Sustainable Food Production Systems and Resilient Agricultural Practices in Sri Lanka

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Introduction

Agriculture in Sri Lanka is not just an economic activity; it is the very essence of the nation's identity, deeply intertwined with its culture, traditions, and livelihoods. For centuries, farming has been central to the social fabric, defining the rhythms of rural life. Today, agriculture in Sri Lanka remains crucial not only for food security but also as a key contributor to employment, engaging nearly 25% of workforce in agricultural activities. However, Sri Lanka's agricultural sector is grappling with an escalating set of challenges climate change, environmental degradation, soil erosion, water scarcity and other over-reliance on chemical inputs that hinder its ability to sustain productivity and long term viability. These interwoven issues threaten the delicate balance needed to balance both ecological health and agricultural output.

Why Agriculture Matters

Sri Lanka's agriculture sector makes up around 7% of the national GDP, with fisheries contributing 1.3% and livestock just 0.9%. Remarkably, over 30% of the population relies on agriculture for employment (Athukorala et al. 2023). However, despite the island's rich, fertile tropical landscape and its vast potential for cultivating and processing a wide range of crops, the sector faces significant challenges. Problems of low productivity and limited profitability continue to stall its progress, hindering its ability to fully thrive. The agricultural and allied sectors contributes approximately

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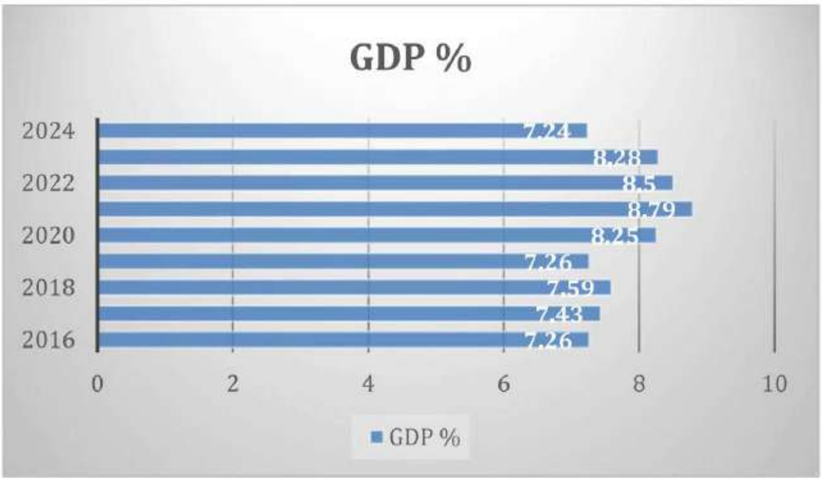

Fig. 1 Contribution of agriculture to Sri Lanka's GDP in % (*Source* DOA, 2024)

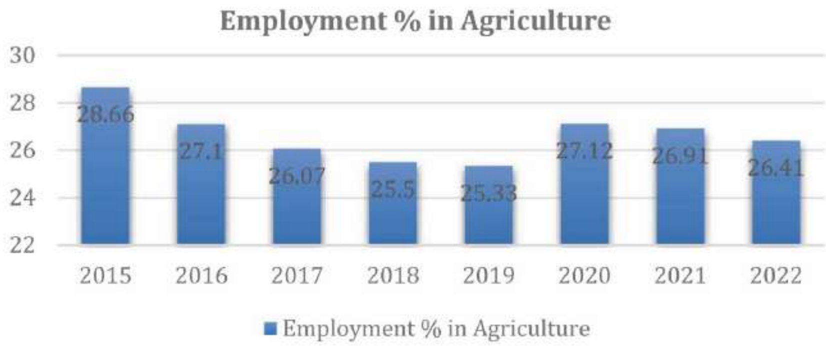

Fig. 2 Employment in agriculture, % of total employment (*Source* DOA, 2022)

7% to Sri Lanka's GDP, spanning a broad spectrum of crops, including rice, tea, rubber, and various fruits, vegetables, and livestock (Athukorala et al. 2023). These diverse agricultural activities not only sustain millions of livelihoods but also foster rural development by providing crucial income streams. Traditional farming techniques, such as the ancient tank systems, are emblematic of the country's agricultural heritage; yet modern challenges are placing immense strain on these long-standing structures (Figs. 1, 2 and 3).

Current Challenges

Agriculture in Sri Lanka now faces unprecedented challenges, many of which are driven by the forces of climate change. Rising temperatures, unpredictable rainfall, and extreme weather events have become more frequent, threatening both crop yields and food security (Samaraweera et al. 2024).The country's distinct climatic zones ranging from the rain-soaked wet zone to the arid dry zone are increasingly subjected

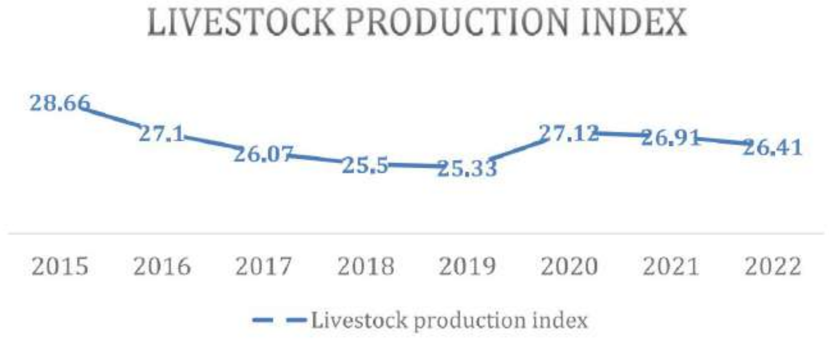

Fig. 3 Livestock production index (*Source* DOA, 2022)

to environmental degradation. Deforestation, soil erosion, and water pollution are compounding these issues, degrading the prime natural resources (Gunaratne et al. 2021).

Additionally, the overuse of chemical inputs has led to soil exhaustion and water contamination, while the expansion of farmland into forested areas is contributing to habitat destruction and increasing greenhouse gas emissions (Padukkage and Nanayakkara 2024). Economic pressures further exacerbate these environmental concerns, as farmers face volatile market prices, escalating production costs and limited access to modern technology and financing particularly in more remote regions.

The Need for Sustainability

In the face of such daunting obstacles, a transition towards sustainable food production systems is no longer just an option it is a necessity. Sustainable agriculture aims to meet the food needs of the present without compromising the ability of future generations to do the same. This approach balances the demands of food production with the need to conserve and restore critical ecosystems, building resilience in both human and environmental systems. Key areas of focus include:

- **Boosting Food Productivity**: By adopting innovative practices that raise yields while improving resource efficiency ensuring optimal use of water, soil and labor for maximum agricultural output.
- **Protecting Ecosystems**: Promoting soil conservation, sustainable water management, and biodiversity preservation.
- **Building Climate Resilience**: Developing climate-resilient crops and implementing disaster preparedness strategies.
- **Improving Land and Soil Health**: Utilizing methods that conserve and restore soil health, ensuring long-term agricultural sustainability.

What to Expect

This chapter will delve into various strategies designed to address these challenges and pave the way for a more sustainable agricultural future in Sri Lanka. It will examine how public–private partnerships, along with innovative policies and cutting-edge techniques (Figs. 4 and 5).

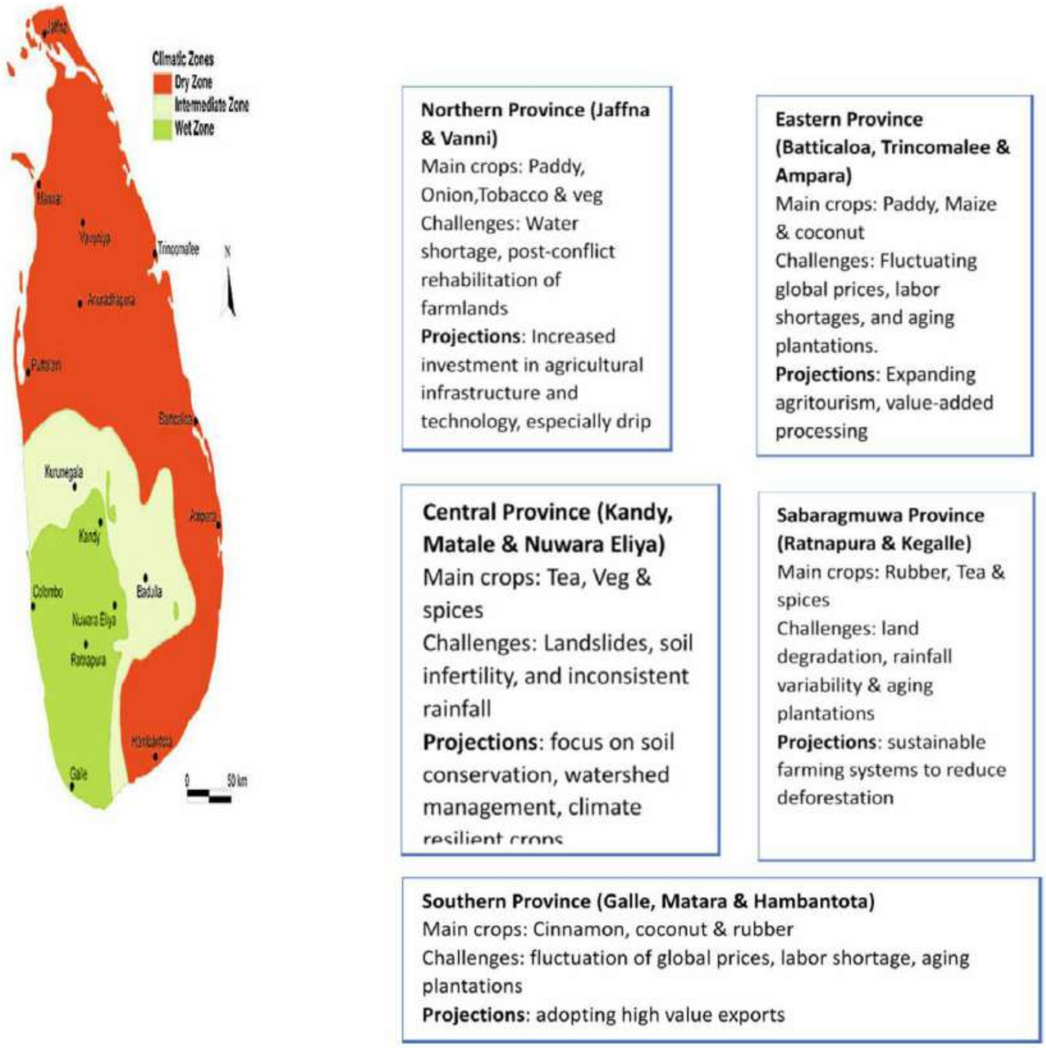

Fig. 4 Region-wise breakdown and projection related agriculture

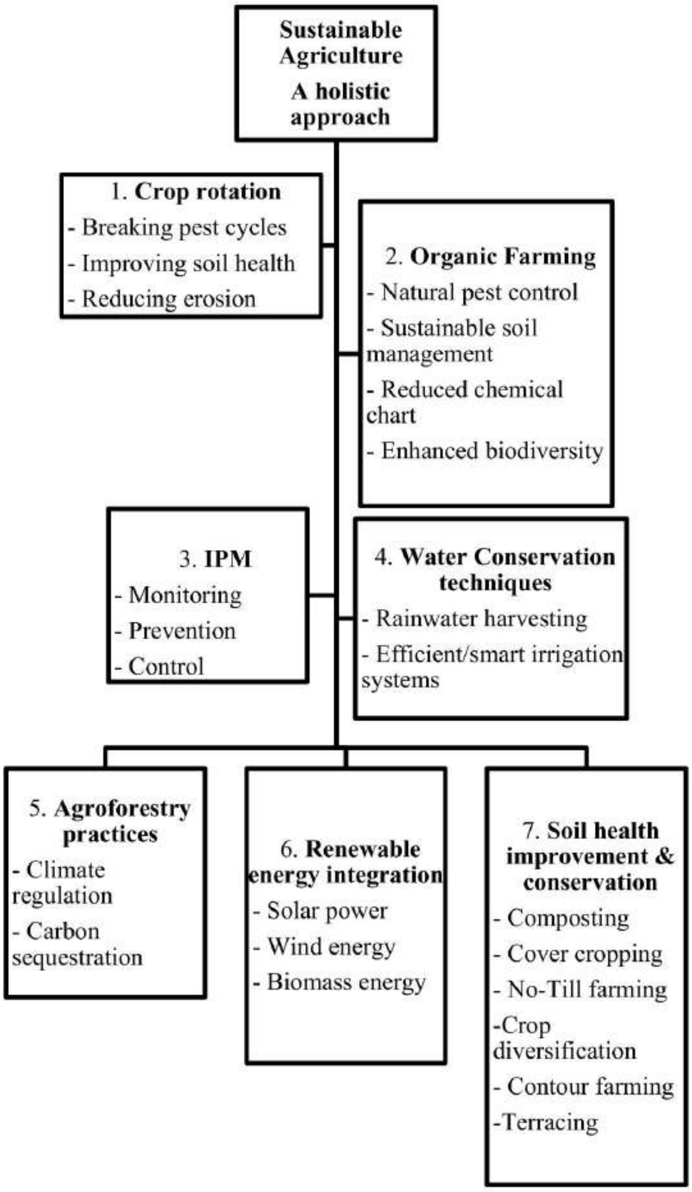

Fig. 5 Roots to sustainable agriculture

Strategies to Increase Food Productivity and Production

Sustainable Agricultural Intensification (SAI) focuses on increasing yields and improving land use efficiency on existing farmlands, without expanding agricultural areas or causing degradation (Merrey et al. 2018). While SAI aims for heightened efficiency and sustainability, it deliberately avoids contributing to deforestation or the conversion of forests into farmland, which is a pressing issue in Sri Lanka (Sooriyaarachchi and Shrestha n.d.). SAI seeks to find equilibrium rather than advocating for agricultural expansion: protecting the environment while meeting the growing food demands of society. This delicate balance is essential, ensuring that

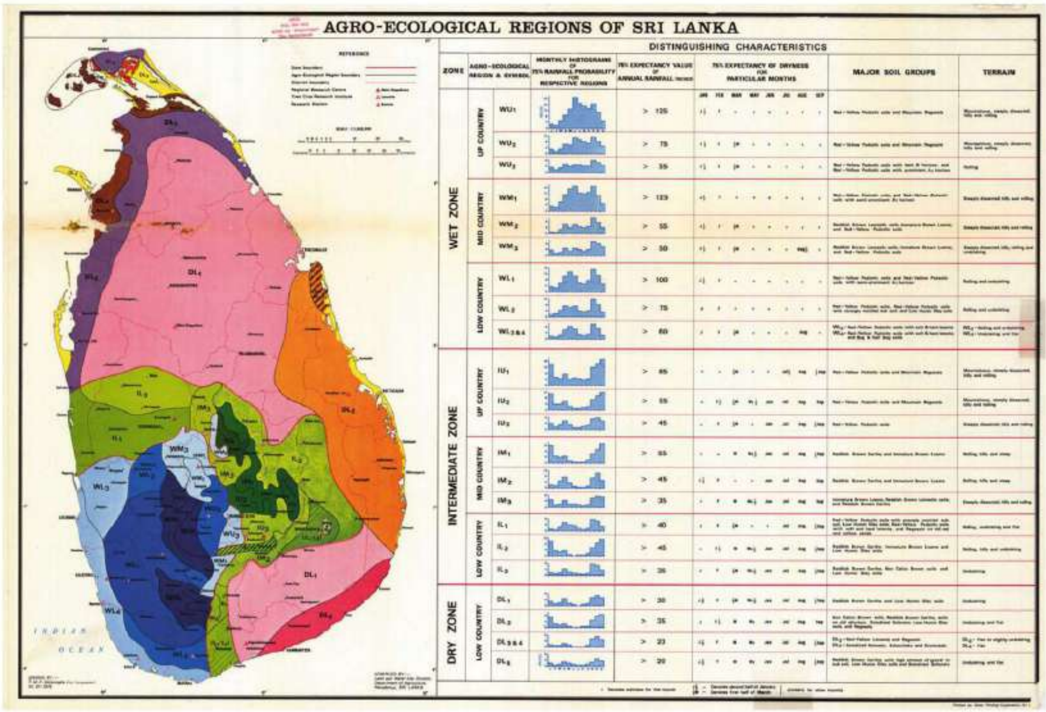

Fig. 6 Agro-ecological zones of Sri Lanka

agricultural advancement does not come at the cost of ecological integrity (Padukkage and Nanayakkara 2024) (Fig. 6).

Sustainable Agricultural Intensification (SAI)

Sustainable Agricultural Intensification (SAI) is at the heart of increasing food productivity in Sri Lanka, a method that not only improves yield but does so with a firm commitment to environmental protection (Padukkage and Nanayakkara 2024). By implementing SAI practices, Sri Lankan farmers are better positioned to achieve higher yields without expanding agricultural lands an increasingly critical goal in a country grappling with deforestation and land degradation (Merrey et al. 2018). One example is the high-yielding rice variety "BG 358," which showcases remarkable drought resistance while also minimizing reliance on harmful chemicals (Samaraweera et al. 2024; Gunaratne et al. 2021). This approach allows for up to a 20% increase in yields when coupled with modern farming practices, underscoring the importance of innovation in agriculture (Merrey et al. 2018).

Smart Irrigation Techniques

Water management in Sri Lanka is crucial for both present needs and future sustainability. With raising droughts and unpredictable rainfall, smart irrigation systems, including micro-irrigation technologies like drip and sprinkler systems, along with IoT-based systems for real time monitoring and control, are essential for farmers to optimize water usage efficiently (Namara et al. 2010). Drip irrigation systems deliver water directly to plant roots, significantly reducing evaporation and runoff, while sprinkler systems provide uniform water coverage, particularly effective in uneven terrains (Kumar and Palanisami 2010). Additionally, the practice of rainwater harvesting, collecting runoff, storing in water harvesting structures like farm ponds and efficient use of harvested rainwater later can reduce groundwater dependency, a critical adaptation in the face of climate change.

The Dam Safety and Water Resources Planning Project, an ongoing initiative supported by the World Bank, aids the Government of Sri Lanka (GOSL) in water resources planning, with a second phase projected for FY 2019 (Wang-LEGEA n.d.). A thorough study conducted by the Bank explored strategic options for water conservation, management, and development. The findings provided valuable insights into policy frameworks, institutional arrangements for water planning, emerging challenges in water management, and a priority framework for addressing sector needs. This initiative is critical for shaping Sri Lanka's water resource strategies moving forward (Wang-LEGEA n.d.).

Precision Agriculture and Technology Integration

The incorporation of precision agriculture technologies, such as drones for aerial field monitoring and soil moisture sensors, is transforming how farmers in Sri Lanka manage their fields. These drones offer real-time data, empowering farmers to make precise decisions regarding water distribution, fertilizer application, and pest control. With these technologies farmers can optimize their use of resources, reducing waste while boosting yields. This not only enhances efficiency but also significantly minimizes the environmental impact, striking a crucial balance between heightened productivity and sustainability. In essence, precision agriculture is revolutionizing the agricultural landscape, fostering smarter farming practices that benefit both the land and those who cultivate it (Priyankara et al. 2022).

The Climate Resilience Improvement Project (CRIP) in Sri Lanka has conducted hydraulic modeling for flood management across ten river basins, including Mahaweli Ganga, Malwathu Oya, and others (Kumari et al. n.d.). These results will enable the Climate Smart Irrigated Agriculture Project (CSIAP), especially in overlapping "hot-spot" areas, where flood management and drought mitigation can be strategically linked (Imbulana et al. 2023). By using excess floodwater for drought relief, both issues can be addressed in tandem. Additionally, the design of agricultural value chain analysis and marketing activities will draw on insights from the Agricultural Sector Modernization Project (ASMP), leveraging prior experiences for more efficient implementation (Sovis et al. 2020).

Traditional Knowledge and Water Management Systems

Sri Lanka's ancient dry zone irrigation clusters, known as "Tank Cascade Systems," are considered one of the most advanced water management systems of their time, dating back to the third century BC (Jayasena et al. 2011). The island is divided into wet and dry zones, with an intermediate zone in between the dry zone, characterized by limited water availability and high temperatures, relies on monsoon rains that last just two to three months annually (Menike and Arachchi 2016). To combat water scarcity, ancient communities in the dry lowlands had built tanks to harness runoff from the highlands, enabling to irrigate vast paddy fields. These tanks, predominantly in dry and intermediate zones with 900 to 1800 mm of annual rainfall, form interconnected cascades within minor or meso-catchments (Kekulandala et al. 2021). Over 12,000 operational tanks still exist, though many remain abandoned. Each meso-catchment covers an average of 21 km^2, storing and distributing water from ephemeral streams to sustain agriculture (Kekulandala et al. 2021). Moreover, the revivals of traditional water management systems, especially the ancient tank (wewa) networks, offer a powerful means to bolster climate resilience. These age-old structures, designed to efficiently store and distribute water, are not only effective but also deeply rooted in Sri Lanka's cultural heritage. By integrating these traditional systems with modern water management techniques, farmers can adopt a sustainable approach that honors the island's natural resources while enhancing agricultural productivity. This fusion of the traditional and modern water management technologies could build a resilient, adaptive framework that meets the challenges of today's changing climate simultaneously addressing the issues of ecological balance.

Policy Framework Supporting Sustainable Practices

Lastly, this chapter underscores the critical need for robust policy frameworks to unlock the full potential of sustainable farming practices in Sri Lanka. Government-led initiatives, such as the National Agriculture Policy and the Green Agriculture Strategy, serve as pivotal drivers in this effort (Zoysa and Inoue 2016). By offering incentives for farmers to diversify their crops and implement water-saving technologies, these policies are shaping the future of agriculture. Beyond national efforts, international collaborations like the Climate Resilience Improvement Project are also instrumental. These partnerships enhance disaster preparedness, introduce resilient crop varieties, and foster the adoption of climate-smart practices (Järnberg et al. 2021). Collectively, these strategies create a comprehensive and cohesive framework that not only boosts food productivity but also ensures the long-term sustainability of Sri Lanka's agricultural sector.

Maintaining Ecosystems and Biodiversity

Biodiversity and robust ecosystems stand as the bedrock of sustainable agricultural production systems. In Sri Lanka, a nation adorned with a rich tapestry of ecosystems ranging from the serene coastal wetlands to the lush canopies of tropical rainforests maintaining biodiversity within agricultural landscapes emerges as a critical necessity (Gunatilleke et al. 2017).This endeavor is not merely an environmental concern; it is crucial for reducing soil erosion, conserving water resources, and preserving biodiversity by implementing climate smart practices like drought resistant crops and efficient water management systems, strengthen resilience to climate change.

This chapter delves into a variety of strategies aimed at conserving biodiversity while simultaneously boosting agricultural output. We will explore the multifaceted approaches of conservation agriculture, the synergistic benefits of agroforestry, the principles of organic farming, and the sustainable management of livestock. Each of these methods offers unique pathways to harmonize agricultural practices with ecological integrity, fostering a landscape where both nature and farming can thrive in concert.

Conservation Agriculture

Conservation agriculture embodies a revolutionary farming paradigm, one that prioritizes minimal soil disturbance, the preservation of soil structure, and the enhancement of biodiversity (Pethiyagoda 2012). This climate-smart approach not only safeguards ecosystems but also champions sustainable productivity, weaving together ecological health and agricultural viability.

At its core, conservation agriculture is anchored by several key principles: minimum tillage, which gently nurtures the soil without excessive disruption; permanent soil cover, which acts as a protective blanket against erosion; and crop diversification, a strategy that enriches the landscape with a variety of plants, bolstering resilience (Jat et al. 2012). In the context of Sri Lanka's diverse agroecological zones where soil erosion and nutrient depletion pose significant challenges these principles become especially pertinent. They offer a pathway to rejuvenate the land, ensuring that agricultural practices align harmoniously with the ecological fabric of the region.

In rice–wheat cropping systems covering over 10 million hectares in the Indo-Gangetic Plains (IGP), Conservation Agriculture (CA) practices have gained greater acceptance among farmers. Delays in wheat sowing can result in yield losses of 1–1.5% per day after the optimum sowing date (Pandey and Gurung 2017). CA adoption in IGP helps mitigate delays caused by field preparation, weed control, and terminal heat during the grain-filling stage. However, challenges to widespread CA adoption in South Asia include small landholdings (<1 ha), limited technological access, lack of suitable implements, and a deeply entrenched conventional farming mindset. South Asia, with its diverse agro-ecologies and rising food demands, presents both challenges and opportunities for CA technology adoption (Pandey and Gurung 2017). This review examines the potential, area coverage, prospects, and benefits of CA in the region, while addressing key challenges.

Minimum Tillage

Minimum Tillage represents a fundamental shift in agricultural practice, focusing on the reduction of mechanical soil disturbance. This method not only preserves the delicate structure of the soil but also safeguards its moisture content, creating an optimal environment for microbial activity and nutrient cycling (Derpsch 1998). In the context of Sri Lanka's dry zone an area grappling with pronounced soil erosion minimum tillage emerges as a powerful ally. By minimizing disruption, this practice not only mitigates erosion but also enhances carbon sequestration, steadily improving soil fertility over time (Somasundaram et al. 2020).The result is a more resilient agricultural system, capable of sustaining productivity while nurturing the land. In the literature, most studies indicate that adopting no-tillage (NT) with crop residue retention has significantly enhanced crop yields and overall system productivity. These practices contribute to better soil health, moisture retention, and nutrient cycling, leading to more resilient and productive agricultural systems.

Permanent Soil Cover

Permanent Soil Cover, achieved through the strategic use of cover crops and mulch, plays a crucial role in preventing erosion and enhancing soil fertility. By planting nitrogen-fixing cover crops such as *Gliricidia sepium* during the off-season, farmers can significantly enrich the soil, reducing reliance on synthetic fertilizers and fostering a more natural nutrient cycle (Jat et al. 2012).

Moreover, the application of mulch acts as a protective layer, enhancing moisture retention in drought-prone regions. This layer not only conserves moisture but also reduces the cracking of soil, creating a favourable environment for roots to thrive (Dharmasena n.d.). Together, these practices form a robust strategy for nurturing the land, ensuring that agricultural systems remain resilient in the face of environmental challenges.

Crop Diversification

Crop Diversification entails the cultivation of a wide array of crops, a practice that not only fosters biodiversity but also disrupts pest cycles and enhances soil health. In

Sri Lanka, this strategy is particularly beneficial; for instance, rotating rice with leguminous crops like mung beans or soybeans not only enriches the soil with essential nutrients but also offers farmers a diversified portfolio of income sources (Nissanka and Sangakkara 2009).

This symbiotic relationship between different crops contributes to a more resilient agricultural system, where the intermingling of plants promotes ecological balance and reduces vulnerability to pests and diseases (Nissanka and Sangakkara 2009).By embracing crop diversification, farmers can cultivate a agricultural landscape that thrives on variety, ensuring sustainability and profitability amid the challenges of modern agriculture.

Agroforestry and Organic Farming

Agroforestry and organic farming are interlinked practices essential for fostering ecosystem health and maintaining agricultural productivity. Agroforestry integrates trees and shrubs into farmland, providing shade, windbreaks, and soil stabilization while promoting water infiltration and biodiversity. In Sri Lanka, this age-old practice enriches home gardens and enhances resilience to climate variability (Zoysa and Inoue 2014).

Conversely, organic farming rejects synthetic inputs, focusing on natural methods to cultivate healthy soils. With rising concerns over the environmental impacts of conventional agriculture, practices like composting and biofertilizers are gaining traction. Composting transforms organic waste into nutrient-rich amendments, while biofertilizers enhance soil fertility through beneficial microorganisms (Atapattu et al. 2017).

Together, these approaches not only improve soil health but also create habitats for beneficial organisms, facilitating natural pest control and pollination vital components for successful crop production. In this harmonious blend, agroforestry and organic farming contribute to sustainable agriculture that thrives in balance with nature.

A survey of 145 households in the Jaffna peninsula assessed socio-economic factors, biodiversity, and food consumption. Families averaged four members and had home gardens of 0.083 hectares, featuring 69 plant species, including 10 vegetables and 18 fruits. Approximately 50% raised livestock and poultry. Food Consumption Scores (FCS) indicated 1% of households were in the poor category, 12% borderline, and 73% acceptable (Lowe 2021). Higher food expenditure correlated with better FCS, indicating market reliance. Coconut was the main income source and dominant tree species. Animal proteins and pulses were key for caloric availability, while most crops ranked low in importance. Diverse home gardens improved caloric security, suggesting they are a promising strategy for enhancing food security in the area. The majority of home gardens (88%) in Jaffna contained at least one coconut tree (1–22 trees), primarily for domestic use (Jeyavanan et al. 2017). Self-sufficient households averaged five coconut trees. Popular perennials included mango, Neem, jackfruit, arecanut, and guava. Banana was the most consumed fruit, with 77% of households eating it in the past week, and 29% producing it at home, contributing positively to nutritional security due to its high vitamin B-6 content. Mango and papaw were consumed moderately, while pineapple, avocado, and wood apple were eaten less frequently (Jeyavanan et al. 2017).

A study was conducted across five villages in the Jaffna Peninsula Kopay, Evenai, Kaithdy, Uduvil, and Tholpuram focusing on the prevalence and benefits of live fences in homegardens (Jayavanan et al. 2014). Data were collected through questionnaires and focus group discussions. Live fences were prevalent, ranging from 40 to 90%. The primary woody species identified was *Commiphora caudata* (Kiluvai), followed by *Thespesia populnea* and *Delonix elata*, along with various associated flora and fauna. Farmers earned an average income of Rs. 4,314 ± 1,368 per year from selling poles. The Shannon–Wiener Diversity Index (SWI)(Pl. give reference) quantifies biodiversity by considering species richness and their relative abundance. In this study, for live fence trees, flora, and fauna was 0.49 ± 0.09, 0.24 ± 0.02, and 0.58 ± 0.07, respectively. The average length of live fences was 108 ± 10 m. Total above-ground biomass (AGB) was 67,152 kg, with above-ground carbon (AGC) content at 33,590 kg (Jayavanan et al. 2014).

Sustainable Livestock Management

Livestock farming is integral to agricultural systems, supplying essential products while playing a crucial role in nutrient cycling. Yet, unsustainable practices can lead to soil degradation and a decline in biodiversity. Enter sustainable livestock management, which aims to enhance ecosystem health without sacrificing productivity.

One effective method is rotational grazing, where livestock are moved between pastures. This practice not only prevents overgrazing but also allows pastures to recover, resulting in healthier grazing lands (Houwers et al. 2015). In Sri Lanka, rotational grazing has proven particularly beneficial in combating overgrazing, improving biodiversity, and increasing soil organic matter.

Another impactful approach is the integration of livestock with crop production, which optimizes resource utilization and promotes ecological balance. Livestock manure serves as a natural fertilizer, enriching soil nutrients, while crop residues can be repurposed as livestock feed. In Sri Lanka, mixed farming systems where crops and livestock coexist offer significant ecological and economic advantages (Vithanage 2013). For example, using livestock manure to enrich paddy fields during fallow periods not only reduces reliance on synthetic fertilizers but also fosters a more sustainable farming ecosystem.

By implementing sustainable livestock management practices, farmers can boost productivity, improve soil health, and support biodiversity. This multifaceted approach contributes to the resilience of agricultural systems, diversifying outputs and minimizing dependence on external inputs, ultimately leading to a more sustainable future for farming.

Strengthening Capacity for Adaptation to Climate Change and Disasters

Global climate change is dramatically altering weather patterns, making agriculture especially in Sri Lanka one of the most affected sectors, jeopardizing food security and livelihoods. This chapter delves into crucial strategies for developing climate-resilient crops, enhancing disaster risk management, and improving water conservation practices. Additionally, promoting integrated pest management (IPM) provides a holistic approach to pest control (Jayasooriya and Aheeyar 2016). Together, these strategies are vital for sustaining food production amid escalating climatic uncertainties, paving the way for a more resilient agricultural future.

Developing Climate-Resilient Crop Varieties

Adapting to climate change requires the cultivation of crop varieties capable of withstanding extreme weather events such as droughts, excessive rainfall, and temperature extremes. Breeding resilient varieties is critical for tackling these climate challenges.

In Sri Lanka, initiatives to develop drought-tolerant and flood-resistant rice varieties, such as BG 300 and BG 358, demonstrate significant potential for bolstering food security (Costa 2010).Collaborative efforts between research institutions and international partners accelerate genetic improvements in staple crops through modern biotechnology. Key traits like deep-rooting systems and heat stress resistance are essential for ensuring that crops can thrive in adverse conditions.

Additionally, developing early-maturing varieties helps to minimize crop exposure to extreme weather conditions such as drought, excessive heat, and heavy rainfall events (Girotto et al. 2023), enabling harvests to occur before extreme conditions set in. Through these innovative approaches, the path toward climate-resilient agriculture becomes clearer, ensuring a more secure food future.

Disaster Risk Reduction Strategies

As climate change amplifies the frequency and intensity of natural disasters, robust disaster preparedness and risk reduction strategies become imperative for Sri Lanka.

Early Warning Systems (EWS) are essential for mitigating the risks associated with climate-related disasters (Hettiarachchi and Weeresinghe 2014). By delivering timely alerts about impending extreme weather, these systems enable proactive measures such as securing crops or relocating livestock. Sri Lanka has made notable strides in developing EWS through collaborations that leverage mobile alerts and satellite-based forecasting. Investing in localized climate modeling and improving communication networks will further enhance the efficacy of these systems (Girotto et al. 2023; Hettiarachchi and Weeresinghe 2014).

Additionally, crop insurance emerges as a vital financial tool for farmers facing losses from climate-induced disasters. Weather-indexed crop insurance schemes are gaining popularity in Sri Lanka, providing compensation based on measurable weather parameters rather than actual crop damage. Expanding access to affordable insurance through government support can significantly reduce the financial vulnerability of smallholder farmers, facilitating recovery in the aftermath of disasters (Silva and Sandika 2012; Prasada n.d.).

Water Management and Conservation

As climate change intensifies water scarcity and increases flood frequency, effective water management becomes crucial for Sri Lanka, where agriculture depends heavily on seasonal rains.

Efficient irrigation systems are at the forefront of water conservation, ensuring optimal delivery to crops. Modern techniques, such as drip and sprinkler irrigation, drastically reduce water wastage and enhance efficiency, particularly in drought-prone areas (Padukkage and Nanayakkara 2024). Drip irrigation, for example, can improve water use efficiency by up to 50% compared to traditional methods. Automated irrigation systems further refine this management approach, providing precise water amounts tailored to soil moisture levels (Sirimewan et al. 2021).

Equally important is the restoration of traditional water systems. Sri Lanka's ancient tank cascade systems, originally designed for effective water capture and distribution, play a pivotal role in climate adaptation (Perera et al. 2021).Revitalizing these systems through repairs and rehabilitation not only increases water storage capacity but also mitigates flood risks. Integrating modern technologies like GIS mapping to analyze and visualize geographic features can enhance the management of these traditional systems. By providing detailed insights into water distribution, infrastructure status, and watershed health, GIS ensures that agricultural communities have reliable water throughout the year (Geekiyanage and Pushpakumara 2013; Samarasinghea et al. 2010).

Integrated Pest Management (IPM)

Integrated Pest Management (IPM) embodies a holistic approach to pest control that minimizes reliance on chemical pesticides while fostering ecological balance.

One key strategy is biological control, which harnesses natural predators and pathogens to manage pest populations. In Sri Lanka, agents like *Trichogramma* wasps and *Bacillus thuringiensis* have proven effective in curbing pests across various crops (Ahangama and Gilstrap 2007). By promoting the use of these natural enemies, farmers can reduce their dependence on chemical pesticides, safeguarding both the environment and economic viability.

Cultural practices also play a pivotal role in IPM. Techniques such as crop rotation and intercropping disrupt pest life cycles, thereby diminishing pest establishment (Pushpa Malkanthi 2021). For instance, alternating rice with legumes effectively breaks pest and disease cycles, reducing the likelihood of outbreaks. Intercropping not only enhances biodiversity but also confuses pests or supports beneficial insects, bolstering overall farm resilience (Pushpa Malkanthi 2021).

Additionally, incorporating organic matter through composting improves soil health, which in turn strengthens plant resistance to pests and diseases. Healthy soils nurture diverse microbial communities that suppress pathogens and enhance plant resilience to environmental stressors (Illipangamuwa and Jayasinghe 2005). Through these integrated strategies, IPM stands as a comprehensive framework for sustainable pest management in agriculture.

The World Bank has financed several projects, including ongoing initiatives, aimed at promoting Integrated Pest Management (IPM) and the safe use of agricultural pesticides (Wanigasundera and Atapattu 2019). The Pest Management Plan developed for the Bank-financed Agriculture Sector Modernization Project will be applied to this project as well. In these projects, pest control typically employs IPM methods like biological control, cultural practices, and the development of pest-resistant or tolerant crop varieties. While the Bank may finance pesticide purchases, it only does so when justified under an IPM framework.

Progressively Improving Land and Soil Quality

Maintaining and enhancing land and soil quality is vital for sustainable agriculture, particularly in Sri Lanka, where soil degradation poses significant risks to agricultural productivity (Lal 2015).

This chapter explores a range of strategies aimed at soil conservation, restoration of degraded lands, and sustainable fertilization practices. These approaches are not only critical for enhancing soil quality but also essential for ensuring long-term agricultural sustainability. By implementing these strategies, farmers can cultivate resilient ecosystems that support both current needs and future generations, safeguarding the health of the land and the livelihoods it sustains (Fig. 7).

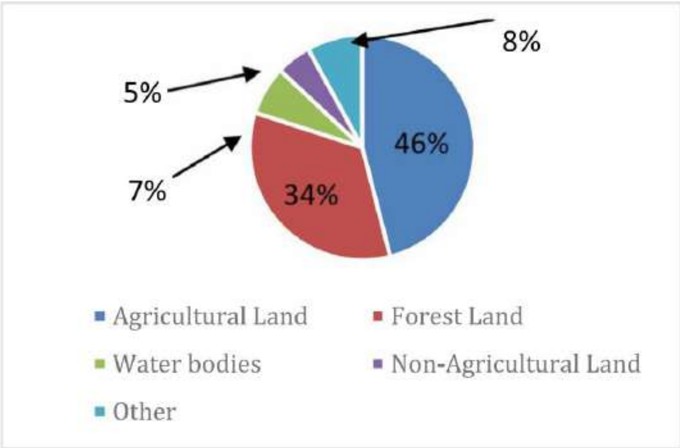

Fig. 7 Land use pattern in Sri Lank. *Source* DOA (2023)

Soil Conservation Techniques

Soil conservation techniques are crucial for preventing land degradation and ensuring productivity, especially on sloped and vulnerable lands. In Sri Lanka's hilly and mountainous regions, soil erosion poses a significant threat to agricultural sustainability.

Contour Farming and Terracing

Contour farming and terracing stand out as effective methods for combating soil erosion. Contour farming involves plowing along the land's natural contours, which reduces water runoff velocity and promotes soil moisture retention an essential factor in areas facing water scarcity (Dharmasena n.d.).On the other hand, terracing transforms steep slopes into level areas, significantly minimizing runoff and enhancing nutrient retention. Both practices not only improve land use efficiency but also bolster resilience against climatic extremes.

Cover Cropping

Cover cropping is another vital strategy, involving the planting of crops to protect the soil during fallow periods. Legumes and grasses serve as a protective barrier against erosion while simultaneously improving soil fertility and organic matter content (Nissanka and Sangakkara 2009).Cover crops shield the soil from the ravages of rain and wind, fix nitrogen, and stimulate microbial activity. When these crops are eventually incorporated back into the soil, they enrich it with vital nutrients, fostering healthier soils capable of withstanding the impacts of extreme weather events (Nissanka and Sangakkara 2009).

Restoration of Degraded Lands

Land degradation resulting from overuse, deforestation, and poor agricultural practices poses a significant challenge to Sri Lanka's agricultural sector. Restoring these degraded lands is essential for enhancing both productivity and ecosystem services.

Reforestation Projects

Reforestation projects play a pivotal role in this restoration effort. Planting trees and perennial vegetation helps rejuvenate soil health, prevent erosion, and improve water retention. In Sri Lanka, reforestation initiatives focus on restoring forest cover in deforested areas, particularly within critical watersheds. This strategy not only enhances ecological balance but also provides vital benefits such as carbon sequestration (Senadheera et al. 2019).

Agroforestry

Agroforestry presents a sustainable approach to land restoration by integrating trees into agricultural landscapes. By planting trees alongside crops, farmers can enhance soil fertility and biodiversity while generating additional income from timber and non-timber products, creating a synergistic relationship between agriculture and forestry.

Furthermore, **land regeneration practices**, such as organic farming and agroecology, rehabilitate degraded lands and boost productivity. Organic farming relies on natural inputs to restore soil fertility, while the incorporation of organic matter, like compost, significantly enhances soil structure and microbial activity. These practices not only revitalize degraded soils but also promote long-term sustainability by enriching them with vital organic matter (Senadheera et al. 2019).

Sustainable Nutrient Management Practices

Sustainable Nutrient management practices are essential for maintaining soil fertility and reducing environmental impacts. The excessive use of chemical fertilizers can lead to degradation and pollution, making alternative methods crucial.

Organic Inputs

Organic inputs such as compost and bio fertilizers are effective for enhancing soil fertility. Compost slowly releases nutrients and improves soil structure, while bio fertilizers boost nutrient availability through beneficial microorganisms. These practices are vital in Sri Lanka, where soil fertility has declined due to heavy reliance on chemicals (Dandeniya and Caucci 2020).

Reducing Chemical Fertilizer Use

Reducing chemical fertilizer use is critical to prevent soil degradation and groundwater contamination. Precision nutrient application the right amount at the right time and at right depth optimizes nutrient use and minimizes waste. Soil testing allows farmers to determine specific nutrient needs, enhancing yields while protecting the environment.

Integrated Nutrient Management (INM)

Integrated Nutrient Management (INM) combines organic and inorganic inputs to enhance soil fertility and minimize synthetic fertilizer use. INM practices ensure balanced nutrient availability, promoting plant health without causing long-term degradation (Jahan and Gurung 2017).

Policy Framework and Support for Sustainable Practices

A robust policy framework, accelerated by government initiatives, research institutions, and public–private partnerships, is vital for fostering sustainable agricultural practices in Sri Lanka. These concerted efforts are fundamentally transforming the agricultural landscape, making it more resilient to climate change while ensuring environmental sustainability and productivity. This chapter details key policy actions and support mechanisms driving this transformation, enriched by compelling local examples.

Government Initiatives

The Sri Lankan government has made remarkable strides in shaping policies that champion sustainable agriculture. The National Policy on Sustainable Agriculture and the National Action Plan for Climate Change delineate strategic priorities that weave environmentally friendly practices into the fabric of mainstream agriculture (Jayasinghe-Mudalige 2010). These policies actively encourage the adoption of organic farming, agroforestry, and soil conservation techniques, aiming to combat climate change, bolster biodiversity, and secure food availability.

In regions such as the Mahaweli Development Zone, large-scale climate adaptation programs have taken root (Paranage 2019). For instance, the rehabilitation of ancient tank systems has revitalized water storage and management, facilitating more efficient irrigation during periods of drought. Meanwhile, the promotion of agroforestry has rejuvenated degraded lands, enriched soil fertility, and fostered biodiversity conservation (Paranage 2019).

Financial incentives are indispensable in galvanizing farmers to embrace sustainable practices. In districts like Kandy and Matale, the government has rolled out subsidized rainwater harvesting programs, empowering smallholder farmers to navigate the challenges of erratic rainfall and drought (Vijitha et al. 2022). These initiatives have effectively nurtured water conservation in the tea and vegetable farming sectors, where reliable access to water is crucial for productivity.

Technical support flows through extensive training programs, enlightening farmers about sustainable practices, including organic farming techniques and innovative water management. Collaborations with NGOs and agricultural extension services ensure that these practices gain traction, enhancing resilience to climate variability.

In 2020, CSIAP allocated $1.72 million to drive five key production initiatives: the Cluster Villages Development Program, COVID Yala-2020 Program, Interseason Cultivation Program, Maha-2020 Cultivation Program, and the Climate-Smart Nutrition-Sensitive Home Garden Program (Perera et al. 2021). These initiatives aligned with government efforts, emphasizing food production through CSA technologies, diversification, inter- and off-season farming, and enhancing household nutrition. Smallholder farmers benefited from free or subsidized seeds, water-saving technologies, and extension services. Additionally, $1.43 million was invested in tank rehabilitation, upgrading extension services, and improving marketing infrastructure (Nagamuthu 2024; Behnassi et al. 2022).

Role of Research Institutions

Research institutions in Sri Lanka are pivotal in the quest for innovations that promote sustainable agriculture. The Field Crops Research and Development Institute in Maha Illuppallama has been instrumental in developing climate-resilient crop varieties. Take, for example, the BG 358 rice variety renowned for its drought tolerance and pest resistance successfully introduced in dry zones like Anuradhapura and Polonnaruwa (Behnassi et al. 2022). Such resilient varieties empower farmers to sustain productivity amidst the unpredictability of weather patterns.

Beyond crop improvement, these institutions advance soil conservation and water management techniques, disseminated through the Department of Agriculture's extension services. In areas like Hambantota and Monaragala, farmers engage in hands-on training to implement organic practices, curb soil erosion, and leverage natural pest control methods. This ensures that cutting-edge research translates into real-world applications (Padukkage and Nanayakkara 2024).

By integrating traditional knowledge with modern innovations, research institutions effectively bridge the chasm between scientific advancement and sustainable agricultural practices. A noteworthy example is the restoration of traditional tank systems in the dry zone, supported by local universities, which has significantly improved water retention and lessened dependency on erratic rainfall.

Public–Private Partnerships

Public–private partnerships (PPPs) emerge as dynamic catalysts for sustainable agriculture in Sri Lanka. By harnessing the expertise and resources of both sectors, PPPs foster the development and dissemination of innovative technologies that underpin sustainability.

A striking example is the collaboration between the Ministry of Agriculture and private firms to roll out solar-powered drip irrigation systems in regions like Jaffna and Batticaloa (Madadeniya and Ekanayake 2021). These systems dramatically enhance water use efficiency, curtail waste, and elevate crop yields, especially in water-scarce locales (Eng et al. n.d.). Smallholder vegetable and fruit farmers reap the benefits of this technology, conserving water while diminishing reliance on traditional electricity and fuel-powered irrigation methods.

Moreover, PPPs have been critical in promoting organic farming practices. Collaborative efforts among government bodies, private enterprises, and NGOs have birthed organic certification programs and established markets for organic produce, offering farmers fresh economic avenues while ensuring broader adoption of environmentally sustainable practices (Madhusanka 2015).

By amalgamating financial, technical, and human resources, these partnerships facilitate the scaling up of sustainable agricultural projects throughout the country, fostering the adoption of climate-smart agriculture, particularly in rural areas where access to resources and technology is limited.

On September 18, 2024, the Smallholder Agribusiness & Resilience Project (SARP) project marked a significant milestone with its first successful fish harvest from Dhumminnegama Tank (Linda Wewa G.N.D). After stocking fingerlings on March 22, 2024, the harvest produced a remarkable 358 kg, predominantly featuring Rohu and Tilapia. This initiative has not only made affordable fish available to the local community but also injected vitality into the local economy through sustainable aquaculture practices. The triumph of this initial harvest is poised to influence future yields positively, promising greater benefits for both farmers and villagers alike. As the project continues to flourish, it paves the way for a thriving aquatic landscape in the region (Bakun et al. 1991).

"Maximizing Red Onion Yields: Farmer Field School Session on Soil Sampling and Plant Bed Preparation in Kurunegala District," organized by SARP, marked an engaging third session of the Farmer Field School (FFS) program. Set in the lush red onion fields of Niyadawanaya Grama Niladhari division, farmers eagerly gathered to explore soil sampling techniques and the intricacies of plant bed preparation. With hands in the earth, participants shared insights and practical skills, blending tradition with innovation. The atmosphere was charged with enthusiasm and determination, fostering a sense of community and shared purpose (Ruwanpura and Mohamed-Saleem 2025; Caron 2025). This session not only equipped farmers for better yields but also ignited hope for thriving red onion crops in Kurunegala's agricultural future.

"Revolutionizing Gherkin Cultivation: Implementation of Drip Irrigation Systems for Enhanced Agricultural Efficiency," organized by SARP, marks a pivotal advancement in gherkin farming. A successful drip irrigation system has been installed in the fields of selected beneficiaries, dramatically improving water efficiency and agricultural productivity (Caron 2025). This innovative approach not only optimizes resource use but also empowers farmers to achieve higher yields, setting the stage for a transformative impact on gherkin cultivation in the region.

"Honeying the Future: Inauguration of Beekeeping Farmer Field School in Pichchai Vaanifa Nedunkulam," organized by SARP, marked a significant milestone on August 20, 2024. The village of Pichchai Vaanifa Nedunkulam in Mannar District celebrated the launch of its third Farmer Field School (FFS) program dedicated to beekeeping (Caron 2025; Dissanayaka et al. 2023).This initiative is designed to empower local farmers with essential beekeeping skills, boosting agricultural productivity while fostering sustainability in the region. Through hands-on training and knowledge sharing, the program aims to create a thriving beekeeping community, enhancing both livelihoods and environmental health.

"Building Resilience: Successful Flood and Drought Preparedness Training for Villagers in Pandaravely GND," organized by SARP, culminated in a successful training program on August 29, 2024. Held in Pandaravely GND, Musali DSD, Mannar District, this initiative equipped villagers with vital skills and knowledge for disaster preparedness in the face of floods and droughts. Participants engaged in hands-on training, learning strategies to enhance community resilience and safeguard their livelihoods against climate-related challenges (Caron 2025; Dissanayaka et al. 2023).This program not only fosters preparedness but also strengthens the community's ability to adapt and thrive amidst environmental uncertainties.

Department of Agriculture and Faculty of Agriculture Project Initiatives

To improve self-sufficiency in other field crops (OFC) and vegetables, the government of Sri Lanka prioritized food production under "Mahinda Chintana: Vision for the Future," aiming to double certified vegetable seed production through public–private partnerships (PPP). In this framework, the government sought technical assistance from Japan via the Japan International Cooperation Agency (JICA) to enhance agricultural productivity and quality by developing effective production technologies for vegetable seed farmers. The project aligns with JICA's "Agriculture, Fishery, and Rural Development Program," addressing low productivity, inadequate management skills, and the need for product diversification, thereby supporting Japan's cooperation strategy (Karunaratne 2012).

Sustainable Agricultural Water Management Project (SAWMP) strives to enhance farm productivity, boost incomes, and transform the lives of rural families in Sri Lanka's dry regions. Initiated in 2005, it made a significant impact by delivering 5,000 solar-powered drip irrigation units to small farmers by mid-2007. Today, the initiative has expanded to install 6,000 drip irrigation units across selected farmlands, spanning 14 districts: Ampara, Anuradhapura, Badulla, Hambantota, Kandy, Kegalle, Kurunegala, Mannar, Matale, Monaragala, Polonnaruwa, Puttalam, Ratnapura, and Trincomalee (Rotawewa and Lokupitiya 2020). This strategic implementation not only enhances agricultural efficiency but also promises to uplift the livelihoods of those who rely on these vital resources.

Conclusions

The journey toward sustainable food production and resilient agricultural practices in Sri Lanka is both intricate and essential. This chapter highlights the diverse strategies needed to bolster resilience, enhance productivity, and protect ecosystems while confronting climate change and environmental challenges.

Government policies form the backbone of this transition, offering strategic guidance to integrate sustainability into agriculture. Programs like the National Policy on Sustainable Agriculture and farmer incentives promote eco-friendly practices. By supporting training, funding, and infrastructure, the government fosters an environment where sustainable food systems can thrive despite climatic and socio-economic pressures.

Research institutions drive innovation by developing climate-resilient crops and advancing sustainable farming methods. These innovations translate into practical improvements in soil health, water management, and biodiversity preservation, which are crucial for building a resilient agricultural framework.

Public–private partnerships (PPPs) act as catalysts for scaling sustainable practices. By combining the resources and expertise of both sectors, PPPs facilitate the deployment of cutting-edge technologies, such as solar-powered irrigation and organic farming certifications. These initiatives demonstrate how sustainability can coexist with resilience to ensure long-term agricultural benefits.

In conclusion, Sri Lanka's path to sustainable agriculture hinges on the synergy of policy, innovation, and collaboration. By addressing climate change and food security challenges through integrated practices, the nation can establish a resilient agricultural sector that benefits both present and future generations. Continued commitment from the government, research bodies, and private enterprises will position Sri Lanka as a leader in sustainable and resilient farming systems.

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