Exact Matching (CEM) using age, education and landholding size as matching variables. The matched sample retained 128 comparable pairs. The estimated association between FPO membership and RCI in the matched model ($\beta \approx 1.18$, $p < 0.001$) remained close to the full-sample estimate ($\beta \approx 1.25$). These checks indicate that the main RCI associations are robust across alternative specifications and to matching on key observables. However, we do acknowledge that no robustness exercise can fully rule out selection on unobserved factors in a cross-sectional design.

3.6 | Summary of Key Findings

Five main patterns emerged from our analysis:

1. Conservation adoption: FPO members showed 51.2% higher Resource Conservation Index scores than non-members (3.25 vs. 2.15, $p < 0.001$). After controlling for confounders, FPO membership is associated with a 1.25-point increase in RCI ($\beta = 1.251$, $p < 0.001$). This is in direct support to hypothesis 1 (H1).
2. Economic outcomes: FPO members earned 37.8% higher income per *nali* (₹4,850 vs. ₹3,520, $p < 0.001$, $d = 1.29$) and achieved 13 percentage points better price realization (0.88 vs. 0.75, $p < 0.001$, $d = 0.97$). Both effects remained highly significant in multivariate models, proving hypothesis 2 (H2) true.
3. Market access: Market distance is associated with worse outcomes – lower RCI ($\beta = -0.045$, $p = 0.003$), lower income per *nali* ($\beta = -28.5$, $p = 0.040$) and also lower price realization ratio ($\beta = -0.005$, $p = 0.024$). This indicates that market access is a bottleneck for hill agriculture.
4. Heterogeneity**:** FPO membership proved most beneficial for marginal farmers (< 3 *nali*) and less educated ones. Marginal farmers showed 64.4% higher conservation scores and 45.1% higher incomes versus 38.0% and 28.1% respectively for medium-sized farmers (> 6 *nali*).
5. Conservation domains: FPO members vs. non-members adoption gaps were large across all three conservation domains. The largest mean gap is in water management practices (23.3 percentage points), followed by soil conservation (18.9 pp) and integrated farming (18.4 pp). Several practices showed particularly pronounced differences as in mulching (27.3 pp), contour farming (26.6 pp), agroforestry (22.7 pp), drip irrigation (19.4 pp) and on-farm water storage structures (23.3 pp).

These patterns maintained consistency when we added demographic and geographic controls. Across the regression models, the explained variance ranged from about 38% to 48% ($R^2 = 0.389 – 0.482$) which indicates substantial explanatory power for both conservation and economic outcomes.

Our question going into this research was straightforward: can FPOs in Uttarakhand's hill agriculture work as institutional innovation that is associated with improvements in both resource conservation and economic outcomes at the same time? The answer appears to be yes, though with some notable patterns in how benefits distribute. Three primary results emerged from the analysis: markedly higher conservation practices adoption among members, sizeable gains in both income and price realization and disproportionately larger effects for marginal and less-educated farmers.

3.7 | FPO Membership and Conservation Adoption

The sizeable gap in Resource Conservation Index (RCI) scores between FPO members and non-members (3.25 vs. 2.15; a 1.10-point gap on 0–5 scale) is the most consequential finding of the study. The fact that these differences remain large after controlling for age, education, land size and market distance suggests that FPOs matter beyond simple compositional differences in who joins.

Our findings resonates with Pradhan et al. (2016)'s work on conservation agriculture adoption in Eastern India. They also found that collective institutions created room for farmers to experiment with sustainable practices. What stands out in our data, though, is the magnitude: a 51% higher RCI compared to 20-30% gains usually seen in technology adoption studies (e.g., improved seeds, micro-irrigation). This suggests something more than individual practice uptake is happening. FPO members appear to be implementing conservation practices as part of a coordinated package. This fits with arguments that institutional innovations like FPO matter most where sustainability depends on multiple practices working together, not just on individual solutions.

Our quantitative design did not directly capture mechanisms of FPO influence, the domain-specific adoption patterns provide useful hints. The largest gaps occur for practices that are relatively knowledge- and capital-intensive such as on-farm water storage (23.3 pp) and drip irrigation (19.4 pp). This is consistent with institutional theory of collective action which emphasises how local organizations can help overcome indivisibilities and cost barriers in provision of capital-intensive technologies like drip irrigation (Ostrom, 2019). FPOs appear to reduce both cognitive and economic barriers to adopting more demanding conservation technologies (North, 1990).

That said, we should be careful not to overstate our findings. We did not measure biophysical outcomes (soil erosion reduction, soil quality changes etc.) directly. While FPO members report higher adoption of conservation practices, we can't claim from our data whether this translates into measurable environmental improvements.

3.8 | Economic Outcomes and Market Access

The story is equally layered on the economic side. FPO members earn substantially higher income per unit of land and secure a larger share of prevailing market prices. For a household with 5 *nali* (an illustrative smallholder plot size), the estimated agricultural income gain is about ₹6,650. This uplift is an indicator that FPO members occupy a stronger position within value chains, probably through aggregation that allows for negotiations and direct sales to bulk buyers. Lower per-unit transport costs and better price information likely play a role too. These income gains are broadly comparable to evidence from Andhra Pradesh (Kumar *et al*., 2023) and Maharashtra (Lalitha *et al.*, 2024), yet the configuration here diverges in key respects. For one, we document simultaneous improvements in conservation adoption and income. Also, while our income gains are broadly similar to those in better-connected plains regions, they occur in a context of far more severe physical and market constraints. This suggests that FPOs can partially offset structural disadvantages associated with remoteness and small holdings even with weak market density and infrastructure.

Role of market access also emerges as a key point. Greater distance from the nearest market town is seen to be associated with lower conservation adoption, lower income per *nali* and lower price realization. This reinforces a basic point: institutional innovations can help farmers negotiate markets better, but they cannot fully substitute for the structural constraints created by remoteness.

Our results are broadly in line with international evidence that producer organizations can overcome market failures in smallholder farmers (Liu *et al*., 2020; Tomorri *et al.*, 2022). The literature though also documents high failure rates and underperformance among farmer organizations globally due to weak professional management and elite capture (Khiangte & Malsawmsanga, 2025).

3.9 | Heterogeneity and The "Equalizing" Pattern

One of the most policy-relevant patterns from this study is that the FPO members vs. non-members differences are largest among marginal farmers (< 3 *nali*) and farmers with lower education. This finding is encouraging from an equity standpoint. FPOs are acting as equalizing institutions benefiting those groups who need them most. This is in contrast to many other support programs that amplify gains for the already-advantaged groups.

There could be many possible explanations for this heterogeneity. One possibility is complementarity: farmers facing strongest constraints may gain proportionally more when FPOs lower barriers to investment, information and market participation. This aligns with Olson's (2003) theory that small disadvantaged actors have stronger incentives for collective action when individual capacity is minimal. Another reason could be selection: many FPO-promoting programs deliberately target smaller and socially disadvantaged farmers (Gurung & Choubey, 2023). Policy implications vary by interpretation. If complementarity dominates, policies should focus on forming and recruiting marginal/less-educated farmers into FPO. The benefits here would be maximum and it would be an equity-promoting strategy. If selection dominates, addressing participation barriers would promote equity. Longitudinal data tracking farmers before and after joining could clarify these mechanisms.

3.10 | Study Limitations and Interpretation

This study faces limitations that restrict causal inference and generalizability. This study is cross-sectional and compares FPO members and non-members at one point in time. We should therefore read the results as associations rather than causal impacts. We controlled for observable characteristics (age, education, landholding size, market distance, and district effects), but unobserved factors like motivation, social networks, risk preference, time preferences etc. may influence FPO participation. So, selection bias cannot be ruled out.

Our sampling focussed on FPOs operational for at least 2 years excluding the failed or struggling FPOs. This introduces a survivor bias as we only see successful instances. Given that approximately 40% FPOs become non-operational within the critical 3-5 years mark (Anand et al., 2025), our estimates likely represent an optimistic upper limit of the outcomes.

Measurement limitations also apply. The Resource Conservation Index is based on self-reported data without independent verification. Income and price realization may also be affected by recall issues. The study explores FPOs simplistically in terms of membership and outcomes only without studying mechanisms and organizational processes. Understanding these mechanisms requires detailed data and qualitative insights. Combining qualitative with quantitative methods would give a fuller picture.

3.11 | Policy Implications

Our findings provide several policy considerations for hill agriculture in Uttarakhand stated carefully as conditional recommendations:

1) Successfully operating FPOs in Garhwal are associated with substantially higher adoption of resource conservation practices and better economic outcomes among members.

This supports continued experimentation with FPO model in hill regions. Here it is important to recognize what we do not know. FPO outcomes may depend on organizational design, management quality, service delivery and other factors we have not identified.

2) Marginal (< 3 *nali*) and less educated farmers benefit more from FPO membership. Promotion should focus on small and marginal farmers. This differs from usual programs favouring early adopters (Aditi et al., 2025). It's unclear if benefits come from complementarity or selection. Still, FPOs seem accessible to broader groups. Government and NGOs could set membership goals (e.g. ≥ 60% marginal/small farmers) and improve outreach for disadvantaged groups.

3) The largest adoption gaps occur in water management and other relatively demanding practices (e.g., drip irrigation and on-farm storage structures). In hill agriculture, support programs that treat FPOs only as marketing vehicles may miss this part of the picture. Our findings show that conservation-related investments may be as important as output aggregation. NABARD and state departments could tie FPO financing to conservation training and adoption goals.

4) Our sample studied only active FPOs, so the results should not be interpreted as evidence that simply forming an FPO will reliably deliver improvements. There is a case for systematic work on organizational traits and contextual factors that differentiate successful from failed FPOs. Aggressive FPO promotion without understanding success conditions risks wasted resources and farmer disappointment.

5) Market access remains a binding constraint. Market distance is negatively associated with all outcomes in the study. While institutional innovations like FPOs help, they can't replace infrastructure investment. Successful hill agriculture development needs strategies combining physical infrastructure (roads, cold storage, market yards) and institutional support (FPOs, value chains). Support for FPOs should be integrated with rural infrastructure programs, not viewed as alternative.

3.12 | Research Agenda

This study establishes clear empirical patterns, but is also highlights gaps that require complementary research designs and data. Future research could prioritize the following:

Priority 1 – Causal identification : Use longitudinal data that track the same farmers before and after joining FPOs (e.g. panel designs and difference-in-differences) to better separate membership effects from selection.

Priority 2 – Mechanism studies: Collect detailed information on FPO functioning such as services offered, service quality, member utilization data etc. Test which specific services are linked to which outcomes. This should be complemented with qualitative work (FGDs/KIIs) to understand how services operate on the ground.

Priority 3 – Success/failure analysis: Sampling both operational and defunct FPOs to identify organizational and contextual success factors; tracking FPO life cycle dynamics.

Priority 4 – Biophysical verification: Combine adoption surveys with biophysical checks (e.g. soil indicators, erosion proxies, water retention/availability measures etc.) to validate whether environmental benefit claims.

Priority 5 – Scalability assessment: Conduct comparative multi-region studies to identify FPO effectiveness in diverse agro-ecological and market situations.

4 | CONCLUSIONS

The study establishes FPOs as crucial institutional platforms in Uttarakhand. FPOs are associated with dual improvements in resource conservation practices and economic outcomes. Using a cross-sectional survey of 300 farm households (150 FPO members and 150 non-members) from three Garhwal districts, we find clear and consistent associations: FPO members report substantially higher adoption of conservation practices and better economic performance than non-members from the same villages.

A major contribution of the study is that it reveals how these associations are distributed across farmers groups. Differences between members and non-members are largest among marginal farmers (<3 *nali*) and farmers with lower formal education. This stands in contrast to many other agricultural schemes which tend to benefit the already advantaged groups. In this sense, FPOs appear to function as equalizing institution in Uttarakhand's hill agricultural economy. This equity dimension in central to their design logic as collective action matters most where individual capacity is most constraints.

For policymakers and practitioners in Uttarakhand and similar hill states, the finding suggests that FPO formation efforts can be targeted toward clusters with high proportion of marginal farmers. FPO promotion should move towards capacity enhancement. Government should shift programme design to performance-oriented support for existing FPOs. Conservation practices adoption should be integrated as a core FPO performance metric alongside economic returns. For NABARD and other financing institutions, the results support extending credit lines specifically for conservation-related capital investment (water storage, drip system, organic input production units) that FPOs can procure collectively.

The study establishes the case for giving serious attention to collective institutional arrangement as part of sustainable hill agriculture strategies. However, FPOs are neither automatic solutions nor uniformly effective. How well they perform seems to depend on several factors including their design, governance, external support and fitment with local agro-ecological conditions.

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CONFLICT OF INTEREST

The author declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data is available with the corresponding author and can be provided on request.

AUTHOR'S CONTRIBUTION

RSB conceptualized the project, conducted the study and wrote the manuscript. PM reviewed the draft manuscript and coordinated the work.

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