Agricultural & Rural Studies

Article

Sustainable and Traditional Agricultural Practices to Reinforce Income Dynamics among Tribal Communities in Rural Wayanad, Kerala, India

Nikhil Prathapachandran * and Varuvel Devadas

Department of Architecture and Planning, Indian Institute of Technology Roorkee, Uttarakhand 247667, India; v.devadas@ar.iitr.ac.in
* Correspondence: nikhil_p@ar.iitr.ac.in

Abstract: This comprehensive study conducted in Wayanad, Kerala, India, explores sustainable traditional farming practices in rural tribal households, with a primary goal of boosting income growth and agricultural productivity. The research delves into the intricate relationship between agricultural methods, income distribution, and ecological factors across household income brackets. Descriptive statistics provide a contextual understanding, while regression analysis offers insights into the relationships between Income and Agricultural Practices. The study assesses the impact of various traditional methods on agriculture, investigates the profitability and practices associated with organic, artificial, and mixed farming, and observes that mixed farming methods are more profitable than relying solely on natural practices, with income levels influencing the adoption of advanced farming technologies. The research explores the correlation between combining animal husbandry and agriculture in households, revealing an association with increased profit margins. Emphasizing the importance of sustainable agricultural practices, the study shows a preference for traditional farming techniques in the low-income bracket and a shift towards artificial methods as income rises. The research offers valuable insights into income, farming practices, and sustainability in this context.

Keywords: traditional farming; rural households; income dynamics; tribal communities

Citation: Prathapachandran, N.; Devadas, V. Sustainable and Traditional Agricultural Practices to Reinforce Income Dynamics among Tribal Communities in Rural Wayanad, Kerala, India. *Agricultural & Rural Studies*, 2023, *1*, 0017. *https://doi.org/10.59978/ar01030017*

Received: 13 November 2023
Revised: 21 November 2023
Accepted: 23 November 2023
Published: 28 November 2023

1. Introduction

India's tribal communities, the oldest ethnic group with unique socio-cultural patterns, have faced challenges in the post-independence era, including poverty, high infant mortality, malnutrition, and low literacy rates (Lal, 2010). In Wayanad, tribal agriculture is vital for the local economy and culture, with indigenous tribes practicing traditional and subsistence farming. Challenges such as land alienation, environmental changes, and limited access to modern resources and markets impact tribal agriculture. Enhancing support for tribal agriculture is crucial for community well-being and sustainable regional development. Indigenous agricultural knowledge, known for its eco-friendliness and sustainability, is a valuable intergenerational legacy. However, the contemporary era of Liberalization, Privatization, and Globalization threatens their preservation. Primitive communities employ unique methods to safeguard and continue their indigenous knowledge for survival (Barekar, 2016). Indigenous agricultural knowledge provides a sustainable alternative to modern practices reliant on potentially harmful chemicals. Its adoption reduces the dependence on pesticides, weedicides, and fertilizers, fostering eco-friendly farming practices (Borthakur & Singh, 2021). Traditional agricultural knowledge is vital for small and marginal farmers in India, encompassing crop production, management, protection, and value-added practices. Farmers actively preserve and pass down this valuable information within rural communities, ensuring its continuity and usefulness. This traditional agricultural knowledge transforms agricultural resources, upholds biodiversity ethics, and offers historical and practical insights to present generations (Sharma et al., 2023). Modern farming practices result in genetic erosion and the extinction of crop seed germplasms, diminishing crop variety. This underscores the importance of raising awareness about healthy soils and sustainable agricultural practices to address concerns about genetically modified food and potential health risks for consumers (Srivastava, 2020). While enhancing agricultural production, the Green Revolution has incurred significant environmental costs, including climate change and agroecosystem degradation. Local technology improvement and global sustainable intensification offer models to reduce greenhouse gas emissions by up to 30%. Achieving sustainable agriculture entails shifting management systems, adopting eco-friendly practices, and implementing integrated insect farming systems (Adegbeye et al., 2020). The key to rapid, broad-based, and self-sustaining economic development lies in enhancing rural income growth and industrialization through productivity increases in agriculture (Balisacan, 1989). Traditional agriculture is gaining global recognition as a solution for sustainable food production in a changing climate. Recognizing the link between climate change and agriculture underscores the importance of adopting a climate-smart approach to food production (Singh & Singh, 2017).

Traditional agriculture optimizes resources, upholds biodiversity principles, and imparts historical and practical wisdom to today's generation (Sharma et al., 2022). Applied in various agricultural facets, it includes crop production, management, protection, farm machinery, soil and water management, medicinal plants, animal husbandry, grain pest control, weed management, and value-added food products. Traditional farming practices like agroforestry, intercropping, crop rotation, cover cropping, organic composting, integrated crop-animal farming, shifting cultivation, and slash-and-burn farming have positive and negative implications. Positively, they enhance soil fertility, sequester carbon, optimize resource use, maintain biodiversity, promote sustainability, and protect the environment. However, certain practices like slash-and-burn techniques in shifting agriculture have negative consequences (Hamadani et al., 2021). Research indicates that upland farmers use indigenous knowledge to adapt to challenging conditions and scarce resources, guiding practices in agriculture, soil conservation, pest control, and ensuring successful harvests. Excessive nitrogen in the environment leads to health and environmental issues, including nitrate contamination in drinking water, negative impacts on freshwater bodies, estuaries, natural ecosystems, greenhouse gases, ozone depletion, acid rain, leaching of bases from soils, and biodiversity loss (Keeney, 1997). While not deemed superior to scientific knowledge, indigenous knowledge is pivotal in equipping farmers with coping mechanisms in degraded uplands (Salomon et al., 2014). Indigenous agriculture plays a vital role in rural development, nature conservation, and the preservation of local ecosystems, ensuring the sustainable use of biodiversity for the well-being of both nature and humanity (Sharma et al., 2020). Studies discuss the importance of incorporating these sustainable cropping practices with modern/corporate agricultural tools to maximize their benefits (KWG & LPHK, 2016; Saha & Bauddh, 2020; Tribe, 1993).

1.1 Sustainable Agricultural Practices and Traditional Knowledge

Research indicates that adopting multiple sustainable agricultural practices (SAPs) in Africa simultaneously results in higher farm income and improved food security for rural households, outperforming single-practice adoption or non-adoption. Households with at least three SAPs experience significantly higher farm income and enhanced food security than those implementing fewer than three practices (Abdallah et al., 2021). The research found that adopting at least three SAPs (improved seed, fertilizer, and soil and water conservation) positively impacted farm income and food security more than adopting one or two SAPs (Setsoafia et al., 2022). Indigenous farming practices within the indigenous knowledge system (IKS) are eco-friendly, sustainable, cost-effective, and crucial for vegetable and livestock cultivation among indigenous communities. Integrating modern technology with traditional methods enhances farming efficiency and reduces energy consumption (Seko et al., 2020). Denitsa Ivanova's study explores best agricultural practices in cultivating traditional and non-traditional crops within organic farming, focusing on the ancient cereal crop Eragrostis tef. The study underscores the potential advantages of employing higher seeding rates and implementing soil and foliar fertilization to enhance crop yields (Ivanova, 2018).

In Mahaulpatha, Polonnaruwa district, Sri Lanka, a survey found 57% of farmers used straw manure before planting, and all employed chemical fertilizers post-sowing paddy seeds. While 87% used machinery for efficient land preparation, some still relied on natural indicators like rainfall patterns and wind direction. Traditional eco-friendly pest control methods were less effective in modern farming, prompting many to use chemical pesticides for immediate results despite their unsustainability (KWG & LPHK, 2016). Amish agriculture, which has evolved over 300 years, is marked by low-input farming systems that have sustained the Amish as a resilient subculture in North America. It centers on traditional practices like horse farming and manual labor, in sharp contrast to high-input conventional agriculture. This distinctive approach provides a unique research opportunity for studying biological pest control, disease management, and nutrient cycling, contributing to sustainability efforts (Stinner et al., 1989).

1.2 Indigenous Agricultural Practices and Traditional Knowledge in India

The traditional knowledge practices in the region, such as wetland rice cultivation of the Apatani tribe in Arunachal Pradesh, Zabo system of farming and Alder agriculture in Nagaland, large cardamom plantation in Sikkim, and bamboo drip irrigation in Meghalaya, are still in use and considered viable and cost-effective for organic agriculture (De, 2021). Studies have identified and described 21 traditional agricultural tools in Tamil Nadu, including ploughs made from locally available materials like stones, wood, bone, shell, teeth, plant fiber, and animal products. These tools were economical, saving labor, money, and time, operating efficiently without requiring special skills (Karthikeyan et al., 2009b). The study by Dhananjay Kumar emphasizes the need to understand the contemporary interrelationship between traditional farming systems and modern agro-technological advancements to develop sustainable agricultural practices in tribal agro-ecological zones (Kumar, 2016). The Apatani tribe in the Ziro Valley of Arunachal Pradesh has a highly evolved indigenous system of farming that involves cultivating rice and fish together. They utilize periphytoplankton and other natural resources to sustain their farming practices (Sarma & Goswami, 2015). In Meghalaya, tribals cultivate ginger, turmeric, paddy, and vegetables using the Khasi pine system, an indigenous tree-based agricultural approach that emphasizes the coexistence of edible and timber-yielding plants in a symbiotic relationship (Jeeva et al., 2006).

The traditional Mao Naga farming practice, "Jhum Cultivation," is intricately tied to their agrarian society and interconnected with socio-economic, socio-cultural, and geophysical factors. Population pressure has shifted from traditional to non-traditional crops, shortening the jhum cycle from 5–7 to 2–3 years. Integrating traditional and ecological knowledge systems is effective in sustainably managing the Jhum land use system (Pfoze et al., 2010). The Mavilan tribe in North Kerala traditionally hunted, gathered, and shifted cultivation, with extensive knowledge in paddy and seed categorization. However, their agricultural practices have undergone substantial changes, primarily due to forest regulations, evolving land use, and encroachment by non-tribal communities (Suresh, 2010). A study in Himachal Pradesh, focusing on Kinnaur and Lahaul-Spiti districts, documented 30 Indigenous Technical Knowledge (ITKs) related to tribal farming. These ITKs encompassed areas such as soil and water management, cropping systems, farm implements, post-harvest technology, storage, horticultural crops, food product development, agro-animal-based yarns and weaves, veterinary science, animal husbandry, medicinal knowledge, and cultural myths and beliefs (Swangla et al., 2021). The traditional cropping pattern in the central Himalayan region, known as ‘Baranaaja,’ includes 12 crops with low-intensity and infrequent economic intervention. This exemplifies ‘conservation agriculture,’ efficiently meeting food requirements and conserving agrobiodiversity with sustainable water and nutrient utilization (Ghosh & Dhyani, 2004). In remote Tamil Nadu villages, dryland farmers employed traditional storage techniques. These included using lime powder to repel insects and preserve pulse grains for a year. Earthen pots filled with paddy husk were used for paddy grains, and groundnut oil combined with tamarind and ash-treated sorghum seeds deterred pests. A mixture of sweet flag powder with grains and seeds acted as a six-month repellent. The study underscores the significance of indigenous storage practices in pest protection and minimizing losses (Karthikeyan et al., 2009a).

The paper begins with an introduction highlighting the importance of sustainable agriculture and income dynamics in various communities. The literature review shapes research objectives and specific questions. The methodology involves an extensive literature review, structured questionnaire-based data collection, and advanced statistical analysis. Insights into data collection, sampling, and analysis are detailed. The results section presents key findings on agricultural practices and income dynamics, with the discussion interpreting results in the context of existing literature. Recommendations offer actionable strategies for sustainable agriculture and income enhancement. The conclusion summarizes vital findings, acknowledges limitations, and suggests future research avenues, maintaining a structured and reader-friendly format.

2. Research Framework

The research context revolves around a comprehensive study conducted in Wayanad, India, focusing on the intricate dynamics between agricultural practices, income levels, and environmental sustainability. The primary aim is to understand how these elements intersect and influence each other in Wayanad’s unique socio-economic and ecological landscape.

2.1 Research Objective

To analyze the interplay between agricultural practices, income levels, and environmental sustainability in Wayanad, India, and provide insights into fostering sustainable agricultural development.

2.2 Research Questions

- How do households in Wayanad engage in different agricultural practices, including organic, artificial, and mixed methods?
- What is the correlation between Wayanad’s income levels and agricultural profit margins?

- To what extent does the practice of mixed agriculture influence agricultural profit margins in Wayanad?
- What do households in Wayanad employ the prevalent pest management strategies, and how do income levels influence the choice of these strategies?
- To what extent are households in Wayanad aware of and adopting sustainable agricultural practices, and how does this awareness vary across income categories?
- How can promoting mixed agriculture contribute to enhanced income levels and environmental sustainability in Wayanad?

The overarching research objective is accomplished through a nuanced exploration of the diverse factors influencing these dynamics, ultimately providing valuable insights for sustainable agricultural development tailored to the socio-economic context of the region.

2.3 Methodology

Initiating with an extensive review of scholarly literature, the research methodology shapes its objectives to explore relationships between income and agricultural practices within Wayanad's tribal communities. Primary data is then meticulously collected through structured questionnaires distributed among tribal households, ensuring representative data. A stringent validation process follows to uphold accuracy. Employing stratified and purposive sampling techniques, the investigation considers a sample size of 384 (400 for increased accuracy), maintaining a 95% confidence level and a 5% margin of error. The combined approach integrates a thorough literature review, primary data collection through surveys and interviews, and advanced statistical and regression analysis. Data encompassing agricultural practices, income sources, and profit margins undergoes systematic organization for analysis, employing both descriptive and inferential statistics. Descriptive statistics provide contextual understanding, while regression analysis offers insights into the relationships between income and agricultural practices. Visualizations are generated to communicate research findings effectively. From the study's insights, actionable recommendations are formulated to positively impact the sustainable agriculture and income dynamics of Wayanad's tribal communities.

2.4 Scope and Limitations

The scope of the study is that it comprehensively analyses agricultural practices, income levels, and their interplay in Wayanad, India, considering ecological and socio-economic factors. However, the limitation is that it is essential to note that the findings are specific to the Wayanad region and may only be partially applicable to other areas. The reliance on self-reported data introduces the possibility of bias, and the study's observational nature limits its ability to establish causal relationships. Additionally, there is a possibility that not all influencing factors have been considered in this research.

3. Analysis and Results

3.1 Agriculture Details

Among the 1,870 individuals across 400 households, approximately one-fourth (25.40%) engaged in daily wage labor, which included agricultural work. Additionally, 5.08% owned farmland and worked as farmers, while 4.22% were involved in animal husbandry. The households are classified into income groups depending on their monthly earnings, which include less than 5,000 Rs/month, 5,000–9,999 Rs/month, 10,000–14,999 Rs/month, 15,000–19,999 Rs/month, 20,000–24,999 Rs/month, 25,000–30,000 Rs/month, and more than 30,000 Rs/month. The analysis further indicates that around one-fifth (18.5%) of the families in the study depend entirely on agriculture to sustain their livelihoods. Within the sample, more than three-fourths (77%) of the families fall within the income range of Rs 5000 to 19999. This concentration implies a predominantly lower middle-income profile for agriculture-dependent families. It indicates that while agriculture is central to their income, these families likely engage in additional income-generating activities, contributing to their moderate economic well-being. These families engage in agricultural and non-agricultural activities, ensuring a potentially more stable income stream. The lowest income group (<5000) has limited participation in agriculture, possibly due to barriers like restricted access to resources, including land and capital or challenges related to markets and technology. Support may be needed for these households to engage in agricultural activities fully. The data highlights a noteworthy trend where the highest average earning from agriculture is observed in the income category of Rs 15,000–19,999. This suggests a significant reliance on agriculture as the primary income source in this income bracket, potentially indicating optimized agricultural practices for greater returns. However, the high average agricultural income in the highest income group is based on only one household, limiting the generalizability of this finding.

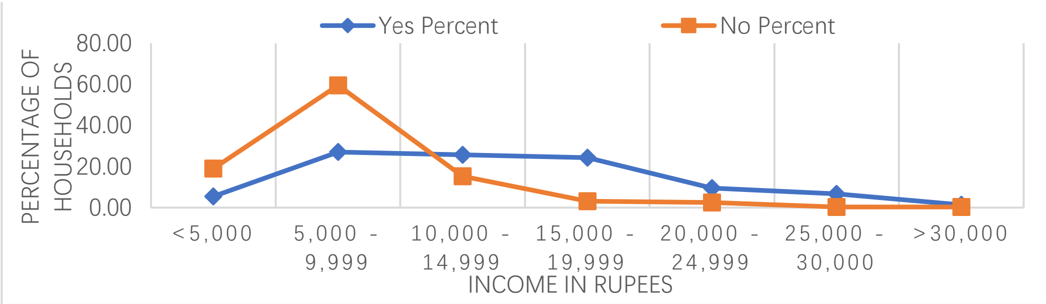

Figure 1. Income vs. families dependent on agriculture.

Analyzing primary crop choices, about one-fourth (23.5%) prioritize fruits and vegetables, 14% focus on coffee, and 10.5% on rice. Middle-income households prefer rice and coffee cultivation, while the lowest-income groups primarily cultivate fruits and vegetables. The Rs 5000–9999 income category dominates rice and coffee production, with limited contributions from the highest and lowest income categories. Pepper production is concentrated in the Rs 5000–9999 income category, with no production in the highest income categories. Tapioca is mainly produced in the Rs 5000–9999 income category, with limited involvement from the highest income categories. Fruit and vegetable production is led by the Rs 5000–9999 income category, with minimal contributions from higher income categories. Ginger production is prominent in the Rs 5000–9999 income category, with some input from the < Rs 5000 and Rs 25000–30000 categories. Chilli production centers on the Rs 10000–14999 income group, and cardamom production is chiefly within the Rs 5000–9999 and Rs 10000–14999 income categories, with no production in other categories. Other crop production is highest in the Rs 5000–9999 income category, with contributions from the < Rs 5000 and Rs 10000–14999 categories. Figure 3 shows Tapioca as the most cultivated secondary crop (22.25%), primarily grown by the Rs 5000–9999 income group. Pepper, the second most cultivated secondary crop (10.5%), is also primarily produced (47.62%) by the Rs 5000–9999 income group. Secondary rice production is found in the Rs 5000–9999 income category, and secondary wheat production is in the Rs 15000–19999 category. Significant secondary coffee production is observed in the Rs 10000–14999 income category, with contributions from the Rs 5000–9999 and Rs 15000–19999 categories. Fruit/vegetable production is significant in the Rs 5000–9999 category, with notable input from the Rs 10000–14999 and Rs 15000–19999 categories. Most secondary ginger, turmeric, chili, and cardamom production is within the Rs 5000–9999 income category, with some contribution from the Rs 10000–14999 category.

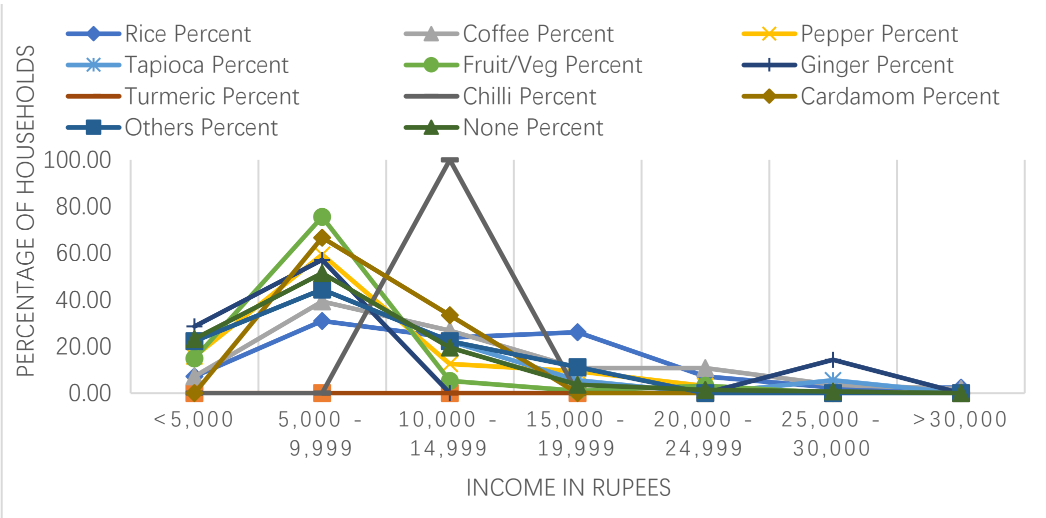

Figure 2. Income vs. primary crop type.

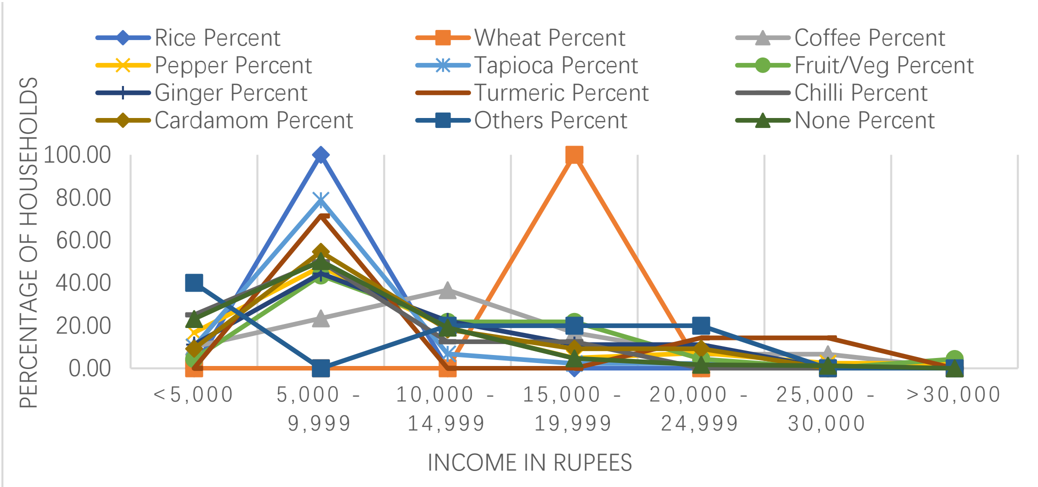

Figure 3. Income vs. secondary crop type.

The regression analysis concerning agricultural income (profit margin) in relation to primary crops reveals that these crops collectively account for about 37.01% of the variability in profit margins. Notably, the positive coefficient for rice implies that cultivating rice tends to increase profit margins. However, it is essential to note that the p-value associated with rice is close to 0.05, suggesting that the statistical significance of this effect is somewhat borderline. In the case of secondary crops, the analysis indicates that approximately 17.55% of the variability in profit margins can be attributed to these crops. However, the results are not statistically significant for crops like wheat, coffee, pepper, Tapioca, ginger, turmeric, chili, cardamom, and others. The lack of statistical significance indicates that the impact of these crops on profit margins remains undetermined. Notably, the "Fruit/Vegetable" category has the highest coefficient, but its p-value at 0.0407 achieves only marginal statistical significance.

3.2 Animal Husbandry

Animal welfare is a crucial priority in organic farming, which strives to create sustainable and eco-friendly farming systems, highlighting its commitment to both animal well-being and environmental sustainability (Lin, 2015) (Lund, 2002). Data shows that 48.25% of households practice animal husbandry, which is more common in the middle to higher income brackets than the lowest. Higher-income households may have more resources, such as land and capital, for successful animal husbandry. The data indicates that while almost half of the households practice animal husbandry, less than one-sixth (14.25%) rely entirely on it for income. This suggests that many households may have diversified income sources, engaging in additional occupations alongside animal husbandry or utilizing animal husbandry products for daily needs. The lowest-income category shows low involvement in animal husbandry due to resource limitations. In contrast, income categories between Rs 5000 and 19,999 actively engage in animal husbandry for income, with the highest participation observed in the Rs 5000–9999 and Rs 10000–14999 income categories.

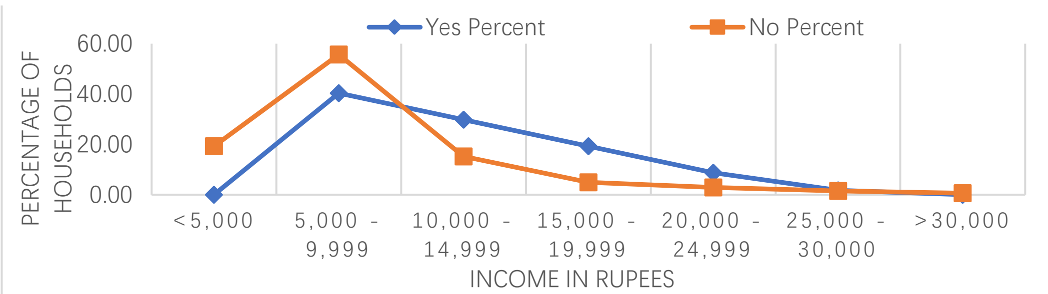

Figure 4. Income vs. families dependent on animal husbandry.

Gross income varies across income brackets, averaging Rs 5158.70 in the Rs 5000–9999 category, Rs 6955.88 in the Rs 10000–14999 category, and Rs 7745.45 in the Rs 15000–19999 category. The Rs 20000–24999 category has an average gross income of Rs 5750.00, while the highest income category (> Rs 30000) records no gross income from animal husbandry, suggesting diversified income sources. In the Rs 20000–24999 range, expenditure on feed and medicine averages

Rs 2020.00. Income from animal husbandry increases with household income, averaging Rs 3041.30 in the Rs 5000–9999 category, Rs 4047.06 in the Rs 10000–14999 category, and Rs 4454.55 in the Rs 15000–19999 category. Among agriculture-dependent households, those practicing both agriculture and animal husbandry have a higher average agricultural profit margin of 4277.5 Rs. In comparison, the 34 households solely engaged in agriculture have a slightly lower average profit margin of 3570.59 Rs. However, regression analysis indicates a minimal impact of animal husbandry on agricultural profit, supported by a low R-squared value of approximately 1.32% and an insignificant coefficient for animal husbandry, suggesting its limited influence on agricultural profit despite observed profit differences. Observations reveal that 8.25% of households own cattle, 36% rear poultry, and 4% have both cattle and poultry. Poultry rearing is more common in all income groups, while cattle and households practicing both are common in middle-income groups. The prevalence of poultry farming is attributed to its advantages, including more minor space requirements, lower investment costs, and quicker returns, making it a viable income-generating activity in rural and peri-urban areas. The 4% of households with cattle and poultry showcase diversified livestock practices for income and resource utilization. Cattle ownership analysis among families dependent on animal husbandry income reveals income-dependent patterns, concentrated in the Rs 5000–9999 (42.42%) and Rs 10000–14999 (33.33%) categories, indicating middle-income households' higher likelihood of owning cattle. The Rs 15000–19999 category exhibits 15.15% ownership, while the lowest and highest income categories have the lowest percentages, potentially due to resource limitations and different livelihood strategies. Poultry ownership analysis shows lower middle-income households' prevalence, with notably high ownership in the 5000–9999 Rs category (61.81%) and a significant percentage in the 10000–14999 Rs category (13.89%). The lowest and highest income categories have lower poultry ownership, possibly due to resource limitations and different livelihood strategies. In the Rs 10,000–14,999 and Rs 15,000–19,999 income categories, 25% of families own cattle and poultry, with the highest percentage in the Rs 5,000–9,999 income group at 37.50%. This suggests a tendency for middle-income households to engage in multiple types of animal husbandry, providing various income sources, including meat, dairy, and egg production. The average profit margin for cattle farming households is Rs 3703.13, while for poultry farming households, it is Rs 2362.5. Remarkably, households practicing cattle and poultry farming achieve the highest average profit margin of Rs 4352.94. Data indicates that these households are more profitable, potentially benefiting from complementary advantages or efficiencies. Tribes in Wayanad prioritize subsistence farming, explaining the lower emphasis on commercial poultry farming for profit.

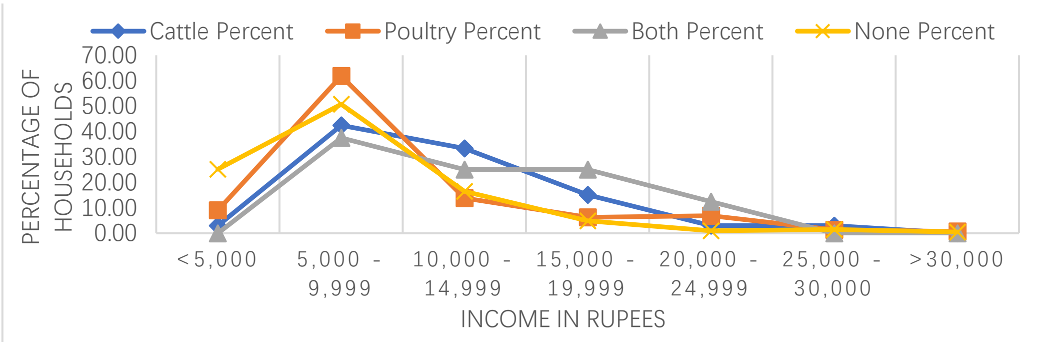

Figure 5. Income vs. type of livestock.

3.3 Fauna and Pest Management

Fauna management is crucial for tribal communities practicing agriculture and animal husbandry, involving sustainable practices to manage local wildlife and habitats. Deeply connected to nature, these communities contribute to biodiversity conservation, ecological balance, and cultural heritage preservation. Active participation empowers them in wildlife conservation decisions, supporting sustainable development and harmonious coexistence with the environment. Involvement in fauna management, seen in almost one-fourth (23.25%) of tribal families, reflects their commitment to conservation and deep understanding of maintaining a harmonious relationship with wildlife and ecosystems. As income brackets increase, participation decreases, with the highest income category at 1.08%, possibly due to other livelihood priorities. Analysis indicates reduced engagement, especially among families no longer working with forest produce and those moved away from forest settlements. Varied participation levels across income categories reveal the highest involvement in the Rs 10000–14999 category at 48.39%, reflecting a strong interest in wildlife conservation. The four lower income categories encompass 93.6% of households in fauna management.

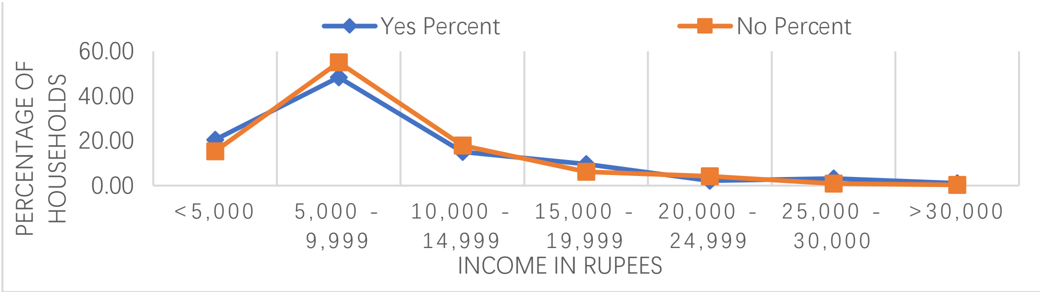

Figure 6. Income vs. fauna management (large mammals and other wildlife).

The data reveals that 8% of families use natural repellents for extensive fauna pest management, showcasing a preference for eco-friendly methods. Stun fencing is the second-highest practice, with 23.65% of households employing it, while 76.35% favor sustainable methods like natural repellents. This positive trend aligns with conservation and biodiversity preservation efforts. Promoting sustainable approaches, such as integrated pest management, minimizes harm to wildlife and the environment. The data underscores the importance of raising awareness about the drawbacks of certain pest management practices, like stun fencing and promoting sustainable alternatives. Lower income brackets prefer fencing or moats around settlements over time-consuming sustainable methods. Stun fences are most common in the Rs 5,000–9,999 category (40.91%), with no usage reported in the highest income group. Moats are predominantly used in the lowest two income categories (90%), while higher income brackets avoid this method. Traps are absent in the lowest-income category but gain prevalence in higher brackets (30.77%, 23.08%, 15.38%, and 15.38% in the Rs 5000–9999, Rs 10000–14999, 15,000–19,999, and the highest-income category, respectively). Repellents are widely used in the Rs 5000–9999 category (56.25%), 10,000–14,999 (18.75%), and the lowest income category (18.75%), with no usage in higher income brackets.

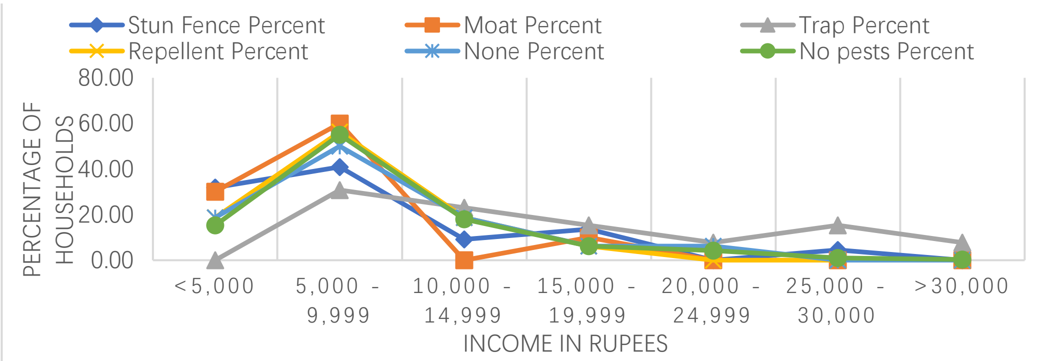

Figure 7. Income vs. pest management (large mammals and other wildlife).

Stun fences and moats show positive coefficients, suggesting potential profit margin increases, but these effects lack statistical significance. The regression analysis does not find any statistically significant correlation between pest control methods for large mammals and profit margins. In simpler terms, pest control method choice does not strongly impact profit margins from a statistical perspective. However, practical and ethical considerations should guide pest control decisions. While stun fences may offer higher profit margins, they raise ethical concerns about animal welfare and the need for safety. The data indicates that more families manage fauna for smaller pests like rodents, insects, and birds than large mammals. This is likely due to the broader issues tiny pests pose. Fauna management is less common in higher-income tribal families, who often have better preventive measures and modern housing that minimizes pest-related problems. The Rs 5000–9999 category reports the highest usage rate at 55.68%, highlighting a significant reliance on these methods for pest management.

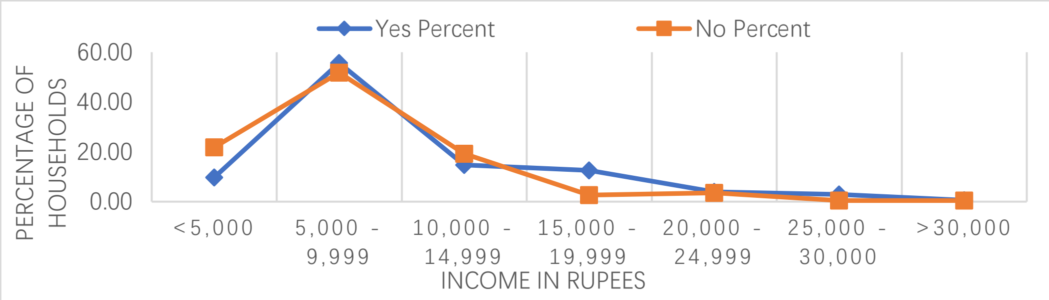

Figure 8. Income vs. fauna management (rodents, insects and birds).

The data reveals that while 76 households use sustainable homemade repellents for pest management, 92 use other fatal methods, excluding pesticides and smoke bombs. The higher use of fatal methods may stem from a lack of awareness about sustainable alternatives or perceived effectiveness. Lower-income groups focus on pest management due to their affiliation with forest produce, while middle-income families prioritize farming, aligning with rural community trends. The study in Wayanad tribes across seven income categories reveals diverse pest management strategies influenced by economic factors. Households in the 5,000–9,999 income category prioritize plowing (36.11%) and traps (29.03%). The 10,000–14,999 income group emphasizes puddling (42.86%). In contrast, the 15,000–19,999 income category does not allocate resources to puddling, indicating a different approach. Smoke bombs see substantial allocation in the 5,000–9,999 and 10,000–14,999 income categories (33.33%), while higher income categories (20,000–24,999, 25,000–30,000, and >30,000) allocate none, indicating limited prominence. Households below 5,000 income allocate moderate resources to smoke bombs (16.67%), demonstrating some reliance on this method. Traps are predominantly used in the <5,000 and 5,000–9,999 income categories, leading at 25.81% and 29.03%, while the 10,000–14,999 and 15,000–19,999 income groups stand at 16.13%. Higher-income categories (20,000–24,999, 25,000 –30,000, and >30,000) allocate fewer resources to traps (6.45%), indicating less reliance, with traps not a significant strategy for the highest-income category. Repellents are most used by the 5,000– 9,999 income category (84.21%), while the <5,000 income category stands at 5.26%. The 10,000– 14,999 and 15,000–19,999 categories show percentages of 3.95% and 2.63%, respectively. Higher-income categories (20,000–24,999, 25,000–30,000, and >30,000) also allocate relatively lower resources to repellents (ranging from 1.32% to 2.63%). The absence of resources allocated to repellents in the highest income category suggests more prominent strategies for pest management. The analysis indicates that households in the 5,000–9,999 and 10,000–14,999 income categories rely significantly on pesticides (both at 33%). However, the 15,000–19,999 category shows a more moderate use of pesticides at 16.67%. Income groups <5,000 and 20,000–24,999 show less reliance (both at 8.33%), likely due to differing financial priorities and pest-related challenges. Higher-income categories (25,000–30,000 and >30,000) do not allocate resources to pesticides, suggesting alternative strategies or fewer pest issues.

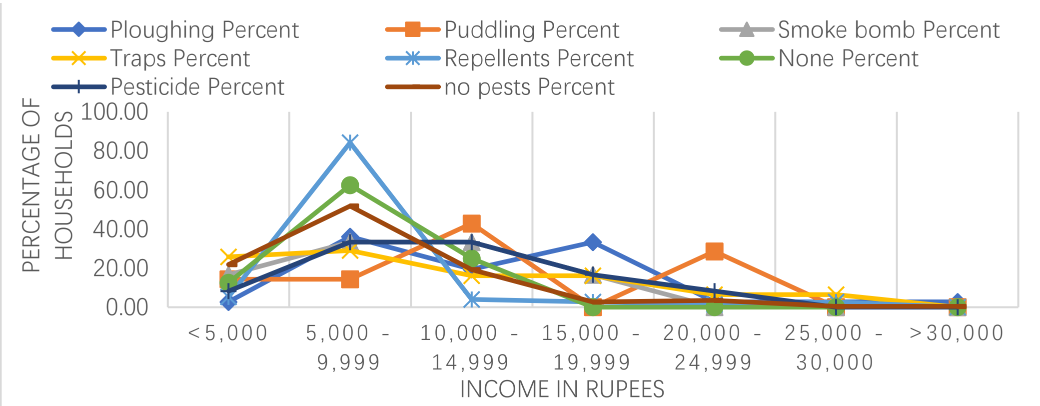

Figure 9. Income vs. pest management (rodents, insects and birds).

The regression analysis indicates that pest control methods significantly impact agricultural profit margins. Ploughing and puddling show substantial and statistically significant positive effects, contributing around 4,785.71 and 3,714.29 Rupees, respectively, to agricultural profit margins. Conversely, smoke bombs, traps, repellents, and pesticides do not affect agricultural profit margins statistically significantly. While smoke bombs and traps yield some gains, these effects lack statistical significance. Repellents and pesticides, while contributing to profit margins, lack statistical significance. Implementing plowing and puddling as pest control methods is favorable for enhancing agricultural profit margins, potentially with secondary benefits like soil quality improvement. Other methods may not provide substantial or statistically supported benefits in Rupees earned. The cost of specific pest control methods, such as pesticides or repellents, could offset gains from increased yields, limiting the improvement in net profit margins.

3.4 Crop Thrashing with Domesticated Fauna

The practice of crop thrashing with domesticated fauna, as indicated by one-seventh (13.25%) households, highlights a direct link between middle-income agricultural families and this method. Crop thrashing with domesticated fauna is a cost-effective and sustainable approach for small-scale farmers. It eliminates the need for expensive machinery or equipment, making it a viable option for those with limited financial resources. Additionally, it aligns with traditional farming practices and has cultural significance within the community. The technique is used by around three-fourths of agricultural households at 72.60%, but there is a notable decline in adoption within higher-income groups. However, it is essential to note that the effectiveness of crop thrashing with domesticated fauna may vary depending on the scale of agriculture, type of crops, and local farming practices. To improve crop production and income sustainably, it is crucial to understand how this practice can be optimized. In the 5,000–9,999 and 10,000–14,999 income categories, 33.96% and 26.42% of households, respectively, engage in crop thrashing with domesticated fauna, indicating substantial reliance on this method. The 15,000–19,999 income category has 30.19% of households practicing this method, reflecting a similar emphasis. The lower income category, < Rs 5,000, refrains from this practice due to limited access to domesticated fauna, as procuring and maintaining such assets might be financially challenging. Mechanized methods or other techniques may be more efficient, so crop thrashing with fauna decreases as the income bracket increases. The regression analysis for the profit margin in agriculture concerning the use of domesticated animals for crop thrashing reveals an R-squared value of approximately 23.02%. The coefficient for "Crop Thrashing with Domesticated Animals" is 2955.58, with a very low p-value ($1.523E^{-05}$), signifying its statistically significant and positive impact on agricultural profit margins.

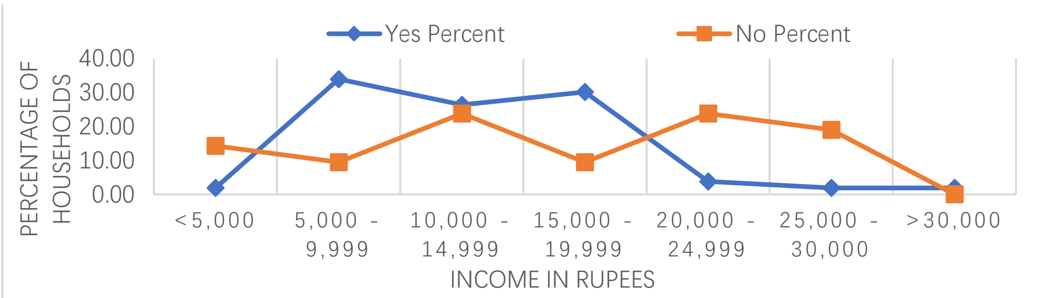

Figure 10. Income vs. crop thrashing with domesticated fauna.

3.5 Irrigation Methods

Regarding irrigation methods, the data shows that more than two-thirds of agricultural households (69.86%) use a combination of surface irrigation from nearby canals or rivers and motors for pumping water. In comparison, 23.29% rely solely on rivers, and 8.22% depend solely on small ponds. The lowest income group effectively utilizes small ponds and rivers for irrigation, showcasing their resourcefulness. Higher-income households favor modern irrigation methods like tube wells and drip irrigation, aligning with their economic capacity and resource management strategies. The income categories of 5,000–9,999 and 20,000–24,999 do not allocate resources to small pond irrigation, while the <5,000 and 10,000–14,999 income categories emphasize small pond irrigation. The lowest four income categories primarily rely on rivulet-based irrigation, with the 5,000–9,999 category significantly utilizing this method (52.94% of households). Among the 50 households that employ a combination of different irrigation methods, their average profit margins were notably higher at Rs 4238, surpassing the average profit margins achieved through natural irrigation sources. This suggests that using mixed irrigation methods yields better agricultural profit margins than relying solely on natural sources for irrigation. The regression analysis for profit in relation to the irrigation method shows a relatively low R-squared value of about 3.55%. This indicates that only a tiny proportion of the variability in profit can be explained by the choice of irrigation method.

The coefficients for "Small Pond," "Rivulet," and "Mixed" are positive, suggesting that these methods might have a positive impact on profit. However, the p-values for these coefficients are more significant than 0.05, indicating that they are not statistically significant. Therefore, the choice of irrigation method, whether a small pond, rivulet, or mixed, does not have a statistically significant effect on profit.

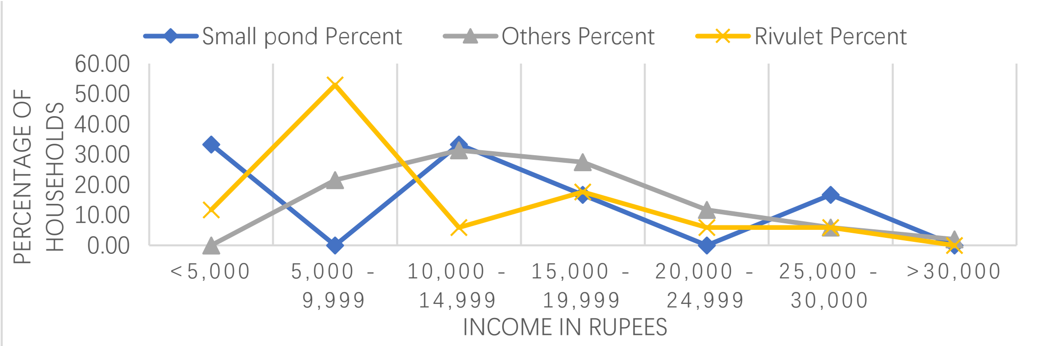

Figure 11. Income vs. water channels for irrigation.

3.6 Organic Farming

Organic farming is an agricultural approach that emphasizes using natural inputs, sustainable practices, and avoiding synthetic chemicals and genetically modified organisms. The data shows that 46.25% of households (185) practice organic farming as their primary method, including farming and subsistence households. Artificial and mixed techniques are more prevalent in the lower middle and middle-income brackets, with 18 of 21 families in these groups using such practices. The 5,000–9,999 income bracket strongly emphasizes sustainable farming, with 43.78% primarily engaged in organic agriculture. The increase in artificial practices in higher-income groups suggests that rising income levels may lead to investment in advanced farming technologies. Driven by the desire to improve productivity, optimize resource utilization, and potentially increase profits, artificial agriculture is prominent in Rs 5,000–9,999 and Rs 10,000–14,999 income households, with 42.86% and 28.57% practicing it, respectively. It is evident among both lower-middle-income and higher-income households. Meanwhile, mixed agriculture prevails in the Rs 5,000 to 19,999 income bracket, with 92.86% of households opting for this approach. This income category's strong inclination towards mixed agriculture suggests a diversified and sustainable farming approach, ensuring food security and economic stability aligned with their socio-economic and environmental context. Among households, 58 primarily practicing organic farming report an average agricultural profit margin of Rs 3668.96, while seven households using primarily artificial techniques achieved an average profit margin of Rs 3171.43. Those engaged in mixed agriculture, combining both organic and artificial methods, demonstrate the highest average profit margin of Rs 5722.2 within a group of nine families. The linear regression analysis indicates a statistically significant relationship between mixed agriculture and agricultural profit margins, with an R-squared value of approximately 8.76%. The coefficient for mixed agriculture is 2773.50, and the p-value is 0.0104, suggesting a significant influence on profit margins. However, the linear regression for organic and artificial agriculture did not show statistically significant relationships, indicating that these practices may not impact agricultural profit margins.

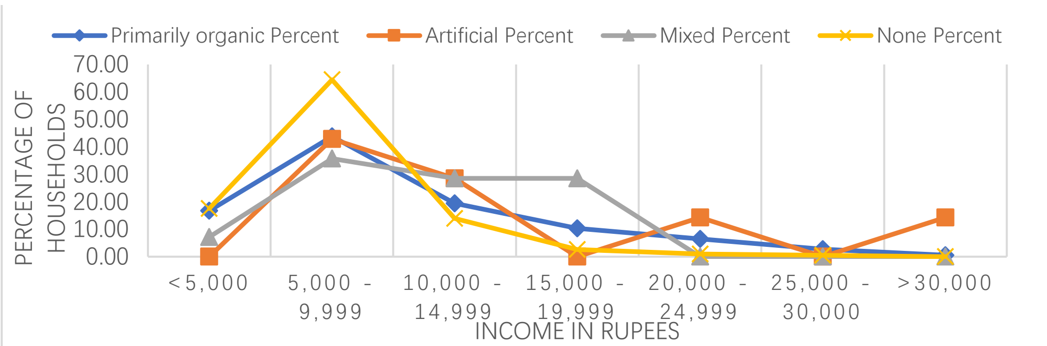

Figure 12. Income vs. practice of organic farming.

4. Findings

A significant portion of the surveyed population is involved in agriculture, with one-fifth relying solely on it for income, concentrated in the 5000–9999 Rs/month bracket. Income levels influence crop choices, with higher income focusing on rice and coffee. Rice cultivation shows a positive coefficient but a borderline significant impact on profit margins in the regression analysis. Animal husbandry is prevalent, with the highest profit margin observed when poultry and cattle are reared, and regression analysis indicates minimal impact. Fauna management is undertaken by one-fourth of tribal households, with decreasing participation as income increases but displays ethical concerns. Stun fences and moats show positive coefficients without statistical significance. Higher-income groups do not allocate resources to pesticides, and plowing/puddling is more common in the upper-middle-income bracket, showing a statistically significant positive impact on profit margins. Cost-effective and sustainable crop thrashing with domesticated fauna is observed, predominantly in middle-income households. Two-thirds of households use a combination of surface irrigation and motors, but the choice of irrigation does not show statistical significance with profit margins. Almost half of the households practice organic farming, but income increase correlates with a shift to mixed or artificial practices. Mixed agriculture demonstrates the highest average profit margin with statistically significant influence.

5. Discussion

The concentration in the middle-income bracket suggests that agriculture plays a vital role in households with moderate income levels, possibly serving as a stable income source. Provide financial incentives for low-income households to transition to sustainable and organic farming practices. Ensure fair resource access by developing customized agricultural strategies considering household income levels and regional characteristics. Diversification in crop choices among income groups indicates varying agricultural strategies and the positive impact of rice cultivation underscores its profitability. Promote crop diversification based on ecological suitability and market demand to enhance food security. The emphasis on combined poultry and cattle rearing suggests a potential for integrated farming, but the minimal impact in regression analysis warrants further investigation into the factors influencing profit margins. Those practicing agriculture and animal husbandry among agriculture-dependent households reported higher average profit margins. Encourage income diversification through combined crop cultivation and animal husbandry for economic stability and sustainability. Research suggests that declining satisfaction and income from livestock farming may lead to reduced intention to utilize improved grassland (Elahi et al., 2021). The ethical concerns associated with fauna management highlight the need for sustainable practices. Although not statistically significant, the positive coefficients of stun fences and moats indicate potential profitability, necessitating a balanced approach. Advocate for wildlife-friendly pest management to minimize ecological impact, focusing on sustainable alternatives to harmful methods. Avoiding pesticides in higher income brackets aligns with sustainable practices, but the use of pesticides in the lower income groups raises concern. Addressing policy distortions, especially in land and migration policies, can significantly reduce agricultural chemical usage (30–50%), decrease environmental impact (50%), and double farmers' total income. This aligns with strategies like enhancing access to modern technologies knowledge and enforcing environmental regulations. Larger farms consistently show lower agricultural chemical intensity, using less fertilizer and pesticide per hectare (Wu et al., 2018). Certain practices, like biofertilizers, natural pesticides, crop choice and rotations, intercropping, and agroforestry, need more agricultural integration and moderate potential for widespread adoption in the next decade. Raise awareness about sustainable farming practices through education and extension services, reducing reliance on synthetic chemicals. The positive impact of plowing/puddling emphasizes their importance in improving profit margins. The decrease in crop thrashing with increasing income levels may be due to the adoption of mechanized methods. However, the statistical significance and positive impact on profit margins underline its sustainability.

Higher-income groups adopt modern irrigation methods, implying technological adoption. The lack of significance in profit margins suggests a need for nuanced understanding. Integrated water management, including a small pond and rivulet-based irrigation, can optimize water use and boost yields. The income-driven shift in farming practices may reflect a trade-off between sustainability and profitability. The significant influence of mixed agriculture highlights its potential for balancing both factors. Agroecological principles enhance sustainable farming, promoting biodiversity, diversified cultivation, organic practices, and reduced chemical inputs. Livestock integration addresses associated challenges, advocating for supportive policies fostering economic stability and environmental sustainability. Agroecology boosts farmers' incomes, with potential regional and national impact on the agricultural sector (Van der Ploeg et al., 2019). Renewable energy, including solar and wind power, is integral to various agricultural processes. It supports irrigation, cultivates solar-powered greenhouses, aids post-harvest activities through solar and geothermal technologies, and powers transportation with biomass-based biofuels. Additionally, renewable energy is utilized for cooking, heating, and in climate-controlled sheds, promoting sustainable agricultural practices (Rahman et al., 2022). With the rise in off-farm income, rural households transition from solid, non-clean fuels like coal to more efficient and cleaner energy sources such as electricity and gas (Ma et al., 2019). It is essential to consider diverse indicators of human well-being and environmental sustainability beyond income or direct health concerns. These indicators encompass gender equality, nutrition, soil health, biodiversity, and climate forcing (Kanter et al., 2018). By distinguishing the poor, marginalized, and dispossessed dimensions, the assessment of multidimensional poverty can help design and execute poverty reduction programs and improve the persistence of alleviating poverty (Fahad et al., 2023). Economic indicators, such as profitability and productivity of inputs, are essential considerations in sustainable agricultural intensification (Shrestha et al., 2021). Promoting practices such as integrated farming systems, precision agriculture, integrated nutrient management, and integrated pest management is crucial for ensuring agricultural sustainability, food security, nutrition, and preserving natural resources for future generations (Muhie, 2022).

6. Conclusions

The research advances agricultural economics by uncovering intricate connections among income, farming practices, and profit margins. The empirical findings bolster existing theoretical frameworks on sustainable agriculture and income dynamics and offer practical insights for policymakers and practitioners. The study advocates for targeted support in the form of integrated farming systems, ethical fauna management, and awareness programs on sustainable pest control. Its interdisciplinary approach, spanning economic, ethical, and ecological dimensions, enriches our comprehension of agricultural practices and their profound implications for rural livelihoods. The emphasis on preserving culturally significant traditional farming practices underscores the importance of promoting sustainability while respecting local heritage. Moving forward, continued research is essential to comprehensively grasp the impact of traditional farming methods on profitability and sustainability in agriculture. The study underscores the profitability of mixed farming. It underscores the influence of income levels on technology adoption, emphasizing the need to tailor strategies to the local context for sustainable rural development. These invaluable insights have the potential to shape policy decisions and drive initiatives that foster more sustainable and prosperous agricultural communities.

CRediT Author Statement: Nikhil Prathapachandran: Conceptualization, Data curation, Project administration, Writing – original draft, Visualization, Investigation, Formal Analysis; **Varuvel Devadas:** Supervision, Validation, Methodology, Writing – review & editing.

Data Availability Statement: Not applicable.

Funding: Please add: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Acknowledgments: Not applicable.

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