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# Machine Learning-driven Prioritization of Adoption Drivers and Constraints in Agro-climatic Zone-specific Integrated Farming Systems

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***Data Availability Statement:*** Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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## ABSTRACT

The experiment was conducted during the month of April to November in 2022 to study integrated farming systems (IFSs) in West Bengal. IFSs offered holistic solutions to food security, resource efficiency, and rural livelihoods, yet adoption remained limited in India due to socio-economic, ecological, and institutional barriers. A significant gap existed in empirical evidence regarding the relative importance of the enabling and constraining factors influencing the adoption and scalability of IFS in the Indian context. This study aimed to bridge that gap by identifying and ranking key factors influencing the adoption of IFSs in Eastern India. A multi-stage sampling approach was used to select 60 farmers practicing IFS for data collection across six agro-climatic zones (ACZs) in West Bengal, India from April to November in 2022. This study identified and ranked key factors, based on relative closeness values (ranging from 0 to 1), influencing IFS adoption in West Bengal through a SWOC (Strengths, Weaknesses, Opportunities, and Challenges)– TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) analysis, a Multi-Criteria Decision-Making (MCDM) method grounded in machine learning principles. Zone-specific insights revealed strengths and/ or opportunities like women's participation, income enhancement, farm production improvement, sustainable livelihood security, and scope of organic farming, alongside major weaknesses and challenges like intensive water requirement, higher labour engagement, greater capital start-up cost, natural calamities, and market volatility. The integrated methodology presented a replicable model for contextual planning and informed decision-making in West Bengal and similar agro-climatic regions across India and beyond.

**KEYWORDS:** IFS, West Bengal, machine learning, SWOC–TOPSIS, decision-making, policy

## 1. INTRODUCTION

Whither Indian agriculture? At first glance, the very framing of this question may appear misplaced, especially considering India's substantial strides in agricultural development. Through decades of intensive policy reforms, technological interventions, and targeted missions, such as the Green Revolution and subsequent initiatives like the National Food Security Mission, India has attained self-sufficiency in food grain production and even emerged as a leading global producer of several commodities (Anonymous, 2022). Policymakers frequently highlight these achievements, sometimes bordering on hyperbole. However, critics rightly raise a pressing concern: are these accomplishments sufficient to ensure long-term food security for India's rapidly snowballing population? Addressing this question is imperative. With the looming challenges of climate volatility, shrinking natural resources, and water scarcity, sustainable agricultural development is not merely an option but a necessity to safeguard the nation's future food needs (Anonymous, 2021; Anonymous, 2023). India must prioritize improving the total factor productivity (TFP), a measure of output per unit of total inputs, through the adoption of modern technology, precision agriculture, and resource-efficient practices. Enhancing input efficiency while minimizing waste will be crucial to achieving sustainable growth and ensuring long-term food security.

India is richly endowed with natural resources essential for agriculture, including a diverse range of agro-climatic zones and some of the most fertile soils in the world, particularly in regions such as the Indo-Gangetic plains (Anonymous, 2015). With conscientious and sustainable management of these natural assets, especially soil, water, and biodiversity, India often boasts of being among the top producers of various food commodities, such as rice, wheat, milk, and pulses. Amid escalating global concerns related to food security, environmental degradation, and rural livelihoods, an integrated farming system (IFS) is one way of a solution as a central component of agricultural policy and practice to secure our future generations' food security (Paroda, 2014). IFSs are increasingly recognized as a critical multifunctional option for smallholder farmers in India and other Asian countries (Lal, 2020; Paramesh et al., 2021, 2022). IFSs, which blend crops, livestock, aquaculture, and other components, have been promoted as a multifunctional approach to enhance productivity, net farm income, reduce production risks, generate rural employment, ensure food security, promote efficient bio-resource recycling, improve soil health, conserve biodiversity, enhance ecosystem services, environmental stewardship, social equity and rural development (Chai et al., 2021; Ngatindriatun and Adzim, 2022). In recent years, several context-specific IFS models tailored to the diverse agro-ecological zones of India have been developed and reported (Srivastava, 2018; Bhargavi and Behera, 2020; Kumar et al., 2022). Despite the growing recognition of the benefits of IFS, the adoption of IFS is uneven and often limited by contextual challenges ranging from biophysical constraints to socio-economic and institutional hurdles (Purnomo et al., 2021). While much has been discussed about the potential of IFS, empirical studies identifying and prioritizing the key factors driving or deterring adoption remain scarce (Haldar et al., 2024). Recognizing the limitations of descriptive diagnostics using the SWOC (Strengths, Weaknesses, Opportunities, and Challenges) framework, this study aims to integrate SWOC with TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) analysis (Roszkowska et al., 2021; Chung et al., 2023; Sathiyamurthi et al., 2024), a quantitative multi-criteria decision-making (MCDM) method grounded in machine learning principles, to prioritize region-specific strengths, weaknesses, opportunities, and challenges influencing IFS performance across six ACZs of West Bengal.

## 2. MATERIALS AND METHODS

### *2.1. Study area*

The study was conducted in the state of West Bengal, India, and encompassed six major agro-climatic zones (ACZs), Hill, Terai, Old Alluvial, New Alluvial, Coastal Saline, and Red Laterite. These zones are delineated based on the classification provided by the National Agricultural Research Project (NARP) under the Indian Council of Agricultural Research (ICAR) (Raman and Balaguru, 1988). These zones vary in topography, rainfall, soil type, cropping pattern, and socio-economic conditions.

### *2.2. Sampling scheme*

A multi-stage sampling procedure was followed to select respondents for the study. In the first stage, the ACZs of West Bengal were selected purposively. In the second stage, one district within each selected ACZ was chosen based on the presence and availability of IFSs, as identified through consultations with officials from the District Agriculture Department, Krishi Vigyan Kendra (KVK), and local non-governmental organizations (NGOs). In the third stage, a block within each selected district was purposively chosen based on the concentration of IFS practitioners. In the fourth stage, a gram panchayat within each selected block was identified, guided by KVK experts, based on the accessibility and prevalence of IFS practices. Finally, a two-stage stratified random sampling method was applied: a village was randomly selected within each gram panchayat, followed by a random selection of IFS-adopting farmers from each selected village. Using this approach, 10 active IFS practitioners were selected as respondents from each of the six ACZs, totalling 60 IFS respondents for the study.

An individual farm household operating on an IFS was considered a primary sampling unit, as shown in Figure 1.

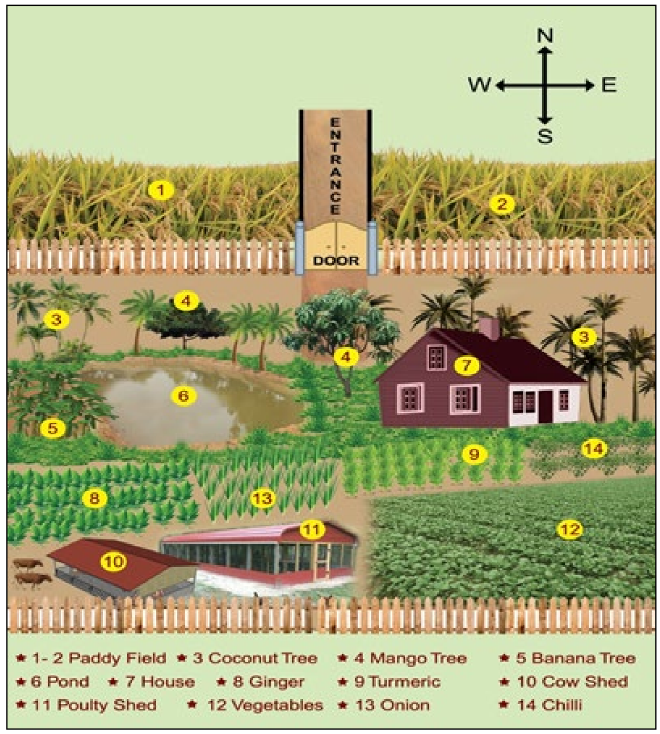


Figure 1: A representative farm layout of integrated farming with different components

### *2.3. Data collection*

A total of 32 SWOC factors (8 per category) were identified and finalized based on literature review, expert consultation, focus group discussions (FGDs), and farmer validation. The farmer's perceptions on 32 SWOC factors were captured through face-to-face interviews, using a closed-ended questionnaire, which consisted of a 9-point pairwise comparison scale (Saaty, 2008).

### *2.4. An integrated SWOC-TOPSIS analysis*

The SWOC framework serves as a foundational tool in strategic planning of a system, enabling planners to focus on key issues critical to system performance and development (Babaesmailli et al., 2012). Given that a purely qualitative SWOC analysis might be inadequate for developing actionable strategies, TOPSIS, a robust multi-criteria decision-making (MCDM) method grounded in machine learning principles, was applied to determine the final weights of the identified SWOC factors for ranking these factors in six ACZs of West Bengal. The TOPSIS method, originally proposed by Hwang and Yoon (1981), is based on the principle that the optimal alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution.

The advantages and applications of the TOPSIS method have been discussed elsewhere (Shih et al., 2007; Yue, 2012). Since TOPSIS analysis is used for decision-making in different fields, such as social science (Roszkowska et al., 2021), medicine (Masmali et al., 2024), engineering (Haddad et al., 2021), environmental fields (Chung et al., 2023), and agriculture (Sathiyamurthi et al., 2024), the TOPSIS tool is applied in IFS fuzzy database to prioritize the identified SWOC factors for strategic planning and adopting IFSs across six ACZs of West Bengal.

TOPSIS compares a set of alternatives based on a pre-specified criterion. The logic behind the TOPSIS is that the chosen alternative should have the shortest geometric distance from the best solution and the longest geometric distance from the worst solution. The whole TOPSIS process can be delineated in 7 steps:

*2.5. Creation of a matrix consisting of **M** alternatives and **N** criteria*

This matrix is usually called an "evaluation matrix".

$(aij)M\times N$

*2.6. Normalization of evaluation matrix*

Each metric j for each solution i is normalized to be between 0 and 1. The higher its value, the better the metric.

*2.7. Calculation of the weighted normalized decision matrix*

It is important to note that each criterion should have its own weight so that all of them will sum up to 1. The weights can be derived randomly or based on expert knowledge.

$$Xij=\alpha_{ij}\times\omega_j$$

$$\omega_j=\frac{\omega_j}{\sum_{j=1}^{N}\omega_j}$$

$$\sum_{j=1}^{N}\omega_j=1$$

After we assign a weight to each metric, we need to normalize those so that they sum up to 1. Then we need to multiply each normalized metric from step 2 by the corresponding normalized weight.

*2.8. Determination of the best and the worst alternative for each criterion*

$$X_j^b=\max_{i=1}^{M} X_{ij}$$

$$X_j^\omega=\min_{i=1}^{M} X_{ij}$$

We want to find the maximum and minimum values of each metric among all solutions.

*2.9. Calculation of the Euclidean distance between the target alternative and the best/worst alternative*

$$d_j^b=\sqrt{\sum_{j=1}^{N}}(X_{ij}-X_j^b)^2$$

$$d_i^\omega=\sqrt{\sum_{j=1}^{N}}(X_{ij}-X_j^\omega)^2$$

This is a calculation of the geometric distance between the value of each metric for a given solution ***i*** and the best/ worst value of such a metric among all solutions.

*2.10. Calculation of the similarity for each alternative to the worst alternative*

We compute a score for each solution that is based on the distances obtained in a step before. The relative closeness ($S_i$) value is the TOPSIS score.

$$Si=\frac{d_i^\omega}{d_i^\omega+d_i^b}$$

*2.11. Ranking of the alternatives according to the TOPSIS score in descending order*

It ranks alternatives based on their distance from an ideal best and ideal worst solution. Relative closeness ($S_i$) values range from 0 to 1. A higher value indicates that the alternative is closer to the ideal solution and thus more desirable. The solution with metrics closest to the best will obtain the highest score and therefore will be at the top of our ranking.

## 3. RESULTS AND DISCUSSION

*3.1. Key strength factors for practicing IFS in different agro-climatic zones*

Table 1 presents the ranking of strength factors across six ACZs in West Bengal based on relative closeness values derived from TOPSIS. Top-ranked strength factors vary across zones. The factor 'ensure women's participation and additional employment opportunities' ranks highest in the hill, terai, and old alluvial zones, as it is closest to the ideal strength profile. 'Enhancement in income' emerges as the strongest factor in the coastal saline zone, the second strongest in the hill, new alluvial, and red laterite zones, and the third strongest in the old alluvial zone. 'Increased farm production and productivity' consistently ranks as a top-tier strength across multiple zones, being the most significant in the red laterite zone, second in the old alluvial zone, and third in both the terai and new alluvial zones. 'Effective utilization of farm by-products' is identified as a key strength in the new alluvial zone, and ranks third in both the hill and red laterite zones. The factor 'year-round food availability' ranks second in the terai zone, while 'multiple

Table 1: Ranking of strength factors for developing IFS in different agro-climatic zones based on relative closeness

| Strength factors | Hill zone | | Terai zone | | Old alluvial zone | | New alluvial zone | | Red laterite zone | | Coastal zone | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RC | R | RC | R | RC | R | RC | R | RC | R | RC | R |
| Ensure women's participation and additional employment opportunities | 0.74998 | 1 | 0.56084 | 1 | 0.59550 | 1 | 0.45042 | 6 | 0.34508 | 8 | 0.58958 | 4 |
| Enhancement in income | 0.71549 | 2 | 0.43282 | 5 | 0.58326 | 3 | 0.71997 | 2 | 0.65349 | 2 | 0.63061 | 1 |
| Increased farm production and productivity | 0.66448 | 4 | 0.50907 | 3 | 0.58964 | 2 | 0.68234 | 3 | 0.79710 | 1 | 0.55935 | 6 |
| Effective utilization of farm by-products | 0.70989 | 3 | 0.48440 | 4 | 0.27770 | 8 | 0.82263 | 1 | 0.54071 | 3 | 0.54160 | 7 |
| Year-round food availability | 0.62800 | 5 | 0.53231 | 2 | 0.31566 | 7 | 0.33981 | 8 | 0.37294 | 7 | 0.31678 | 8 |
| Multiple species biodiversity | 0.45773 | 6 | 0.37943 | 8 | 0.51159 | 5 | 0.59280 | 5 | 0.43529 | 5 | 0.61482 | 2 |
| Lower dependency on external input | 0.18897 | 7 | 0.41952 | 7 | 0.51042 | 6 | 0.66640 | 4 | 0.49222 | 4 | 0.60063 | 3 |
| Dietary diversity | 0.70989 | 3 | 0.42693 | 6 | 0.53019 | 4 | 0.42089 | 7 | 0.37519 | 6 | 0.56617 | 5 |

RC: Relative Closeness; R: Rank

species biodiversity' holds the same position in the coastal saline zone. 'Lower dependency on external input' and 'dietary diversity' are ranked as the third most important strengths in the coastal saline and hill zones, respectively.

Strengths are internal factors key to developing and operating IFS. 'Ensuring women participation and employment opportunity' ranks highest in the hill, terai, and old alluvial zones of West Bengal. This finding underscores the critical role of women's involvement and employment generation in driving rural development and agricultural sustainability in these specific ACZs. Agriculture in the hill zone is predominantly characterized by greater female participation compared to male involvement, thereby ensuring more stable employment for women in agricultural activities (Bhati and Singh, 1987). In terai and old alluvial zones, women's involvement in agro-enterprises boosts socio-economic resilience. Despite overall low female participation in India due to poor conditions and wages (Mahata et al., 2017; Kumar and Arya, 2019), inclusive efforts foster sustainable, stable agriculture. IFS can escalate employment by 143% over a single enterprise (Paramesh et al., 2022). Integration of dairy and goatery further enhances productivity, profit, and job creation (Elamathi et al., 2021).

'Enhancement in income' is the top strength in the coastal saline zone, second in the hill, new alluvial, and red laterite zones, and third in the old alluvial. Coastal areas face poor agricultural conditions due to high tides, salinity, water scarcity, and floods (Misra et al., 2017). Land shaping and IFS adoption, combining rice, fish, vegetables, and salt-tolerant crops, have improved income in this zone (Bandyopadhyay et al., 2009; Mandal et al., 2019). Despite varied rankings, income enhancement is vital for rural sustainability. IFS offers higher returns than traditional rice–wheat farming up to USD 5,050 vs. USD 1,258 (Bhargavi and Behera, 2020).

'Increased farm production and productivity' consistently ranks high across four major ACZs of West Bengal, highlighting its key role in regional agricultural growth. Despite agro-ecological differences, boosting yields remains a common strength. In the red lateritic zone marked by poor soils and low water retention, increased farm production and productivity have emerged as the most significant strengths, likely due to the adoption of IFS by utilizing the available resources, besides the adoption of soil conservation practices, watershed management, micro-irrigation, and crop diversification with the use of drought-resistant varieties (Behera and Mahapatra, 1999). In the fertile old alluvial zone, high-yielding varieties, irrigation, and crop diversity support sustained output. Terai and new alluvial zones also show strong productivity due to good soils, rainfall, irrigation, and input use. IFS enhances yields, returns, resource use, food security, ecosystem services, and employment (Dadabhau and Kisan, 2013; Garrett et al., 2017).

'Effective utilization of farm by-products' reflects increasing focus on resource efficiency and sustainability in West Bengal's varied agro-climatic zones. Using crop residues, animal waste, green biomass, compost, vermicompost, and mulch reduces waste, boosts soil fertility, supports circular bioeconomy and integrated farming principles (Ghosh et al., 2019). Recycling crop residues into livestock feed and livestock manure into crop fields enhances nutrient cycling and productivity (Panwar et al., 2021). Integrating maize provides food and fodder, while livestock manure sustains crop growth (Setimala et al., 2017). Crop-livestock-fish integration improves nutrient use efficiency, nutrient cycling, and soil microbial activity for sustainable farming (Nayak et al., 2018; Ramana et al., 2025).

'Year-round food availability' is particularly important for small and marginal farmers in the terai zone, many of whom rely on subsistence-oriented systems. IFSs ensure a steady supply of diverse foods, such as cereals, legumes, pulses, oilseeds, vegetables, fruits, milk, meat, fish, and eggs, thereby meeting year-round food and nutrition needs (Kumar et al., 2022). 'Multiple species biodiversity' reflects ecological resilience in diversified IFS of the coastal saline zone. The Sundarbans, a UNESCO Biosphere Reserve, supports rich biodiversity, which can be preserved through diverse cropping and indigenous livestock integration (Shyam et al., 2023).

'Lower dependency on external input' underscores the value of self-reliant farming in IFS. IFS reduces market input needs by generating resources like fodder, compost, and biofertilizers within the system, lowering costs and risks (Paramesh et al., 2019). 'Dietary diversity' is vital for food and nutrition security. IFS ensures a steady supply of food like vegetables, milk, and eggs (Panwar et al., 2021).

*3.2. Key weakness factors for practicing IFS in different agro-climatic zones*

Table 2 presents the ranking of weakness factors across six ACZs of West Bengal, based on TOPSIS relative closeness analysis. The factor 'intensive water requirement' is identified as the biggest weakness in the hill zone and red laterite zone, and the second biggest weakness in the old alluvial zone of West Bengal. In contrast, it is identified as the least significant weakness in the terai zone. 'Preference towards specialized farming' ranks as the biggest constraint in adopting IFS in both the terai and coastal saline zones. 'Complexity in farm management' emerges as the most critical weakness in the old alluvial zone. 'Higher labour engagement' emerges as a prime weakness in the new alluvial zone and the second biggest weakness in the hill, terai, red laterite zones. 'Limited knowledge and skill of the farmers' is the second biggest weakness in the coastal saline zone and the third biggest weakness in both the terai and red laterite zones. 'Resistance in adoption' of IFS is identified as the third biggest weakness in both the new alluvial and coastal saline zones. Although 'small and fragmented land holdings' is the third biggest weakness in the old alluvial zone, it is also considered a notable challenge in other zones. In general, 'over/extra burden on women's family members' is recognized as an important and recurring weakness in the practice of IFS across all zones.

Weaknesses are the internal factors that can hinder the IFS's performance or success. 'Intensive water requirement' is the biggest weakness in the hill zone due to runoff and poor water storage despite high rainfall. The red lateritic zone faces comparable constraints due to its coarse-textured soils, low rainfall, poor water-holding capacity and limited irrigation infrastructure. The old alluvial zone also faces water stress from irrigation-heavy crops like Boro rice (Pandey et al., 2019). In contrast, the terai zone, with ample rainfall and rivers, is least affected.

'Preference towards specialized farming' is the biggest

Table 2: Ranking of weakness factors for developing IFS in different agro-climatic zones based on relative closeness

| Weakness factors | Hill zone | | Terai zone | | Old alluvial zone | | New alluvial zone | | Red laterite zone | | Coastal zone | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RC | R | RC | R | RC | R | RC | R | RC | R | RC | R |
| Intensive water requirement | 0.78818 | 1 | 0.28465 | 8 | 0.55649 | 2 | 0.48592 | 5 | 0.62771 | 1 | 0.49116 | 4 |
| Preference towards specialized farming | 0.72443 | 3 | 0.55715 | 1 | 0.36775 | 7 | 0.47676 | 6 | 0.42106 | 4 | 0.68544 | 1 |
| Higher labour engagement | 0.78162 | 2 | 0.50124 | 2 | 0.49072 | 4 | 0.60454 | 1 | 0.54043 | 2 | 0.28794 | 7 |
| Complexity in farm management | 0.56931 | 5 | 0.43596 | 5 | 0.55757 | 1 | 0.57603 | 2 | 0.40745 | 6 | 0.27048 | 8 |
| Limited knowledge and skill of the farmers | 0.33002 | 7 | 0.50124 | 3 | 0.42473 | 5 | 0.37858 | 7 | 0.51614 | 3 | 0.55247 | 2 |
| Resistance to adoption | 0.18902 | 8 | 0.37229 | 6 | 0.31618 | 8 | 0.56227 | 3 | 0.26632 | 8 | 0.54011 | 3 |
| Small and fragmented land | 0.49061 | 6 | 0.33018 | 7 | 0.50107 | 3 | 0.55802 | 4 | 0.31489 | 7 | 0.42154 | 6 |
| Over/extra burden on women's family members | 0.62707 | 4 | 0.46894 | 4 | 0.38897 | 6 | 0.31675 | 8 | 0.42292 | 5 | 0.46785 | 5 |

RC: Relative Closeness; R: Rank

obstacle in practicing IFS in the terai and coastal saline zones of West Bengal reflects both socio-economic and structural barriers rooted in market orientation, institutional support patterns, and farmer's perception. This challenge has been recognized in the Terai zone, where monoculture-based intensification, like high-value crops, such as tea, pineapple, etc. (Basu Majumder et al., 2012), and aquaculture in the coastal saline zone (Mandal et al., 2022) dominate due to well-established procurement channels, price premiums, and high-income expectations, making farmers reliant on IFS practices.

'Higher labour engagement' is a major constraint across ACZs in West Bengal, especially a prime weakness in the new alluvial zone and the second biggest weakness in the hill, terai, and red laterite zones. IFS is labour-intensive due to diverse activities and limited mechanization (Behera and Mahapatra, 1999). Labour shortages arise from migration to urban areas like Kolkata, the state capital (new alluvial), tea estates (terai), and mines (red laterite), driven by better wages. Farmers struggle to maintain IFS without sufficient family labour or affordable hired labour.

'Complexity in farm management' is the greatest difficulty for operating IFS in West Bengal's old alluvial zone. Farmers, accustomed to traditional rice–wheat–jute systems, face psychological and cultural barriers to adopting IFSs. IFSs are knowledge-intensive, requiring multi-dimensional skills in managing multiple enterprises (Behera and France, 2014). Farmers tend to resist change unless the alternative is demonstrably profitable and less risky.

'Limited farmer knowledge and skill' is the second biggest weakness in coastal saline and the third biggest weakness in both the terai and red laterite zones. In ecologically fragile, resource-poor areas, the lack of adequate knowledge, skill, and training hinders integration and management of IFS (Panwar et al., 2021). Building farmer capacity is crucial for successful and sustainable IFS.

'Resistance in adoption' of IFS, driven by risk aversion, traditional practices, limited awareness, and economic uncertainty, hinders its spread across ACZs, including those in West Bengal (Nababan and Regina, 2021). 'Small and fragmented land holdings' hinder IFS scaling in densely populated West Bengal, where the average landholding size is less than 0.8 ha. This fragmentation probably disrupts enterprise integration and resource recycling essential to IFS. Involvement of family labour may create 'over/ extra burden towards women family members' in practicing IFS. Without supportive labour-saving tools, IFS operation increases female drudgery (Ghosh and Ghosh, 2014). When family labour cannot be fully available, it can accelerate the hiring of labour (Purnomo et al., 2021).

### *3.3. Key opportunity factors for practicing IFS in different agro-climatic zones*

Across West Bengal's ACZs, several key opportunities have been identified to enhance the adoption and success of IFS as depicted in Table 3. Opportunity factors are prioritized differently across zones. From TOPSIS relative closeness, it reveals that 'sustainable livelihood security' scores the highest relative closeness in both the new alluvial and red laterite zones. 'Promotion of organic farming' emerges as the top-ranked opportunity in the terai and coastal saline zones and the second most significant opportunity in the new alluvial zone. In the hill zone, 'incorporation of high-value crops' is identified as the most significant opportunity. In the old alluvial zone, 'uses of high-end technology' such as IoT, IT,

Table 3: Ranking of opportunity factors for developing IFS in different agro-climatic zones based on relative closeness

| Opportunity factors | Hill zone | | Terai zone | | Old alluvial zone | | New alluvial zone | | Red laterite zone | | Coastal zone | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RC | R | RC | R | RC | R | RC | R | RC | R | RC | R |
| Sustainable livelihood security | 0.67168 | 5 | 0.54916 | 2 | 0.47169 | 5 | 0.85757 | 1 | 0.77427 | 1 | 0.60042 | 2 |
| Promotion of organic farming | 0.83471 | 3 | 0.67598 | 1 | 0.53592 | 3 | 0.59201 | 2 | 0.57830 | 6 | 0.66879 | 1 |
| Incorporation of high-value crops | 1 | 1 | 0.39665 | 8 | 0.46587 | 7 | 0.45587 | 6 | 0.59758 | 5 | 0.56529 | 5 |
| Uses of high-end technology (IoT, IT, Remote sensing) | 0.14954 | 8 | 0.40459 | 7 | 0.62150 | 1 | 0.31186 | 7 | 0.28964 | 8 | 0.30833 | 8 |
| Exploration of innovation potential | 0.54864 | 6 | 0.47960 | 6 | 0.53641 | 2 | 0.49434 | 4 | 0.63691 | 3 | 0.46628 | 7 |
| Agri-tourism | 0.83471 | 2 | 0.49762 | 5 | 0.43882 | 6 | 0.18012 | 8 | 0.51365 | 7 | 0.59322 | 3 |
| Better risk management | 0.77331 | 4 | 0.50570 | 4 | 0.30641 | 8 | 0.54813 | 3 | 0.69643 | 2 | 0.58630 | 4 |
| Climate-resilient farming practices | 0.44571 | 7 | 0.54238 | 3 | 0.53102 | 4 | 0.45719 | 5 | 0.63497 | 4 | 0.49297 | 6 |

RC: Relative Closeness; R: Rank

and remote sensing, is ranked as the foremost opportunity, followed by 'exploration of innovation potential'. The latter also ranks as the third most important opportunity in the red laterite zone. 'Agri-tourism' is recognized as the second most significant opportunity in the hill zone and the third in the coastal saline zone. 'Better risk management' is viewed as the second most important opportunity in the red laterite zone and the third in the new alluvial zone. Lastly, 'climate-resilient farming practices' is identified as the third most significant opportunity in the terai zone, though it holds potential importance across other zones as well.

Opportunities are external factors that can provide the IFS with the potential to grow, develop, or enhance its effectiveness. 'Sustainable livelihood security' is the top opportunity for IFS in new alluvial and red laterite zones, and second in terai and coastal zones. There is clear evidence that integrated crop–animal systems support sustainable agriculture and better livelihoods (Herridge et al., 2019).

Ecological richness in the terai and coastal zones favours 'promotion of organic farming'. In the new alluvial zone, it stands out as a high-potential opportunity to restore soil health and capture emerging organic markets. Morris and Winter (1999) conceptualize IFS as a middle ground between organic and conventional farming. The promotion of organic farming represents the greatest opportunity within the IFS framework (Pramanik et al., 2008).

The hill zone of West Bengal, rich in biodiversity and organic matter-rich soil, is ideal for 'incorporation of high-value crops' to fetch a premium price. Renowned produce like Darjeeling tea (GI-tagged), Mandarin orange, and large cardamom offers strong market value (Gurung et al., 2023; Vineeta et al., 2023). This opportunity boosts income and sustainability for local farmers.

'Uses of high-end technology' and 'exploration of innovation potential' are key opportunities in old alluvial and red laterite zones. Tools like information and communication technologies (ICTs), internet of things (IoT), wireless sensor networks (WSN), global positioning system (GPS), artificial intelligence (AI), and drone technology enable precision farming and make farming more resilient, efficient, and sustainable (Haldar et al., 2022b).

'Agri-tourism' offers high income and employment opportunities in West Bengal's hill and coastal zones (Doley, 2022). It boosts local livelihoods and rural welfare, as seen in Uttarakhand through IFS-based tourism (Bhatt and Kameshwari, 2022). Countries like Indonesia and China promote agri-tourism for rural growth through supportive policies (Budiasa and Ambarawati, 2014; Jiang, 2022). To fully realize the potential of agri-tourism, Government support in infrastructure development, training, and incentives to farmers is key (Lal et al., 2023).

'Better risk management' is a key IFS opportunity, especially in the red laterite zone with its poor soil, dry spells, and climate risks. IFS reduces dependency on a single source of income, improves resilience against climate shocks, and stabilizes earnings through diversified farming (Faria Corrêa et al., 2019).

'climate-resilient farming practices' is a critical opportunity factor in operating IFS. In the face of increasing climate variability, such as erratic rainfall, rising temperatures, droughts, and floods, climate-resilient practices within IFS reduce the impact of climatic shocks on overall farm output and protect livelihoods (Haldar et al., 2022a, 2022c; Paramesh et al., 2022).

### *3.4. Key challenge factors for practicing IFS in different agro-climatic zones*

Table 4 reveals key challenge factors with their rankings in adopting IFS across ACZs in West Bengal. An analysis of the challenge factors based on TOPSIS relative closeness reveals that 'natural calamity' is perceived as the greatest challenge in three zones, namely, coastal saline, terai, and new alluvial zones. 'Greater capital start-up cost' has been identified as the principal challenge to the adoption of IFS in both the hill and old alluvial zones and the third highest challenge in the terai and red laterite zones. 'Market challenge-volatile price' is advocated as the chief challenge in the red laterite zone and a major hindrance in the terai, old alluvial, coastal saline and new alluvial zones. 'Biotic stress' is the second and third highest challenge in the new alluvial zone and coastal saline zone, respectively. 'Lack of technical support' is seen as a key challenge to IFS, ranking second in the hill zone and third in the old alluvial zone. 'Limited access to credit' is recognized as the second biggest challenge in the red laterite zone. 'Migration of family labour' from villages to cities in search of jobs is ranked as the third most significant challenge in the hill zone. Lastly, 'agro-ecological zone-specific limitations' are reported as a persistent challenge to the adoption of IFS across all zones.

Challenges are the external factors that can negatively impact the IFS's performance or success. 'Natural calamity' is the top challenge to IFS in coastal saline, terai, and new alluvial zones due to zone-specific vulnerabilities. Coastal areas face floods and cyclones; the terai sees frequent flood damage; and the new alluvial zone, with intensive farming, suffers pest outbreaks. These challenges are not just environmental events, but socio-economic disruptors in vulnerable agro-ecosystems.

'Greater capital start-up cost' is a major challenge to establishing IFS in most of the zones of West Bengal. Initial investments for livestock, irrigation, and infrastructure are high to develop IFS (Patra and Samal, 2018). In the hill zone, rugged terrain raises costs further due to land shaping

Table 4: Ranking of challenge factors for developing IFS in different agro-climatic zones based on relative closeness

| Challenge factors | Hill zone | | Terai zone | | Old alluvial zone | | New alluvial zone | | Red laterite zone | | Coastal zone | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RC | R | RC | R | RC | R | RC | R | RC | R | RC | R |
| Natural calamity | 0.23391 | 8 | 0.66220 | 1 | 0.39113 | 7 | 0.71651 | 1 | 0.54770 | 4 | 0.89757 | 1 |
| Greater capital start-up cost | 0.82133 | 1 | 0.57627 | 3 | 0.66628 | 1 | 0.48471 | 4 | 0.59588 | 3 | 0.24789 | 8 |
| Market challenge-volatile price | 0.39308 | 7 | 0.57880 | 2 | 0.60519 | 2 | 0.52375 | 3 | 0.77956 | 1 | 0.52618 | 2 |
| Biotic stress (like disease pest parasite pathogen infestation) | 0.45699 | 6 | 0.42984 | 5 | 0.50008 | 4 | 0.61577 | 2 | 0.48793 | 5 | 0.50235 | 3 |
| Lack of technical support (like custom hiring centres, suitable farm inputs) | 0.71551 | 2 | 0.49776 | 4 | 0.54048 | 3 | 0.41745 | 6 | 0.45516 | 6 | 0.47347 | 4 |
| Limited access to credit | 0.56947 | 4 | 0.41110 | 6 | 0.46114 | 5 | 0.19285 | 8 | 0.66208 | 2 | 0.39659 | 6 |
| Migration of family labour | 0.68197 | 3 | 0.36325 | 7 | 0.34999 | 8 | 0.42181 | 5 | 0.39820 | 7 | 0.38483 | 7 |
| Agro-ecological zone- specific limitation | 0.54417 | 5 | 0.17864 | 8 | 0.41397 | 6 | 0.27358 | 7 | 0.36399 | 8 | 0.40019 | 5 |

RC: Relative Closeness; R: Rank

and limited access to markets and services.

'Market challenge–volatile price' arises from frequent price fluctuations in IFS components like horticulture, livestock, poultry, and fishery. This creates income instability for small and marginal farmers, hindering IFS adoption.

'Biotic stress' is a dangerous threat to IFS in new alluvial as well as coastal saline zones. involving pests, diseases, and pathogens affecting both crops and livestock. Biotic stress is a recurring issue in IFS due to the close integration of plant, animal, and microbial components (Singh and Burark, 2016). Cross-contamination from organic inputs like poultry manure can spread harmful microbes such as fecal coliforms, *Escherichia coli*, and fecal streptococci (Atidégla et al., 2016), and *Salmonella* (Singh et al., 2007; Siddiqui et al., 2008), posing public health risks.

'Lack of technical support' has been flagged as another major challenge to IFS in hill and old alluvial zones. IFS needs expert guidance on enterprise integration, waste recycling, and resource optimization, but inadequate extension services for technical know-how hinder effective adoption of IFS. Similar issues are reported in northern India (Tiwari et al., 2021).

'Limited access to credit' is the second biggest challenge to IFS, especially in the resource-poor red laterite zone. This is also reported by IFS farmers elsewhere (Tiwari et al., 2021). This challenge restricts farmers' investment in enterprises and inputs. Smallholders often depend on costly informal loans, limiting IFS adoption. 'Migration of family labour' challenges IFS adoption as small and marginal farmers move to urban areas for alternative jobs due to high production costs, crop risks, and low market prices.

'Agro-ecological zone-specific limitations' are natural challenges to IFS success, such as acidic soils in hills, saline/waterlogged soils in coasts, and infertile red soils in laterite zones. These reduce productivity, soil health, and integration viability, making IFS adoption more challenging. Behera and France (2016) emphasize the need for agro-ecologically tailored IFS models due to soil, climate, and topographical constraints.

### *3.5. Policy recommendations*

The SWOC-TOPSIS analysis suggests prioritization of the factors for planning in holistic and inclusive manners for the practice and adoption of IFS. The findings of this research may contribute to the development of evidence-based policy interventions for promoting IFS as a sustainable agricultural development strategy.

## 4. CONCLUSION

The SWOC–TOPSIS framework prioritized key drivers and barriers influencing IFS adoption across diverse agro-climatic zones of West Bengal. The zone-specific insights highlighted the heterogeneity in strengths, weaknesses, opportunities and challenges, underscoring the need for tailored policy responses. The SWOC-TOPSIS analysis would help decision-makers to realize the complexity of the real world where the farmers and farm families operationalized IFS. This study not only illustrated the practical benefits of machine learning in IFS, but also offered evidence-based policy recommendations

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## 6. REFERENCES

Anonymous, 2015. FAO-ITPS, 2015. Status of the world's soil resources. Food and Agriculture Organization of the United Nations and the Intergovernmental Technical Panel on Soils, Rome, Italy. Available at: http://www.fao.org/3/a-i5199e.pdf. Access date: 22/12/2025.

Anonymous, 2021. FAO, 2021. The state of food and agriculture 2021. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: https://doi.org/10.4060/cb4476en. Access date: 22/12/2025.

Anonymous, 2022. Government of India, 2022. Agricultural statistics at a glance. Ministry of Agriculture and Farmers Welfare. https://agriwelfare.gov.in/en/Agricultural_Statistics_at_a_Glance. Access date: 22/12/2025.

Anonymous, 2023. OECD-FAO, 2023. Agricultural outlook 2023–2032. Organisation for Economic Co-operation and Development and the Food and Agriculture Organization (FAO) of the United Nations. Available at: https://www.oecd.org/content/dam/oecd/en/topics/policy-issues/agricultural-trade-and-markets/agrioutlook23_%20execsum_en.pdf/_jcr_content/renditions/original./agrioutlook23_%20execsum_en.pdf. Access date: 22/12/2025.

Atidégla, S.C.J., Huat, E.K., Agbossou, H.S., Macary, Kakai, R.G., 2016. Vegetable contamination by the fecal bacteria of poultry manure: Case study of gardening sites in Southern Benin. International Journal of Food Science, 4767453. Doi: 10.1155/2016/4767453.

Babaesmailli, M., Arbabshirani, B., Golmah, V., 2012. Integrating analytical network process and fuzzy logic to prioritize the strategies-a case study for a tile manufacturing firm. Expert System 39, 925–935. https://doi.org/10.1016/j.eswa.2011.07.090.

Bairam, S.K., Chunchu, S., 2022. IoT in Agriculture. Doi: 10.13140/RG.2.2.15314.89285.

Bandyopadhyay, B., Burman, D., Sarangi, S.K., Mandal, S., Bal, A.R., 2009. Land shaping techniques to alleviate salinity and waterlogging problems of mono-cropped coastal land for multi-crop cultivation. Journal of the Indian Society of Coastal Agricultural Research 27(1), 13–17. https://www.researchgate.net/publication/279916633_land_shaping_techniques_to_alleviate_salinity_and_waterlogging_problems_of_mono-cropped_coastal_land_for_multi-crop_cultivation. Access date: 22/12/2025.

Basu Majumder, A., Bera, B., Rajan, A., 2012. Tea statistics: global scenario. International Journal of Tea Science 8(1), 121–124. Available at: https://www.teaboard.gov.in/pdf/Tea%20Statistics%20Global%20Scenario.pdf.

Behera, U.K., Mahapatra, I.C., 1999. Income and employment generation for small and marginal farmers through integrated farming systems. Indian Journal of Agronomy 44, 431–439. https://doi.org/10.59797/ija.v44i3.3529.

Behera, U.K., France, J., 2014. Integrated farming systems for livelihood security of small and marginal farmers in India. Reviews in Agricultural Science 2, 1–19. https://doi.org/10.1016/bs.agron.2016.04.001.

Behera, U.K., France, J., 2016. Integrated farming systems and the livelihood security of small and marginal farmers in India and other developing countries. Advances in Agronomy 138, 235–282. https://doi.org/10.1016/bs.agron.2016.04.001.

Bhargavi, B., Behera, U.K., 2020. Securing the livelihood of small and marginal farmers by diversifying farming systems. Current Science 119, 854–860. https://www.currentscience.ac.in/Volumes/119/05/0854.pdf. Access date: 22/12/2025.

Bhati, J.P., Singh, D.V., 1987. Women's contribution to the agricultural economy in the hill regions of North-West India. Economic and Political Weekly 22(17), WS7–WS11. https://www.epw.in/journal/1987/17. Access date: 22/12/2025.

Bhatt, K., Kameshwari, V.L.V., 2022. Agritourism to enhance an integrated farming model: A case of agritourism centre in Uttarakhand. Biological Forum – An International Journal 14, 449–454. https://www.researchgate.net/publication/373990067_agritourism_to_enhance_integrated_farming_model_a_case_of_agritourism_centre_in_uttarakhand. Access date: 22/12/2025.

Budiasa, I.W., Ambarawati, I.G.A.A., 2014. Community-based agro-tourism as an innovative integrated farming system development model towards sustainable agriculture and tourism in Bali. Journal of the International Society for Southeast Asian Agricultural Sciences 20, 29–40. https://www.researchgate.net/publication/289428810_.

Chai, Q., Nemecek, T., Liang, C., Zhao, C., Yu, A., Coulter, J.A., Wang, Y., Hu, F., Wang, L., Siddique, K.H.M., Gan, Y., 2021. Integrated farming with intercropping increases food production while reducing environmental footprint. Proceedings of the National Academy of Sciences of the United States of America 118(38), e2106382118. doi:10.1073/pnas..2106382118.

Chung, H.Y., Chang, K.H., Yao, J.C., 2023. Addressing environmental protection supplier selection issues in a fuzzy information environment using a novel soft fuzzy AHP–TOPSIS method. Systems 11, 293. https://doi.org/10.3390/systems11060293.

Dadabhau, A.S., Kisan, W.S., 2013. Sustainable rural livelihood security through integrated farming systems: A review. Agricultural Reviews 34, 207–215. https://doi.org/10.5958/j.0976-0741.34.3.005.

Doley, K., 2022. Tea meets travel: The culture of tea tourism. Financial Express. Available at: https://www.financialexpress.com/lIFSe/travel-tourism-tea-meets-travel-2654198.

Elamathi, S., Singh, S., Rangaraj, T., Anandhi, P., 2021. Integrated farming system model for sustained farm income and employment generation under rainfed vertisol of the southern zone of Tamil Nadu. National Academy of Sciences Letters 44, 485–487. Available at: https://doi.org/10.1007/s40009-021-01059-6.

Faria Correa, R.G.F., Kliemann, F.J., Souza, J.S., Lampert, V.N., Barcellos, J., 2019. Enterprise risk management in integrated crop-livestock systems: a method proposition. Journal of Agricultural Science 156, 1222-1232. https://doi.org/10.1017/S002185961900008X.

Garrett, R.D., Niles, M.T., Gil, J.D.B., Gaudin, A., Chaplin-Kramer, R., Assmann, A., Assmann, T.S., Brewer, K., Carvalho, P.C.F., Cortner, O., Dynes, R.A., Garbach, K., Kebreab, E., Mueller, N.D., Peterson, C., Reis, J.C., Snow, V., Valentim, J., 2017. Social and ecological analysis of commercial integrated crop livestock systems: current knowledge and remaining uncertainty. Agricultural Systems 155, 136–146. https://doi.org/10.1016/j.agsy.2017.05.003.

Ghosh, A., Mondal, S., Chatterjee, S., 2019. Sustainable resource recycling in the New Alluvial Zone of West Bengal. Indian Journal of Agricultural Sciences 89(3), 532–537. Available at: https://epubs.icar.org.in/index.php/IJAgS. Access date: 22/12/2025.

Ghosh, M., Ghosh, A., 2014. Women in agriculture: A case study from West Bengal. Indian Journal of Gender Studies 21(2), 225–244. https://doi.org/10.1177/0971521514525087.

Gurung, B., Tamang, S., Roy, D., 2023. Darjeeling mandarin production constraints and future prospects in the Darjeeling hills. Agri-India Today 3(12), 14–16. Available at: https://www.researchgate.net/publication/376835095.

Haddad, A.N., da Costa, B.B.F., de Andrade, L.S., Hammad, A., Soares, C.A.P., 2021. Application of fuzzy-TOPSIS method in supporting supplier selection with focus on HSE criteria: A case study in the oil and gas industry. Infrastructures 6, 105. https://doi.org/10.3390/infrastructures6080105.

Haldar, A., Kumar, D., Behera, M., Ghosh, S., Joshi, S.K., Das, U., A. Kumar, A., Roy, S.K., 2022a. Climate resilient technologies for augmenting livestock production and enhancing farmer's income under smallholder farming system. Indian Journal of Animal Health 61(2), 41–54. Doi: 10.36062/ijah.2022.spl.02022.

Haldar, A., Maiti, S., Goswami, R., Mandal, S.N., Shee, A., Goswami, B., Mahato, D., Ghorai, D., Pal, K., Khan, M., Samanta, M.K., Das, M.K., Dey Gupta, M., Dey, M., Barma, P., Chatterjee, P., Deb Mukherjee, R., Roy, R., Das, S., Ghosh, S., Das, U., Roy, K., Das, A., Mukherjee, S., Roy, S.K., Pradip Dey, P., 2024. Driving factors for developing integrated farming: Multi-criteria decision-making analysis. Indian Journal of Agricultural Sciences 94(3-S1), 49–55. https://doi.org/10.56093/ijas.v94i3.148603.

Haldar, A., Mandal, S.N., Deb, S., Roy, R., Laishram, M., A., Kumar, P., Kumar, S.S., Singh, B.H., Trisasongko, M., Rani, 2022b. Application of information and electronic technology for best practice management in livestock production systems. In Agriculture, Livestock Production and Aquaculture, ed. 173-218. Springer, Cham. Doi: 10.1007/978-3-030-93262-6_11.

Haldar, A., Samanta, I., Patra, A., P., Kumar, A.K., Pandey, S.K., Singh, S.S., Singh, V.K., Singh, 2022c. Knowledge-intensive livestock resource management in a changing environment. In sustainable agriculture systems and technologies, ed., 117–168. John Wiley and Sons Ltd. https://doi.org/10.1002/9781119808565.ch7?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle.

Herridge, D.F., Win, M.M., Nwe, K.M.M., Kyu, K.L., Win, S.S., Shwe, T., Min, Y.Y., Denton, M.D., Cornish, P.S., 2019. The cropping systems of the Central Dry Zone of Myanmar: Productivity constraints and possible solutions. Agricultural Systems 169, 31–40. Doi: 10.1016/j.agsy.2018.12.001. Access date: 22/12/2025.

Hwang, C., Yoon, K., 1981. Multiple attribute decision making: Methods and applications. Springer-Verlag. Doi:10.1007/978-3-642-48318-9_3.

Jiang, G., 2022. How does agro-tourism integration influence the rebound effect of China's agricultural eco-efficiency? An economic development perspective. Frontiers in Environmental Science 10, 921103. Doi: 10.3389/fenvs.2022.921103.

Kumar, B.P., Arya, S., 2019. Participation of Indian women in the agricultural sector: A study based on rural areas in India. MPRA 107405. https://mpra.ub.uni-muenchen.de/107405.

Kumar, S., Shivani, Dey, A., Kumar, U., Kumar, R., Mondal, S., Kumar, A., Manibhushan, 2022. Location-specific integrated farming system models for resource recycling and livelihood security for smallholders. Frontiers in Agronomy 4, 938331. Doi: 10.3389 /fagro.2022.938331.

Lal, R., 2020. Integrating animal husbandry with crops and trees. Frontiers in Sustainable Food Systems 4, 113. Doi: 10.3389/fsufs.2020.00113.

Lal, S.P., Mahendra, A., Rozi, A., Verma, M., 2023. Origin and history of integrated farming system: Few grassroots experiences and their revival through agro-tourism. In Entrepreneurship in Integrated Farming System Ed., 1-15. ISBN: 978-93-5461-712-6. Daya Publishing House, A Division of Astral International Pvt. Ltd., New Delhi-110 002, India. http://dayabooks.com/NewRelease.aspx. Access date: 22/12/2025.

Mahata, D., Kumar, A., Kumar, A.R., 2017. Female force participation and women's empowerment in Haryana. International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering 11(4), 992–998. Available at: https://scispace.com/pdf/female-work-force-participation-and-women-empowerment-in-38ogc6q53s.pdf.

Mandal, S., Sarangi, S.K., Mainuddin, M., Mahanta, K.K., Mandal, U.K., Burman, D., Digar, S., Sharma, P.C., Maji, B., 2022. Cropping system intensification for smallholder farmers in the coastal zone of West Bengal, India: A socio-economic evaluation. Frontier of Sustainable Food System 6. Doi: 10.3389/fsufs.2022.1001367.

Mandal, U.K., Burman, D., Bhardwaj, A.K., Nayak, D.B., Samui, A., Mullick, S., Mahanta, K.K., Lama, T.D., Maji, B., Mandal, S., Raut, S.S., Sarangi, S.K., 2019. Waterlogging and coastal salinity management through land shaping and cropping intensification in climatically vulnerable Indian Sundarbans. Agricultural Water Management 216, 12–26. https://doi.org/10.1016/j.agwat.2019.01.012.

Masmali, I., Ahmad, A., Azeem, M., Koam, A.N.A., Alharbi, R., 2024. TOPSIS method based on intuitionistic fuzzy soft set and its application to the diagnosis of ovarian cancer. International Journal of Computational Intelligence Systems 17, 161. https://doi.org/10.1007/s44196-024-00537-1.

Misra, S., Goswami, R., Mondal, T., Jana, R., 2017. Social networks in the context of community response to disaster: study of a cyclone-affected community in coastal West Bengal, India. International Journal of Disaster Risk Reduction 22, 281–296. https://doi.org/10.1016/j.ijdrr.2017.02.017.

Morris, C., Winter, M., 1999. Integrated farming systems: the third way for European agriculture? Land Use Policy 16, 193–205. https://doi.org/10.1016/S0264-8377(99)00020-4.

Nababan, R., Regina, A., 2021. Socio-cultural dimensions in the adoption of IFS in South Asia. Asian Journal of Agricultural Extension 12(2), 34–45.

Nayak, P.K., Nayak, A.K., Panda, B.B., Lal, B., Gautam, P., Poonam, A., Shahid, M., Tripathi, R., Kumar, U., Mohapatra, S.D., Jambhulkar, N.N., 2018. Ecological mechanism and diversity in rice-based integrated farming system. Ecological Indicators 91, 359–375. https://doi.org/10.1016/j.ecolind.2018.04.025.

Ngatindriatun, Adzim, F., 2022. An agribusiness-based farmer empowerment model with a sustainable integrated farming system approach to increase the income multiplier effect. ABAC Journal 42, 267–292.

Pandey, P.R., Gupta, J.K., Narvariya, R.K., Meena, S.C., Narwariya, D., 2019. Constraints faced by farmers in the adoption of the integrated farming system in the Vindhyan Plateau of Madhya Pradesh. Plant Archives 19, 512–514. Available at: https://aercjbp.com/static/media/RP-74.8ba8c9f3.pdf.

Panwar, A., Ravisankar, N., Singh, R., Prusty, A., Shamim, M., Ansari, M., Noopur, K., 2021. Potential integrated farming system modules for diverse ecosystems of India. Indian Journal of Agronomy 66, 15–32. https://www.researchgate.net/publication/356355264_.

Paramesh, V., Arunachalam, V., Nath, A.J., 2019. Enhancing ecosystem services and energy use efficiency under organic and conventional nutrient management systems to a sustainable arecanut-based cropping system. Energy 187, 115902. doi.org/10.1016/j.energy.2019.115902.

Paramesh, V., Chakurkar, E.B., Bhagat, T., Sreekanth, H.B., Kumar, C., Rajkumar, S., Gokuldas, P.P., Mahajan, R., Manohara, K.K., Ravisankar, N., 2021. Impact of integrated farming system on residue recycling, nutrient budgeting, and soil health. Indian Journal of Agricultural Sciences 91, 44–48. https://doi.org/10.56093/ijas.v91i1.110923.

Paramesh, V., Ravisankar, N., Behera, U.K., Arunachalam, V., Kumar, P., Rajkumar, R.S., Misra, S.D., Kumar, R.M., Prusty, A.K., Jacob, D., Panwar, A.S., Mayenkar, T., Reddy, V.K., Rajkumar, 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. doi.org/10.1002/fes3.321.

Paroda, R.S., 2014. Need for promoting integrated and sustainable farming systems. Current Science 106(11), 1385–1386.

Patra, S., Samal, K.C., 2018. Constraints and opportunities in the adoption of an integrated farming system by smallholders in Eastern India. Indian Journal of Agricultural Sciences 88(6), 905–909.

Pramanick, B., Singh, R., Singh, A.P., Chaturvedi, S., Singh, D.K., Singh, M., Neelam, C., Dhyani, B.A., Kesarwani, S., Chaturvedi, G., Singh, D.S., Pandey, Kewlanand, A., Shukla, S., Chandra, B.S., Mahapatra, 2008. Integrated farming system approaches for sustainable production and livelihood security. In: Proceedings of National Agronomy Congress, ed. V, 172–174. Pantnagar, India, GBPUAT. https://www.researchgate.net/publication/335960867_.

Purnomo, S.H., Sari, A.I., Emawati, S., Rahayu, E.T., 2021. Factors influencing the adoption of integrated crop-livestock to support land conservation of organic agriculture in the Mojosongo area, Karanganyar, Indonesia. IOP conference series. Environmental Earth Science 724, 12049. Doi: 10.1088/1755-1315/724/1/012049.

Raman, K.V., Balaguru, T., 1988. NARP—An innovative approach towards FSR in India, Agricultural Administration and Extension 30(3), 203–213. https://doi.org/10.1016/0269-7475(88)90055-4.

Ramana, M.V., Kumari, C.P., Karthik, R., Alibaba, M., Reddy, G.K., Chiranjeevi, K., Kumar, M.S., Chandra, M.S., Ravisankar, N., Bhatt, R., Gaber, A., Hossain, A., 2025. Integrated farming systems improve the income of small farm holdings-An overview of earlier findings in the Indian context. Food and Energy Security 14, e70064. https://doi.org/10.1002/fes3.70064.

Roszkowska, E., Kusterka-Jefmanska, M., Jefmanski, B., 2021. Intuitionistic fuzzy TOPSIS as a method for assessing socioeconomic phenomena based on survey data. Entropy 23, 563. https://doi.org/10.3390/e23050563.

Saaty, T.L., 2008. Decision making with the analytic hierarchy process. International Journal of Services Sciences 1, 83–98. Available at: https://www.rafikulislam.com/uploads/resourses/197245512559a37aadea6d.pdf.

Sathiyamurthi, S., Murugan, S., Saravanan, S., Rengasamy, G., Sivakumar, K., Shankar, K., 2024. Assessment of crop suitability analysis using AHP-TOPSIS and geospatial techniques: A case study of Krishnagiri District, India. Environmental and Sustainability Indicators 24, 100466. https://doi.org/10.1016/j.indic.2024.100466.

Setimala, P.S., Mangorokosho, C., Lunduka, R., Gasura, E., Makumbi, D., Tarekenge, A., 2017. On-farm yield gains with stress-tolerant maize in Eastern and southern Africa. Agronomy Journal 109, 406–417. https://doi.org/10.2134/agronj2015.0540?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle.

Shih, S.H., Syur, J.H., Lee, S.E., 2007. An extension of TOPSIS for group decision making. Mathematical and Computer Modelling 45, 801–813. https://doi.org/10.1016/j.mcm.2006.03.023.

Shyam, C.S., Shekhawat, K., Rathore, S.S., Babu, S., Singh, R.K., Upadhyay, P.K., Das, A., Fatima, A., Kumar, S., Sanketh, G.D., Singh, V.K., 2023. Development of integrated farming system model-a step towards achieving a biodiverse, resilient, and productive green economy in agriculture for small holdings in India. Agronomy 13, 955. https://doi.org/10.339.

Siddiqui, M.H., Ahmad, S., Khan, M.N., 2008. Potential risks from irrigation with pathogen-contaminated water. Archives of Agronomy and Soil Science 54(6), 655–665. https://doi.org/10.1080/03650340801941862.

Singh, H., Burark, S.S., 2016. Constraints faced by the households in existing farming systems in Chittorgarh and Banaswara districts of Southern Rajasthan. Advances in Social Research 2, 71–76. https://doi.org/10.5958/2277-940X.2016.00149.2.

Singh, R., Sharma, R.R., Kumar, S., 2007. Spread of Salmonella in vegetables irrigated with contaminated water. Indian Journal of Microbiology 47(2), 188–192. https://doi.org/10.1007/s12088-007-0036-5.

Srivastava, A.P., 2018. Selected integrated farming system models for enhanced income. Indian Farming 68, 13-16. Available at: https://epubs.icar.org.in/index.php/IndFarm/article/view/80408.

Tiwari, R., Mishra, D.K., Sharma, P., 2021. Challenges and prospects of IFS in marginal ecosystems of India. Journal of Farming Systems Research and Development 27(2), 122–130.

Vineeta, Tamang, B., Shukla, G., Chakravarty, S., 2023. The urge to conserve tradition from climate change: A case study of Darjeeling Himalayan large cardamom-based traditional agroforestry farming system. Nature-Based Solutions, 3. DOI: doi.org/10.1016/j.nbsj.2023.100064.

Yue, Z., 2012. A method for group decision making based on determining the weights of decision makers using TOPSIS. Applied Mathematical Modelling 35(4), 1926–1936. https://doi.org/10.1016/j.apm.2010.11.001.