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Systematic Review of Agricultural Systems and Sustainability Challenges in Caraga Region (Region XIII) of Northeastern Mindanao, Philippines

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ABSTRACT: The objective of this paper is to undertake a systematic review of agricultural systems and sustainability challenges in Caraga Region (Region XIII) of Northeastern Mindanao, Philippines using appropriate standard methods involving a comprehensive analysis of peer-reviewed literature, government reports, and statistical data, focusing on six key dimensions: geographical distribution of research, agricultural commodity assessment, farming practices evaluation, challenges analysis, policy intervention assessment, and sustainability framework development. The result shows a higher density of research in Agusan del Sur and Surigao del Sur, and comparatively little research is done in Dinagat Province. Rice is the most dominant agricultural commodity, and distinct farming practices, from conventional upland rice production to advanced techniques, such as rice-duck farming, have been identified, showing enhanced productivity and ecological efficiency. Critical challenges affecting agricultural sustainability include climate vulnerability, problems with market access, environmental degradation, especially in the Agusan Marsh, and gender relations in farming activities and access to agricultural resources. Analysis of policy interventions reveals that climate-resilient agriculture, improved market infrastructure, enhanced extension services, and gender-sensitive programs are essential for sustainable development. The study proposes an integrated framework emphasizing climate adaptation strategies, market development initiatives, environmental protections, and capacity-building programs. Future research directions should address geographical gaps, particularly in Dinagat Province, and focus on developing comprehensive solutions considering the interconnected nature of agricultural challenges in Caraga.

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Caraga Region XIII in Northeastern Mindanao, Philippines, represents a complex agricultural landscape predominantly characterized by smallholder farming populations across Agusan del Norte and Sur, Surigao del Norte and Sur, and Dinagat Province. Encompassing 18,846.97 square kilometers and covering 6.3% of the Philippine territory, the region maintains a balanced land use between forestry (31.36%) and agriculture (23.98%), though facing pressures on its agricultural systems and productivity (DTI, 2024). The agricultural sector in Caraga have distinct characteristics that set it apart from other Philippine regions yet faces significant challenges. In 2021, palay (rice) production declined by 7.07%, driven by a 5.25% decrease in harvested Riceland and a 1.92% reduction in per-hectare yield. Simultaneously, the livestock and fisheries sectors encountered setbacks due to disease outbreaks like

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Avian Influenza and African Swine Fever (ASF), with Typhoon Odette further complicating productivity and market stability (PSA, 2021).

The region's agricultural landscape supports a diverse commodity, including rice, corn, coconut, banana, various fruits and vegetables, and plantation crops (Mercado, 2015; Austral and Cablinda, 2015; Carandang *et al*., 2015; Baldelovar *et al*., 2019; Nacorda *et al*., 2019; Varela *et al*., 2022). Caraga produces more than 80 percent of the Philippines' soybean output (Dela Cruz and Neric Jr, 2016), while its tilapia production is a key protein source for households with limited spending power (Rayos *et al*., 2019). However, these agricultural systems face mounting pressures from climate change, market access limitations, and structural challenges threatening their sustainability. Climate vulnerability emerges as a primary concern, revealing significant hazards, including flooding, drought, and tropical cyclones impacting agricultural productivity. Research in Agusan del Norte demonstrates substantial risks to rice production, with some areas experiencing inundation for 2-3 months annually (Varela *et al*., 2022). These challenges are compounded by structural factors like limited market access, inadequate post-harvest facilities, and environmental pressures (Mercado, 2015, 2018; Piepiora *et al*., 2016; Varela *et al*., 2022). Notably, Dinagat Province, a mineral-rich area with specific environmental challenges, needs to be more represented in agricultural research (Gagula *et al*., 2024; MGB-13, 2019).

Given these complex challenges, this study systematically examines the agricultural systems and sustainability prospects of the Caraga Region through six primary objectives: (1) geographical mapping of agricultural research, (2) evaluation of the major agricultural commodities and the focus of the research done on them, (3) evaluation of the best farming practices, (4) identification of critical challenges affecting productivity and sustainability of agriculture in the region, (5) review of the policy interventions, and (6) proposal of a sustainable framework suitable for the region's context. Hence, the objective of this paper is to undertake a systematic review of the agricultural systems and sustainability challenges in the Caraga Region (Region XIII) of Northeastern Mindanao, Philippines

MATERIALS AND METHODS

Systematic search strategy: A comprehensive literature search was conducted to collect research articles, reports, and studies on agricultural systems and sustainability in the Caraga Region, Philippines. Databases searched included Google Scholar, ScienceDirect, JSTOR, and Philippine-based repositories. The search covered publications from inception through 2024, focusing on relevant agricultural commodities, climate adaptation, policy interventions, and regional sustainability efforts.

Search strategy and keywords: The following search strings were implemented: ("Agricultural Systems" OR "Sustainability" OR "Climate Resilience" OR "Climate Adaptation") AND ("Caraga Region" OR "Philippines" OR "Northeastern Mindanao"). Boolean operators (AND, OR) were applied to refine the results, ensuring relevant studies across commodity analysis themes, farming practices, and policy impact.

Eligibility criteria: The review incorporated empirical research, case studies, and mixed-method analyses specific to Caraga's agricultural sector. Studies were published in English and focused on the Caraga region's farming practices, climate issues, and policy frameworks. Studies not centered on Caraga or not addressing agricultural sustainability, climate adaptation, or policy relevance were excluded. Additionally, review articles and opinion pieces without original empirical data were excluded from the analysis.

Study selection and quality assessment: Following a PRISMA approach, initial search results were screened for eligibility by title and abstract. The initial database searches yielded 92 articles, of which 31 met the inclusion criteria after preliminary screening. Following the initial screening, forward and backward citation chaining was performed on these 30 articles to identify additional relevant studies. Backward citation chaining involved screening the reference lists of all included articles to identify older studies meeting our inclusion criteria. Forward citation chaining was conducted using Google Scholar and Web of Science to identify newer publications that had cited our included articles. This citation-chaining process yielded an additional 10 articles for screening, of which 2 met our inclusion criteria, bringing the total number of included studies to 33. Relevant studies were then thoroughly reviewed to ensure alignment with the study's scope. Data extraction was conducted using MS Excel to organize information, capturing study characteristics (authors, year, focus area, methodology), agricultural commodities, challenges, and policy responses highlighted in each study. The extraction also documented climate adaptation strategies, policy evaluations, and geographic distribution of research attention in Caraga.

Evidence synthesis and analysis: Qualitative and quantitative data were synthesized using narrative synthesis and thematic analysis methods. Thematic analysis identified recurring patterns and themes across farming practices, sustainability challenges, and policy impacts, focusing on qualitative insights from case studies. Quantitative data were tabulated to summarize trends and frequency across commodities and challenges.

RESULTS AND DISCUSSION

Distribution of agricultural research: Agricultural research studies in the Caraga Region demonstrate an uneven distribution across different geographic locations as detailed in Figure 1. The 33 included articles underwent comprehensive data extraction and analysis, representing research conducted between 2013 and 2024, with the majority of studies (75%) published in the last five years. These articles encompassed various research methodologies, including quantitative surveys, qualitative case studies, and mixed-method approaches. The Single-province studies indicate a higher concentration of research in Agusan del Sur and Surigao del Sur, with moderate research attention in Agusan del Norte and Surigao del Norte, while Dinagat Province needs to have documented studies. This distribution pattern suggests varying research priorities or accessibility among provinces. The presence of region-wide studies indicates efforts to understand agricultural systems at a broader scale, while studies linking Caraga with other regions demonstrate attempts to establish comparative analyses. Cross-provincial research between adjacent provinces like Agusan del Sur with Surigao del Sur, Agusan del Norte with Surigao del Norte, and Agusan del Sur with Agusan del Norte reflects efforts to understand agricultural patterns across provincial boundaries.

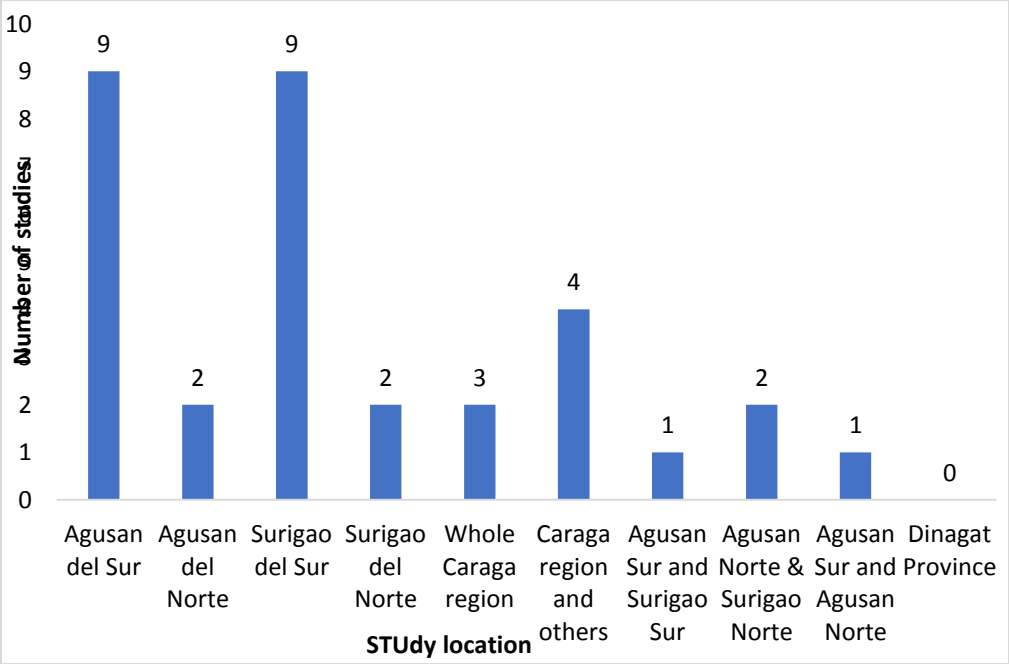

Fig. 1: Geographical distribution of agricultural research studies across Provinces in the Caraga region

Agricultural commodities: Agricultural research data in the Caraga Region shows it has centered on diverse commodities, with rice emerging as the most studied agricultural product, followed by fish (Table 1). The secondary research focus includes tilapia, soybeans, and vegetables. The prominence of rice studies reflects its significance as a staple crop and its central role in the region's agricultural research landscape. Fisheries research, encompassing both capture and aquaculture studies, indicates the importance of aquatic resources in the region, influenced by Caraga's geographical features including its coastal areas and inland waters. Studies also cover various crops and livestock, suggesting the presence of integrated farming systems in the region. Research attention to commercial crops such as oil palm, rubber, and coconut demonstrates Caraga's participation in broader agricultural market systems beyond subsistence farming.

Table 1: Major agricultural commodities in the Caraga region and corresponding research sources

Agricultural Commodity	Study References
Rice	Varela *et al*., 2022; Varela and Gapud, 2013; Pacamalan, 2016; Doloriel, 2023; Nacorda *et al*., 2019; Sarmiento *et al*., 2013; Austral and Cablinda, 2015; Baldelovar *et al*., 2019
Corn	Varela *et al.*, 2022; Dela Cruz and Neric Jr, 2016; Baldelovar *et al.*, 2019
Banana	Varela *et al*., 2022; Austral and Cablinda, 2015
Tilapia	Rayos *et al*., 2019; Baclayo *et al*., 2020; Formento *et al*., 2023
Soybean	Dela Cruz and Neric Jr, 2016; Balanay and Laureta, 2021; Mercado, 2015
Ducks	Pacamalan, 2016
Swine	Armenia *et al.*, 2016
Goats	Baldelovar *et al*., 2019
Buffalo	Escarlos *et al*., 2016
Native Pig	Artiza *et al*., 2022
Falcata (timber crop)	Carandang *et al*., 2015
Rubber	Carandang *et al*., 2015; Furoc-Paelmo *et al.*, 2018
Abaca	Matildo, 2023; Mercado, 2015, Sagocsoc, 2023
Vegetables	Austral and Cablinda, 2015; Dorado *et al*., 2018; Mercado, 2018
Tree Crops	Peras *et al*., 2020
Oil Palm	Hambloch, 2022
Fish (General)	De Guzman *et al*., 2015; Gascon *et al*., 2023; Macusi *et al*., 2023; Alapan *et al*., 2016
Blue Swimming Crab	Gascon *et al*., 2023
Mangrove Crab	Cai *et al*., 2021
Mangroves	Tomaquin-Malong, 2014; Odtojan *et al*., 2023
Coconut	Serato *et al*., 2024; Mercado, 2015

Prevailing farming practices: Research in the Caraga region reveals rice farming as the most extensively studied agricultural practice, with numerous studies examining rice cultivation, pest management, and production systems (Table 2). Small-scale fisheries also receive considerable focus, addressing aquatic resources such as blue-swimming crabs and fishing activities in the Agusan Marsh. Multiple studies document backyard animal raising, encompassing swine, native pigs, buffalo, chicken, and carabao, underscoring its role in local livelihoods. Crop diversification, tilapia farming, and tree farming with agroforestry systems are each covered by a range of studies, reflecting efforts to diversify and sustain agricultural productivity. Research on soybean and coconut farming, as well as on aquaculture, agrochemical use, and vegetable gardening, highlights various approaches to enhancing productivity in these sectors. Livelihood programs, mangrove management, and rubber-based agroforestry systems are each covered in separate studies, demonstrating efforts to integrate environmental management with income generation.

Unique farming practices in the region include integrated rice-duck farming and contract oil palm farming, each documented in single studies. Post-harvest practices and market dynamics are discussed across multiple commodities, with emphasis on challenges and opportunities in swine, coconut, and general market systems. Pest and disease control practices across crops, including rice, rubber, and buffalo, are explored in various studies, detailing both conventional and innovative management strategies. Specific animal-raising practices, such as swine, buffalo, and native pig production, receive focused attention, illustrating the diversity of animal husbandry practices in the region. Additional studies highlight climate-resilient agriculture and women-led farming and fisheries, indicating emerging interest in sustainable and inclusive farming practices. Research on integrated farming systems, which combine diverse agricultural activities and livelihood diversification strategies, further illustrates the adaptive approaches adopted by local farmers. Mangrove management practices, including conservation and resource management, are also documented, reflecting an awareness of ecological preservation in farming practices. Finally, studies on agricultural technologies and management practices emphasize ongoing efforts to improve efficiency and resilience across Caraga's farming systems.

Challenges in regional farming practices: Agricultural systems in the Caraga region face diverse challenges impacting both productivity and sustainability (Table 3). Climate-related issues, including flooding, drought, and typhoons, are significant disruptors across sectors, affecting crop production, tilapia farming, and rubber agroforestry. The overuse of agrochemicals, particularly pesticides, herbicides, and fungicides, is prevalent in rice

farming, leading to environmental concerns and increased production costs. Effective pest and disease management also remains a challenge, with limited resources for veterinary and crop disease prevention across rice, buffalo, and abaca farming. Market access and price instability are common issues for Caraga's agricultural producers. Farmers of oil palm, coconut, swine, and vegetables often struggle with market access and receive low prices influenced by intermediaries or agribusiness-controlled contracts, limiting income stability. Infrastructure and post-harvest facilities are insufficient for coconut and soybean production, affecting the quality and marketability of produce. Additionally, financial constraints limit access to resources for farmers across sectors, with low income and poverty levels documented among fishers, smallholder tree farmers, and upland rice farmers. Environmental degradation poses further challenges, with siltation affecting Agusan Marsh, habitat loss around Lake Mainit, and deforestation from oil palm farming. Overfishing, as seen with immature fish species in Agusan Marsh, adds to resource strain, while gender-related disparities persist across fisheries, native pig farming, and abaca craft production. Gaps in technical knowledge further impact productivity in swine raising, buffalo disease management, and abaca crafts. Social. and economic inequities, limited water management for rain-fed communities, and competition among vendors exacerbate the challenges facing Caraga's agricultural systems. Invasive species and health issues, such as schistosomiasis in rice farming, add complexity to the region's agricultural landscape. Addressing these persistent challenges requires comprehensive interventions across climate resilience, sustainable practices, market access, and support for underrepresented groups in agriculture.

Table 2: Common farming practices in the Caraga region and supporting research

Farming Practice	Study References
Rice Farming	Varela *et al*., 2022; Varela and Gapud, 2013; Pacamalan, 2016; Doloriel, 2023; Nacorda *et al*., 2019; Sarmiento *et al*., 2013; Austral and Cablinda, 2015; Baldelovar *et al.*, 2019
Crop Diversification	Doloriel, 2023; Austral and Cablinda, 2015; Furoc-Paelmo *et al*., 2018
Integrated Rice-Duck Farming	Pacamalan, 2016
Soybean Farming	Dela Cruz and Neric Jr, 2016; Balanay and Laureta, 2021
Fish Farming (Tilapia)	Rayos *et al*., 2019; Formento *et al.*, 2023
Small-Scale Fisheries	De Guzman *et al.*, 2015; Macusi *et al*., 2023; Gascon *et al*., 2023; Alapan *et al.*, 2016
Aquaculture and Pond-Based Farming	Formento *et al*., 2023; Rayos *et al*., 2019
Agrochemical Use in Farming	Nacorda *et al*., 2019; Balanay and Laureta, 2021
Contract Farming	Hambloch, 2022 (oil palm)
Tree Farming and Agroforestry and Abaca	Peras *et al*., 2020; Carandang *et al.*, 2015; Furoc-Paelmo *et al*., 2018; Sagocsoc, 2023
Upland Farming	Doloriel, 2023
Backyard Animal Raising	Armenia *et al.*, 2016 (swine); Artiza *et al*., 2022 (native pigs); Escarlos *et al*., 2016 (buffalo); Austral and Cablinda, 2015 (chicken, swine, carabao)
Vegetable Farming (Backyard Gardens)	Dorado *et al.*, 2018; Mercado, 2018
Coconut Farming	Serato *et al*., 2024; Mercado, 2015
Livelihood Programs and Livelihood Diversification	Tomaquin-Malong, 2014 (mangrove reforestation, goat dispersal, seaweed farming); Austral and Cablinda, 2015 (off-farm livelihoods)
Mangrove and Coastal Resource Management	Tomaquin-Malong, 2014 (mangrove reforestation); Odtojan *et al*., 2023 (mangrove conservation and harvesting)
Rubber-Based Agroforestry Systems	Carandang *et al*., 2015; Furoc-Paelmo *et al*., 2018
Swine Raising	Armenia *et al.*, 2016
Buffalo Raising	Escarlos *et al*., 2016
Native Pig Raising	Artiza *et al*., 2022
Fishing Practices	De Guzman *et al.*, 2015; Gascon *et al*., 2023 (blue swimming crabs); Baclayo *et al*., 2020 (Agusan Marsh)
Post-Harvest and Market Practices	Dela Cruz and Neric Jr, 2016; Hambloch, 2022; Armenia *et al.*, 2016 (swine); Mercado, 2015 (coconut); Sagocsoc, 2023 (abaca)
Climate-Resilient Agriculture	Varela *et al*., 2022
Pest and Disease Control	Varela and Gapud, 2013 (rice pest management); Furoc-Paelmo *et al*., 2018 (rubber pest management); Nacorda *et al*., 2019 (pesticide use); Escarlos *et al.*, 2016 (buffalo disease control)
Women-Led Farming and Fisheries	Macusi *et al.*, 2023 (fisheries)

Regional gaps and concentration in agricultural research: The uneven distribution of agricultural research in the Caraga Region reflects research concentration patterns and gaps. This distribution pattern suggests focused research attention in specific areas due to agricultural system diversity or pressing challenges. The absence of studies on Dinagat Island raises particular concern given its environmental challenges, with only 1.27% of its land suitable for abaca plantations and over half of its territory covered by mining claims (Gagula *et al*., 2024; MGB-13, 2019; Asuncion, 2023, Sagocsoc, 2023). This research gap could reflect either minimal agricultural activity or systematic research neglect. Limited region-wide studies indicate a need for comprehensive research approaches, while the scarcity of cross-provincial studies suggests gaps in understanding interconnected farming systems.

Table 3: Challenges and issues affecting farming practices in the Caraga region

Issue/Concern	Details	Study References
Climate-Related Issues	(Flooding, drought, and typhoons affecting agricultural productivity); (floods, droughts, temperature fluctuations affecting tilapia farming); (climate impacts on rubber agroforestry); (unpredictable weather affects fiber drying)	Varela *et al*., 2022, Formento *et al.*, 2023, Furoc-Paelmo *et al*., 2018; Sagocsoc, 2023
Overuse of Agrochemicals	(overuse of pesticides, herbicides, fungicides, molluscicides in rice farming); (heavy reliance on fertilizers and herbicides in rice farming)	Nacorda *et al*., 2019; Sarmiento *et al*., 2013
Pest and Disease Management	(rice pest management through habitat connectivity); (buffalo surra disease); (abaca disease "ugpong")	Varela and Gapud, 2013; Escarlos *et al*., 2016; Matildo, 2023
Market Access and Price Instability	(low prices for oil palm); (coconut price fluctuations); (low prices for swine products); (market competition for vegetable vendors); (marketing is heavily trader-controlled)	Hambloch, 2022; Mercado, 2015; Armenia *et al.*, 2016; Mercado, 2018; Sagocsoc, 2023
Infrastructure and Post-Harvest Challenges	(lack of threshers, dryers, storage facilities for soybeans); (insufficient infrastructure for coconut production); (abaca fiber not adequately dried)	Dela Cruz and Neric Jr, 2016; Mercado, 2015; Sagocsoc, 2023
Limited Access to Financial Resources	(smallholder tree farmers dependent on purchase order holders); (limited access to microfinance for rice farmers); (lack of capital for swine raising)	Peras *et al*., 2020; Sarmiento *et al.*, 2013; Armenia *et al*., 2016
Low Income and Poverty	(low income among Lake Mainit fishers); (smallholder tree farmers remaining poor); (upland rice farmers facing economic hardships); (low income among vegetable vendors)	De Guzman *et al.*, 2015; Peras *et al*., 2020; Doloriel, 2023; Mercado, 2018
Environmental Degradation	(siltation from upland farming and illegal logging affecting Agusan Marsh); (habitat degradation around Lake Mainit); (deforestation from oil palm farming)	Baclayo *et al*., 2020; De Guzman *et al*., 2015; Hambloch, 2022
Overfishing and Resource Exploitation	(overfishing of immature fish species in Agusan Marsh); (blue swimming crab overexploitation)	Baclayo *et al*., 2020; Gascon *et al.*, 2023
Gender Issues and Women's Involvement	(limited recognition of women's roles in fisheries); (gender roles in native pig farming); (abaca craft production primarily led by women)	Macusi *et al*., 2023; Artiza *et al*., 2022; Matildo, 2023
Lack of Technical Knowledge and Training	(lack of training for swine raisers); (low knowledge about surra disease in buffalo raising); (lack of procedural knowledge in abaca craft production)	Armenia *et al.*, 2016; Escarlos *et al.*, 2016; Matildo, 2023
Social and Economic Inequities	(inequitable distribution of income from tree farming); (economic challenges in oil palm cooperatives); (poverty among small-scale fishers)	Peras *et al*., 2020; Hambloch, 2022; De Guzman *et al*., 2015
Water Management Issues	(lack of irrigation in rain-fed communities); (water quality degradation in Agusan Marsh); (pond water management in tilapia farming)	Austral and Cablinda, 2015; Baclayo *et al.*, 2020; Formento *et al*., 2023
Competition in Local Markets	(mobile fish liner system creating competition for fixed market vendors); (competition among street vegetable vendors)	Rayos *et al*., 2019; Mercado, 2018
Invasive Species	(invasive janitor fish in Agusan Marsh threatening native species)	Baclayo *et al.*, 2020
Health and Public Safety	(schistosomiasis reduced through rice-duck farming system); (buffalo surra disease posing financial losses and health concerns)	Pacamalan, 2016; Escarlos *et al.*, 2016

Significance and implications of key agricultural commodities: Rice studies' dominance in agricultural research aligns with its significance in the Philippines, serving as the main food source for the population and supporting the agriculture sector (German *et al.,* 2022). This commodity significantly contributes to Filipinos' caloric intake and farmer income (Mamiit *et al*., 2021). Research focus on

fisheries reflects the region's geographical advantages, with its coastal areas and inland waters contributing to employment, food security, and trade opportunities (Rabo *et al*., 2014). The region's marine biodiversity benefits from its location, bordering multiple seas and irregular coastlines (PhilAtlas, 2019; DTI, 2024). The presence of inland water bodies and suitable irrigation systems (Apdohan, 2021; Solania and Fernandez-Gamalinda, 2018) further supports agricultural diversity. Studies on integrated farming systems and cash crops indicate the region's potential for agricultural development beyond subsistence farming, suggesting opportunities for improved productivity through crop-livestock integration and market system participation.

Climate-adapted cropping systems and vulnerability mapping: Climate-resilient agriculture (CRA) emerges as a critical approach for addressing climate-related challenges in agricultural systems. Varela *et al*. (2022) and Formento *et al*. (2023) emphasize that CRA strategies are essential for mitigating the negative impacts of climate change, particularly in regions experiencing variable weather conditions. In the Caraga Region, where climate variability significantly impacts agricultural productivity, implementing CRA approaches could enhance farming system resilience. This suggests the need to restructure traditional farming methods and develop climate-adaptive strategies tailored to Caraga's specific environmental conditions. Adjusted cropping systems require innovative approaches to resource management and soil health. Yasodha *et al*. (2023) demonstrate the effectiveness of integrating synthetic chemicals, organics, and biofertilizers for efficient resource utilization while preserving soil quality. For Caraga's agricultural landscape, this integration could address soil degradation issues while optimizing resource use in various cropping systems. The implementation of these practices should focus on developing location-specific fertilizer recommendations and promoting organic farming techniques that suit Caraga's soil conditions and crop varieties. Zuma *et al*. (2023) further support this through their research on site-specific nutrient management (SSNM) and the use of plant-based products (PBPs) and microbials (MPBs), suggesting that Caraga farmers could benefit from adopting these sustainable alternatives to conventional inputs.

Climate risk vulnerability mapping provides essential data for targeted adaptation strategies. Apdohan, (2021) apply geospatial analysis to identify vulnerable municipalities in Agusan del Norte, Philippines, by evaluating climate hazard exposure and adaptive capacity. This approach could be expanded across the Caraga Region to identify areas most susceptible to climate impacts and prioritize intervention measures. Parker *et al*. (2019) complement this with their documentation of declining crop suitability in climate-vulnerable regions, indicating the need for Caraga to develop comprehensive vulnerability maps that guide crop selection and resource allocation decisions. These mapping efforts should be integrated into regional agricultural planning to enhance climate risk management. Local context significantly influences vulnerability assessment and adaptation planning effectiveness. Nadeem *et al*. (2022) illustrate this through their development of district-level climate vulnerability maps in Punjab province, incorporating socio-economic and biophysical factors. Applied to Caraga, this approach could help identify specific areas requiring targeted interventions based on local environmental and socio-economic conditions. The region should invest in developing detailed vulnerability assessments that consider unique local characteristics, enabling more effective climate adaptation strategies and resource allocation. The research on adjusted cropping systems and climate vulnerability mapping indicates the need for integrated approaches to agricultural resilience in Caraga. Regional agricultural policies should prioritize the development of climate-resilient farming systems while utilizing vulnerability mapping to guide adaptation efforts. Recommendations include establishing a comprehensive vulnerability mapping system, implementing locally adapted cropping adjustments, and developing capacity-building programs that enable farmers to adopt climate-smart agricultural practices. These interventions should be supported by regular monitoring and assessment to ensure their effectiveness in enhancing Caraga's agricultural sustainability and climate resilience.

Integrated pest management and veterinary health services: Integrated Pest Management (IPM) and veterinary services constitute essential components of agricultural sustainability in regions facing pest management challenges. Nacorda *et al*. (2019) and Sarmiento *et al*. (2013) document the prevalence of agrochemical overuse and pest management issues in the Caraga region, advocating for IPM adoption. For Caraga's agricultural sector, transitioning to natural pest control methods could reduce chemical dependency while maintaining crop productivity. This shift requires developing comprehensive IPM programs that integrate traditional knowledge with modern ecological approaches. Eco-engineering techniques offer effective strategies for sustainable pest management. Ali *et al.* (2019) demonstrate how

planting nectar-rich flowering plants enhances biocontrol agent activity in rice fields, significantly reducing pest populations while maintaining yields. These findings suggest potential applications in Caraga's rice-growing areas, where similar ecological approaches could reduce pesticide dependency. Implementation should focus on identifying locally suitable flowering plants and developing guidelines for their integration into existing farming systems. Akter *et al.* (2018) further support this through research on habitat management, suggesting that Caraga farmers could benefit from adopting diverse landscapes, crop rotation, and intercropping practices.

Biological control methods provide sustainable alternatives to chemical pest management. Sanda and Sunusi, (2014) outline various strategies, including conservation, classical, and augmentation biological control, emphasizing the effectiveness of natural enemies and microbial agents like *Bacillus thuringiensis*. In Caraga's context, these approaches could be adapted to local pest challenges and farming conditions. Recommendations include establishing biological control programs, training farmers in natural enemy conservation, and developing regional facilities for producing microbial control agents. Veterinary service improvement plays a crucial role in livestock health management. Varela and Gapud, (2013) and Escarlos *et al*. (2016) highlight the importance of controlling diseases like surra in Caraga's buffalo populations. For effective implementation in Caraga, Ilukor, (2017) recommendations on strengthening institutional arrangements between professional veterinarians and para-professionals should be considered. The region should prioritize expanding veterinary extension services, enhancing disease reporting systems, and increasing government support for extensive livestock production systems. The integration of IPM strategies and improved veterinary services requires coordinated policy implementation in Caraga. Regional agricultural policies should focus on developing IPM training programs, establishing biological control infrastructure, and strengthening veterinary service networks. Recommendations include creating demonstration farms for IPM techniques, establishing regional pest monitoring systems, and developing capacity-building programs for both crop and livestock sectors. These interventions should be supported by regular assessments of their effectiveness in reducing chemical inputs and improving animal health outcomes.

Strengthening cooperatives, market access, and price stability mechanisms: Price stabilization and market infrastructure require targeted interventions in the Caraga Region's agricultural sector. Studies highlight the necessity of price stabilization policies for coconut and oil palm commodities (Hambloch, 2022; Mercado, 2015, 2018), while the development of farmer cooperatives reduces middlemen dependency (Armenia *et al.,* 2016). These findings suggest that Caraga needs to strengthen its cooperative systems and implement price protection mechanisms for smallholder farmers. Market organization and infrastructure development play crucial roles in agricultural sustainability. Research from India demonstrates how unorganized market systems limit smallholders' capacity to meet urban consumer demands, suggesting solutions through direct linkages and electronic sales platforms (Pingali *et al*., 2019). Evidence from Mozambique shows that improved transportation infrastructure reduces regional price disparities (Jones and Salazar, 2021). For Caraga, this implies the need for enhanced transportation networks and organized market systems to support smallholder farmers' market access and reduce regional trade barriers. Information systems and stakeholder cooperation emerge as critical factors for market efficiency. Studies show that reduced reliance on intermediaries effectively mitigates price fluctuations and enhances farmer economic security (Fudjaja *et al*., 2024). The implementation of ICT-based price information systems provides farmers with real-time price data, enabling fair trade practices (Rajon *et al*., 2014). These findings indicate that Caraga should prioritize the development of digital market information systems and strengthen cooperation between farmers and stakeholders to improve market outcomes and ensure sustainable agricultural practices.

Advancing mechanization, post-harvest facilities, and access to microfinance: Agricultural infrastructure development and financial access serve as fundamental drivers of agricultural progress as Dela Cruz and Neric Jr., (2016) and Sagocsoc, (2023) emphasize that investments in mechanization and post-harvest infrastructure are crucial for enhancing productivity and reducing post-harvest losses in the Caraga region. This observation is validated by evidence from multiple geographical contexts, demonstrating the universal importance of these interventions in agricultural development. Mechanization significantly impacts agricultural productivity and operational efficiency. In South Africa, Mdoda *et al*. (2022) document increased productivity and farm returns following agricultural mechanization implementation among smallholder farmers. These findings suggest that similar mechanization approaches in Caraga could enhance

farming operations while reducing labor demands. The research in Nigeria by Castelein *et al*. (2022) further supports this, showing that mechanization reduces not only post-harvest losses but also generates socio-economic benefits by freeing up labor and creating opportunities for rural youth. Post-harvest infrastructure development plays a crucial role in maintaining crop quality and reducing waste. Studies from Tanzania by Ngowi and Selejio, (2019) and Maziku, (2019) demonstrate that improved post-harvest storage technologies (IPHSTs) effectively minimize post-harvest losses (PHL). The implementation of advanced storage facilities and combined harvesters in Caraga could address significant post-harvest losses while contributing to food security and economic resilience. These studies emphasize that proper training in storage techniques and post-harvest handling optimizes infrastructure utilization. Financial support systems, particularly microfinance, demonstrate a substantial impact on agricultural development. Research from Zimbabwe by Mago and Hofisi, (2016) reveals that microfinance positively affects smallholders through enhanced asset accumulation, productivity, and agricultural education. This aligns with findings from Caraga by Peras *et al*. (2020) and Armenia *et al*. (2016), which confirm that microfinance programs and cooperatives contribute to income stabilization and increased market participation among farmers. Specifically, in Agusan del Sur, Sarmiento *et al*. (2023) report a 27% increase in production among microfinance clients compared to non-clients, demonstrating improved resource utilization through financial access. However, limited access to microfinance loans in the region indicates the need for expanded financial outreach to maximize the potential benefits for Caraga's agricultural sector.

Enforcing regulations on deforestation and unsustainable agriculture: Environmental concerns in agricultural policy frameworks require urgent attention, particularly regarding illegal logging and unsustainable farming practices in vulnerable ecosystems like the Agusan Marsh. Baclayo *et al.* (2020) and De Guzman *et al.* (2015) emphasize the need for stricter regulations and conservation-focused interventions. These local findings align with global research demonstrating the critical balance between agricultural expansion and environmental sustainability. Effective regulatory frameworks and enforcement mechanisms are essential for sustainable agricultural practices. Sotirov *et al*. (2022) examine how transnational trade policies and domestic regulations in Brazil address illegal and unsustainable agricultural practices, identifying political challenges and regulatory gaps that impede enforcement. These challenges parallel the situation in Caraga, where weak enforcement enables the persistence of illegal logging and unsustainable farming. The research suggests that combining international governance with local regulatory frameworks could strengthen conservation efforts and promote sustainable production in Caraga through the collaborative engagement of local stakeholders and national agencies. The gap between knowledge and implementation of sustainable practices presents a significant challenge. Kum *et al*. (2021) document in the Bamenda Highlands that despite farmers' awareness of sustainable methods, economic and practical barriers hinder their adoption. This study identifies crop rotation, intercropping, and legume integration as effective sustainable practices. Similar approaches could benefit Caraga through targeted farmer education and support programs that enable the transition to conservation-friendly methods while maintaining productivity. Sustainable agriculture practices offer solutions to environmental degradation caused by conventional farming. Saikanth *et al*. (2023) advocate for precision farming, agroecological practices, and renewable energy integration to reduce pollution, preserve biodiversity, and enhance soil health. These findings suggest that Caraga could benefit from policy frameworks that incentivize agroforestry and organic farming. The study emphasizes that public awareness and farmer training programs are essential for the widespread adoption of sustainable methods, indicating the importance of similar initiatives in Caraga to facilitate the transition to environmentally friendly practices while maintaining economic viability. Agricultural intensification poses significant environmental risks that require mitigation through sustainable practices. Majumder, (2023) identifies soil degradation, water depletion, and greenhouse gas emissions as key environmental costs of intensive agriculture. These concerns are particularly relevant to Caraga's vulnerable ecosystems. The research supports the implementation of sustainable farming practices such as reduced tillage, organic fertilizers, and biodiversity-friendly crop rotations to mitigate the environmental impact of intensified agriculture while protecting the region's unique ecosystems.

Promoting gender-sensitive agricultural programs: Gender-sensitive agricultural policies play a vital role in supporting women's contributions to agricultural development. Macusi *et al*. (2023) and Artiza *et al*. (2022) demonstrate that women who receive training and leadership opportunities contribute significantly to agricultural productivity and community resilience. These local findings align with global research, highlighting the transformative potential of

gender-sensitive agricultural programs. Cultural barriers and structural constraints limit women's participation in agricultural development. Meinzen-Dick *et al*. (2011) identify how cultural gender roles and male-dominated extension services undervalue women's contributions to agricultural productivity and poverty reduction. This mirrors the situation in Caraga, where women's substantial involvement in agricultural tasks contrasts with their limited access to resources, training, and decision-making positions. The research suggests that agricultural development frameworks should expand beyond production-focused models to recognize women's role in household food security, indicating the need for gender-sensitive research and extension services in Caraga's agricultural policies. Land ownership and resource access present significant challenges for women in agriculture. Singh *et al*. (2020) report that despite policy initiatives for joint leasing rights and resource access in India, substantial gender gaps persist in land ownership and agricultural input access. Similar cultural and structural barriers in Caraga restrict women's access to land ownership and financial support, limiting their economic empowerment and productivity. The implementation of policies ensuring secure land tenure, financial services, and training for women could enhance agricultural output and contribute to sustainable development in the region.

Gender dynamics significantly influence agricultural productivity and household nutrition outcomes. Malapit, (2019) emphasizes the importance of considering interactions between men and women in agricultural households rather than focusing solely on women's issues. This approach is particularly relevant to Caraga, where agricultural responsibilities are often shared between genders. The research supports the implementation of gender-sensitive programs that engage both men and women in training on nutrition-sensitive and climate-resilient agriculture to enhance household food security and climate resilience. Addressing gender disparities in resource access offers substantial potential for agricultural productivity gains. Manfre *et al*. (2013) data indicate that reducing gender gaps in land ownership, credit, and extension services could increase women's farm yields by 20-30%, potentially raising agricultural output in developing countries by 2.5-4%. These findings support Caraga's policy recommendations for gender-sensitive interventions, providing women with equal access to agricultural inputs and gender-specific credit programs could significantly enhance regional agricultural productivity and sector-wide benefits.

Scaling training programs and strengthening extension services: Technical capacity building and water management serve as fundamental components for sustainable agricultural development as Armenia *et al*. (2016), Matildo, (2023), Austral and Cablinda (2015), and Formento *et al*. (2023) collectively emphasize the necessity of expanded training programs, enhanced extension services, and investments in irrigation and conservation practices. These findings establish the critical role of knowledge transfer and resource management in agricultural sustainability. Extension services significantly impact agricultural productivity through knowledge dissemination and practical application. Raji *et al*. (2024) demonstrate the transformative role of extension services and innovative training programs in modernizing farming practices. Their research highlights successful models like Farmer Field Schools and India's e-Extension program, which have enhanced productivity and resilience. These approaches could be adapted for Caraga to bridge knowledge gaps and build technical capacity, particularly in regions where traditional farming methods face environmental and production pressures. Agricultural extension services demonstrate measurable improvements in technical efficiency. Kalogiannidis and Syndoukas, 2024) quantify the impact of extension programs, showing efficiency improvements of 4.8% to 7.6% through meta-regression analysis. The study reveals that program effectiveness varies by region, crop type, and program specifics, suggesting the need for tailored interventions in Caraga. Implementation of localized extension services, training workshops, and field demonstrations could optimize resource use and enhance adaptation to environmental changes in the region's agricultural sector. Training methodology and implementation significantly influence program success. Kalogiannidis and Syndoukas, (2024) identify that workshops, training, and demonstration farms enhance farm productivity when aligned with quality training, local relevance, and sustained support. For Caraga, this implies the need for customized training programs addressing specific crop types, soil conditions, and water management needs. The research supports establishing continuous learning structures and adapting techniques to local conditions, particularly in water management practices such as irrigation scheduling, rainwater harvesting, and soil moisture conservation. Water management practices play a crucial role in sustainable agricultural production. Austral and Cablinda (2015) and Formento *et al*. (2023) emphasize the importance of sustainable water use in agriculture, particularly relevant to Caraga's investment needs in irrigation infrastructure and

conservation practices. Their research indicates that techniques such as drip irrigation, mulching, and rainwater harvesting, promoted through demonstration projects and extension services, could reduce vulnerability to climate variability and protect agricultural yields. The findings from Armenia *et al.* (2016), Matildo, (2023), and global research supports a comprehensive approach to agricultural development in Caraga. This approach should integrate technical training, extension services, and water management innovations tailored to local conditions. Implementation of these research-based practices could enhance agricultural productivity, build farmer capacity, and strengthen climate resilience across the region.

Conclusion: This systematic review of agricultural systems in the Caraga Region reveals complex intersections between environmental challenges, socioeconomic factors, and policy interventions that collectively shape the region's agricultural sustainability. The analysis of studies demonstrate significant research disparities across the region's provinces, with concerning gaps in Dinagat Province despite its unique agricultural challenges. Future research should prioritize understudied areas, particularly Dinagat Province while focusing on the interconnections between climate resilience, market access, and social equity. Success in transforming Caraga's agricultural sector will depend on coordinated efforts between government agencies, research institutions, and local communities, supported by evidence-based policies and sustained investment in agricultural infrastructure and human capital development.

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