FACTORS AFFECTING TECHNICAL EFFICIENCY OF DAIRY PRODUCTION IN THE DRY ZONE OF SRI LANKA

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FOREWORD

The dairy sector is a cornerstone of rural livelihoods in Sri Lanka, contributing significantly to income generation, nutritional security, and employment across the country. Despite its importance, dairy farming in the Dry Zone remains largely underdeveloped and underutilized, constrained by environmental, technical, and institutional challenges. In this context, the research report titled "Factors Affecting Technical Efficiency of Dairy Production in the Dry Zone of Sri Lanka" offers timely and valuable insights into a sector with untapped potential for growth and development.
This study, conducted using a rigorous and evidence-based methodology of Stochastic Frontier Analysis (SFA) evaluates the technical efficiency of dairy production across various farming systems in key Dry Zone districts, namely Kurunegala, Anuradhapura, Hambantota, and Jaffna. Dairy farming in this region is predominantly practiced by small to medium-scale farmers under semi-intensive management systems. These farmers typically rely on roadside and natural grasses as feed and possess substantial experience in the field, often exceeding 15 years.

Despite this depth of experience, the study reveals that the average technical efficiency of dairy farming in the Dry Zone is only 60.2%, suggesting that milk production could potentially increase by nearly 40% with more effective resource utilization. The research also highlights stark regional disparities: Kurunegala and Anuradhapura demonstrate relatively high efficiency levels at 77%, while Hambantota and Jaffna trail behind at 55% and 32%, respectively. These variations are closely linked to differences in farming practices, infrastructure, and access to support services.

The findings of this report are highly relevant to policymakers, development practitioners, researchers, and farming communities. At a time when improving food security and strengthening rural resilience are national imperatives, enhancing the technical efficiency of dairy production presents a practical and impactful pathway for sustainable development.

I sincerely commend the authors for their thorough and methodical investigation into this vital yet often overlooked area of agricultural development. I am confident that the insights presented in this report can serve as a catalyst for evidence-based interventions, strategic investments, and forward-looking policy reforms that elevate the dairy sector in Sri Lanka and improve the well-being of rural farming communities.

Prof. A.L. Sandika
Director/Chief Executive Officer

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EXECUTIVE SUMMARY

The dairy sector plays a vital role in Sri Lanka's rural economy by generating income and creating employment opportunities (Vidanaarachchi, 2019). With roots stretching back thousands of years, dairy farming has been instrumental in providing essential nutrition for infants and addressing nutritional deficiencies across all age groups (FAO, 2007).

The industry supplies the population with crucial nutrients including high-quality protein, minerals, and vitamins, through both milk and meat products. Small-scale dairy farmers in rural areas view their livestock as a form of financial security, essentially serving as a 'living bank' that can be relied upon during times of economic hardship (Perera & Jayasuriya, 2008).

The nutritional value of milk and dairy products contributes significantly to national development by supporting proper brain development and bone health among the population (Rahman et al. 2019). Furthermore, Perera and Jayasuriya (2008) emphasize that developing the dairy industry yields multiple benefits: it strengthens food security, helps alleviate rural poverty, reduces dependence on imports, and provides incentives for rural residents to remain in their communities rather than migrating to urban areas.

The agriculture sector contributed 8.3% to Sri Lanka's GDP in 2023, with the animal production sub-sector accounting for only 0.8% (Central Bank Annual Report, 2023). Despite this seemingly modest contribution, the dairy sector's importance cannot be understated, particularly given that 77% of Sri Lanka's population lives in rural areas. The sector plays a crucial role in social and economic empowerment of rural communities through sustainable income generation and employment opportunities (Vidanarachchi, 2019).

The country's total livestock population consists of 2.02 million animals, including 1.57 million cattle and 0.47 million buffaloes, with milk-producing animals representing 37% of the total herd. In 2023, domestic milk production reached 370.32 million litres, with cow milk accounting for 317.06 million litres and buffalo milk contributing 53.26 million litres (Department of Animal Production and Health, 2023). The nation's heavy reliance on dairy imports poses a significant economic challenge. In 2022, Sri Lanka imported substantial quantities of milk powder: 12,117,564 kg of low-fat milk powder (Fat<1.5%), 37,407,965 kg of full-fat milk powder (Fat>1.5%), and 1,523,462 kg of whey powder (DAPH, 2023).

These imports resulted in a substantial financial burden, exceeding Rs. 63 billion (Department of Customs, 2022). In this context, dairy farming represents a valuable investment opportunity for farmers to enhance their socio-economic status, not only through milk production but also through diversified farming activities that create additional employment opportunities.

The Sri Lankan dairy sector faces numerous challenges that impact its production efficiency. According to Achchathan and Kajanathan (2012), key constraints include insufficient feed supply, lack of improved breeding programmes, ineffective management practices, and inadequate veterinary and extension services. Wijethilake, et al. (2018) identified several factors crucial for sustainable dairy farming, including the proper functioning of Farmer Managed Societies, effective herd management, accessibility to artificial insemination services, and the provision of affordable quality concentrate feed.

The importance of financial and technical support is highlighted by Silva and Sandika (2012), who demonstrated that access to credit, subsidies, extension services, and farmer training in dairy farming significantly increases smallholder farmers' income. Additionally, several researchers (Ibrahim, 1999; Ranaweera, 2006; Perera and Jayasuriya, 2008) have identified common challenges affecting the sector's production efficiency, including problems in herd development, low productivity, animal health issues, difficulties in clean milk production, inadequate feed provision (both natural and processed), high production costs, insufficient quality and quantity of feed, and limitations in livestock extension services.

The Dry Zone of Sri Lanka, particularly the Northern, Eastern, North Western, and North-Central provinces, is home to the majority of extensive dairy farming operations (Ibrahim et al., 1999). According to the Department of Animal Production and Health, (2020), of Sri Lanka's total cattle and buffalo population of 2.1 million, the Dry Zone accounts for 1.6 million animals, representing 79% of the total livestock population.

However, this significant animal population contributes only 50% of the country's total milk production. This disparity is highlighted by the fact that the remaining 21% of the national herd, located primarily in the wet zone, produces the other 50% of the country's milk output.

The current smallholder dairy farming system in Sri Lanka is unable to meet demand, necessitating the exploration of new dairy farming strategies (Ranaweera, 2006). While the Government of Sri Lanka has implemented various projects and programmes aimed at developing the dairy sector to achieve self-sufficiency, maintaining industry sustainability within existing resource constraints remains a critical challenge. Andrew, et al. (2017) highlight the importance of adopting a farming system approach, recognizing that different farming systems have varying resources available for dairy production.

Although production efficiency studies are crucial for improving dairy farming performance, there has been limited research focusing on efficiency analysis of dairy farming in Sri Lanka's dry zone. Consequently, analysing dairy production efficiency in the Dry Zone is essential for developing effective policy strategies that promote efficient dairy farming practices. The main aim of this study is to understand the factors affecting technical efficiency of dairy production in different farming systems in Dry Zone of Sri Lanka and to propose policy suggestions to enhance the technical efficiency of dairy farming in the respective areas.

The Stratified Random Sample Method is used to select the sample. Accordingly, based on the dairy management methods such as intensive semi-intensive and extensive, farmers were selected from different districts to represent farming systems of Dry Zone of Sri Lanka. The selected districts for the study include Kurunegala, Anuradhapura, Hambanthota and Jaffna. Depending on the number of registered farms in the Department of Animal Production and Health, a total of 215 farmers were selected for the questionnaire survey.

Accordingly, 65 farmers from Kurunegala, 60 farmers from Anuradhapura, 45 farmers from Hambanthota and 45 farmers from Jaffna were selected for the study. Stochastic Frontier Analysis was applied to measure the efficiencies in dairy production, and STATA statistical package was utilized for data analysis.

For the efficiency model calculation dairy farm factors include input variables such as feed provision, labour, medicine, technology, veterinary service, number of milking animals in the herd, breed type, management type (intensive, extensive and semi-intensive) scale of production (small scale, medium scale and large scale). In the inefficiency model, farmer factors such as age, sex, experience of dairy farming, level of education, data related to characteristics of farming systems will be gathered using key informant and focus group discussions.

The Cobb-Douglass Production Frontier Model is commonly used in its linear form, applying logarithms of input and output quantities. The production function was applied for each herd was applied and in the second stage analysis, the technical efficiency score estimates (TE) score estimates for its herd/farm were regressed against selected farm and producer characteristics.

The study area includes 8.3% intensive farmers, 68.1% semi-intensive farmers and 23.6% extensive farmers, and clearly indicating that the semi-intensive method of management is dominant in the area. The sample farmers consisted of 93% of the male farmers and 8% of the female farmers. Age distribution showed that farmers under 30 years represent 4% of the sample, those aged 30–60 represent 77% and farmers over 60 years old represent 22%. Regarding education levels, 82% of the sample studied up to GCE (O/L), 11% passed GCE (O/L), and the remaining farmers have passed GCE (A/L), degree or diploma.

Further, majority of the sample farmers (72%) have dairy farming as their main occupation, while 16% primarily engage in crop farming. More than 60% of the farmers have over 15 years of experience in dairy farming. Additionally, 72% of the farmers rely on roadside and natural grasses, 28% own grasslands. In the Dry Zone dairy, dairy farming consists of 0.5% large scale farms, 46.3% medium scale farms and 53.2 % small scale farms, with 8.3% practicing intensive, 68.1% semi-intensive and 23.6% extensive management systems.

The farm factors that significantly contribute for milk production in the Dry Zone include the number of milking cows in the herd, amount of concentrate feed given, amount of pasture feed /day, water supply frequency/day and the availability of cattle shed. Farmer factors that significantly influence milk production are training received and experience of dairy farming. The number of milking cows and the quantity of feed intake play a crucial role in milk production. For every additional milking animal, milk output increases by 0.8% litres and for each additional kilogram of feed, total milk output increases by 0.72 litres.

This implies that providing an adequate amount of feed positively impacts achieving higher milk yields up to the recommended level. The technical efficiency of dairy farming in the dry zone, based on the sample is 0.602 (60%), indicating that available the milk production can be increased by 40% through more effective use of available resources. This includes increasing the number of milking animals in the herd, providing the recommended concentrate feed and roughages, and ensuring 24-hour water availability to the animals.

In the Dry Zone study areas, Kurunegala, Hambantota, Anuradhapura and Jaffna show technical efficiency of 77%, 55%, 77% and 32%, respectively. Hambanthota district has the lowest technical efficiency, as most of the farmers practise extensive type of dairy farming. It is noted that while most of the essential dairy technologies have been adopted by farmers, about half of them do not provide the correct amount of feed or ensure 24-hour water availability for the milking animals.

According to the Stochastic Frontier Analysis, providing 24-hour water to milking animals can increase milk production by 25% within the available resources. The average cost of production of per litre of milk, excluding family labour and without considering the management type, was Rs.103.2 in the study area. District-wise, the cost of production per litre was Rs. 100.73 in Kurunegala district, Rs.101.75 in Anuradhapura district, Rs.105.85 in Hambanthota district, and Rs.104.78 in in Jaffna district. Feed costs accounted for 70% of the total cost of production. However, the average cost per animal per day was around Rs.225.

The main dairy breeds in the study area include jersey, Friesian, Jersey- Frisian cross breeds, and Jersey-Sahiwal crossbreeds. Their maximum production ranges from 12 to 20 litres per day. To enhance the milk production with available resources, it is important to educate dairy farmers on the correct amount of concentrate feeding, the optimal number of milking animals per herd, ensuring 24-hour water provision on the farm and the presence of a cattle shed in the dry zone.

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AI	–	Artificial Insemination
AMZ	-	Australian Milking Zebu
BCC	–	Banker–Charnes–Cooper
CCR	–	Charnes–Cooper–Rhodes
COP	–	Cost of Production
DAPH	–	Department of Animal Production and Health
DCD	–	Dicyandiamide
DCS	-	Department of Census and Statistics
DEA	–	Data Envelopment Analysis
DMU	–	Decision-Making Units
DTVS	–	Dry Zone Traditional Village System
DZ	–	Dry Zone
EM	–	Effective Microorganisms
FAO	–	Food and Agriculture Organization
FBS	–	Farmer Business School
FOs	–	Farmer Organizations
GCE (A/L)	–	General Certificate of Education (Advanced Level)
GCE (O/L)	–	General Certificate of Education (Ordinary Level)
GDP	-	Gross Domestic Product
HARTI	–	Hector Kobbekaduwa Agrarian Research and Training Institute
HHH	-	House Hold Head
KPI	-	Key Performance Indicator
MILCO	–	Milk Industries of Lanka (Pvt) Ltd
MLE	–	Maximum Likelihood Estimation
OLS	–	Ordinary Least Squares
SFA	–	Stochastic Frontier Analysis
TE	–	Technical Efficiency

CHAPTER ONE

Introduction

1.1 Background

Dairy development is significant to Sri Lanka's rural economy because of its capacity to generate income and create employment opportunities (Vidanaarachchi, 2019). Milk production is a traditional industry that has survived thousands of years playing a key role in infant nutrition and alleviating nutritional deficiencies across all age groups (FAO, 2007). It provides a crucial source of high-quality protein, minerals, and vitamins to the population, through both milk and meat.

For many rural smallholder farmers, dairy animals are a 'living bank', acting as a financial reserve during periods of economic distress (Perera & Jayasuriya, 2008). Additionally, milk and milk products contribute to building up strong nations by supporting brain development and bones health (Rahman, et al. 2019). According to Perera and Jayasuriya (2008), developing the dairy industry is crucial because it enhances food security, reduces rural poverty, lowers import bills, and helps prevent rural to urban migration.

According to the Central Bank Annual Report 2023, agriculture contributed 8.3% to the GDP, with the animal production sub-sector accounting for only 0.8 %. The rural population makes up 77% of Sri Lanka's population, and the dairy sector's importance cannot be underestimated, as it contributes to the social and economic empowerment of the rural communities through employment and sustainable income (Vidanarachchi, 2019). The total cattle and buffalo population in Sri Lanka was 2.02 million, comprising 1.57 million cattle and 0.47 million buffaloes. Milk producing animals represent 37% of the total herd.

Further, total domestic milk production was estimated at 370.32 million litres in 2023, comprising 317.06 million litres of cow milk and 53.26 million litres of buffalo milk (Department of Animal Production and Health, 2023). In 2022, imports included 12,117,564 kg of low-fat milk powder (Fat <1.5%), 37,407,965 kg of full-fat milk powder (Fat >1.5%), and 1,523,462 kg of whey powder, with the total import bill exceeding Rs. 63 billion (Department of Customs, 2022). This heavy reliance on imports, which accounts for 60% of the milk and milk-based product demand, places a significant burden on Sri Lanka's economy. Rearing dairy cow is one of the most important investments a farmer can make to improve their socio-economic condition, due to the valuable nutritional milk produced and diversified farming activities that increase employment opportunities.

Due to Sri Lankan climatic variations and diverse crop farming patterns, dairy farming systems have been categorised. Abeyagunawardene (1997) identified four farming systems as Dry Zone Traditional Farming System, Dry Zone Irrigation Settlement System, Intermediate Zone System and Wet Zone System. Meanwhile, Ibrahim, et al.

(1999) classified four main farming systems as Hill Country and Mid Country Farming System, Low Country Wet, Low Country Dry and the Coconut Triangle. These classifications reflect differences in resource availability—such as breeds, natural grasslands, land, and management practices —across farming systems, which also result in variations in average milk production per animal (Abeyagunawardene, et al., 1997)

According to Vidanaarachchi (2019), small-scale dairy farms contribute approximately 75% of the total milk production in Sri Lanka, with the remaining 25% coming from medium and large-scale farms. In addition, the predominant cattle breeds in the country include indigenous breeds, cross breeds, pure exotic breeds and buffaloes (Perera and Jayasuriya, 2008; Ranaweera, 2006).

Dairying offers substantial benefits to all stakeholders in the supply chain, from producer to consumer. However, due to several constraints, some farmers leave the industry, and the involvement of youth in dairy farming is around 7 % (Hitihamu, et al., 2021). Per capita milk availability in Sri Lanka gradually increased, reaching 58.03 kg per year by 2018, but then declined to 48.6 kg by 2021. According to the ourworlddata.org, the world average per capita milk consumption in 2017 was 83.5 kg and in India per capita milk consumption was 123 kg in the same year. Despite these figures, the Ministry of Health in Sri Lanka recommends a daily milk intake of 200 ml, which translates to approximately 73 kg annually.

Milk collection in Sri Lanka involves both formal and informal collection (Ibrahim et al. 1999). The main formal milk collectors are Milco, Nestle, Kothmale, Pelawattha, CIC Dairies and other collectors. Informal milk collection is prevalent in areas where formal collection networks are lacking. Key players in the informal sector are local small scale milk processors, hotels and small-scale sellers (Hitihamu et al, 2021).

In the formal system, milk collection, transport, storage, processing and distribution are managed by the formal collectors (Ranaweera, 2006). According to the DAPH (2020), the number of chilling centres in 2020 was 283 with the capacity of 1,074,130 litres. This highlights the need for further development and upgrading of dairy market infrastructure to support and enhance the efficiency of the dairy sector.

As Herath (2016) pointed out that Sri Lanka's milk industry faces significant challenges including poor distribution channels, high input costs particularly for feed along with rising labour and veterinary service expenses. Additionally, inadequate storage facilities, market inefficiencies, and various technical problems further threaten the industry's growth. Enhancing milk production is essential, particularly in the context of increasing milk prices. Historically, local milk producers have received prices significantly lower than the cost of imported milk, which has undermined their profitability and competitiveness.

The increase in milk prices is a crucial factor for boosting local dairy production. However, Sri Lanka's dairy sector faces several constraints, including low herd yields, limited availability of grassland, and rising input costs (Weerahewa, 2009). According Animal Production and Health (2020), hill and mid country dairy farming systems producing average 6- 8 litres per day and dry and dry intermediate zones produce averagely around 2 litres per day due to varies challenges in dairy production sector. Lower average milk production with resources indicates the stagnation of the country's dairy industry, especially in the dry zone, contributing inefficiencies in milk production systems. Therefore, studying technical efficiency to study the efficiency of dairy production is important.

Further, in general, economic production efficiency refers to the level of maximum capability where all resources are fully utilized to produce the most cost-efficient product possible. Maximizing resource use when resources are limited is essential to enhance the milk production efficiency, which contributes to increasing milk production with the lowest level of input. Therefore, studying efficiency of dairy production is crucial. Analysing dairy production efficiency in dry the zone of Sri Lanka is important to enhance dairy production in Dry Zone in that region.

1.2 Challenges in Dairy Production

Jayasuriya and Perera (2008) found that political, technical and socio-economic factors contributed to the virtual stagnation of dairy farming, with low farm gate prices and dairying often considered as a secondary source of income. They identified several constraints in the dairy production sector, including technical issues that lead to shortage of quality breeding stock, lack of seasonal green fodder, inadequate extension services, and the absence of infrastructure facilities in the input market.

Further, in the marketing sector, the monopolistic nature milk collector's results in farmers receiving low farm gate prices. In addition, farmers' participation in marketing of milk is minimal, which leads to malpractices. Strong advertising for imported milk has also lowered consumer preference for locally produced milk. However, in 2014, the DCD issue and the current economic crisis created a significant increase in demand for locally produced milk. Furthermore, it is recommended that the small-scale farms be commercialized and linked with large scale farms.

According to Jayasuriya and Perera (2008), both the production and marketing sectors exhibit inefficiencies, as reflected in the four dairy farming systems described by Abeyagunawardene, et al (1997). However, their study criticizes the inefficiency of milk production. In Killinochchi district of Sri Lanka, a study on dairy value chain analysis identified several production and marketing problems along the value chain. With input supply especially feed supply being a dominant issue.

Further, milk price variation, milk collection, cooling and distribution issues are common in the Killinochchi district. Farmers face several major challenges including insufficient knowledge, frequent disease outbreaks, lack of high yielding animals, limited investment, an unorganized supply chain, and inadequate capacity to expand the dairy sector. Additionally, milk cooling facilities are lacking both at the collector and farmer levels. The milk collection systems appear inefficient and requires further infrastructure development. At the retailer level, issues such as adulteration occur and a proper milk distribution mechanism for consumers is lacking. Government supported veterinary services are also insufficient in the district.

The formal milk market includes farmer managed societies, small dairy cooperatives, district cooperatives and dairy cooperative unions. The main milk collector is MILCO, which collects 32% of the total formal milk market. In addition, Nestle, Pelawatta and other collectors are involved in milk collection and provide facilities such as farmer managed societies, collecting centres and chilling facilities. Moreover, milk processing is also led by these collectors.

The main factors influencing the stagnation of dairy production are the lack of integrated approach and insufficient coordination of development activities. Furthermore, countries such as India and Pakistan have focused on buffalo production using low quality roughages. However, Sri Lanka's focus on buffalo production needs to be strengthened. The majority of milk processors are small scale and lack the capital and land necessary to grow quality fodder. Further, naturally available fodder is seasonally available, limiting consistent supply.

Therefore, suitable feeding strategies, both qualitatively and quantitatively, are needed. In addition, innovative small-scale farms should be transformed into medium or large scale dairy enterprises. Furthermore, proper management practices on the farm are essential to achieve better yields, with adequate provision of water and feed being crucial to increasing production (Perera and Jayasuriya, 2008, Vidanaarchchi, 2019).

The Market Oriented Dairy Project was initiated to support Sri Lanka's dairy sector through improved technological, financial and management practices for the benefit of all stakeholders including consumers. Vyas et al. (2020) studied gaps and challenges in dairy management practices, extension services, milk quality management standards and artificial insemination services. The researchers concluded that lack of good quality feed, poor dairy management practices, and ineffective extension services are the main constraints to improving milk productivity. Moreover, the absence of milk quality standards and inadequate cooling facilities are significant challenges.

1.3 Dry Zone Dairy Farming in Sri Lanka

Sustainable agricultural practices are important for enhancing farmer profits and improving resource efficiency. In Sri Lanka, milk, predominantly from cows, is a key dietary staple, and increasing domestic production is vital for food sovereignty and reducing dependency on imports. Although the dairy sector in Sri Lanka has been extensively studied, there is a notable productivity gap in the Dry Zone dairy farming systems.

These systems, such as the Dry Zone Traditional Village System (DTVS), depend on extensive rearing practices where cattle graze on communal lands with minimal external inputs. Previous studies have primarily focused on other farming systems, highlighting the need to better understand productivity, costs, and profits in the dry zones, particularly in regions like Batticaloa (Bandara et al., 2018).

The dairy sector in Sri Lanka primarily consists of smallholders who rear 2-5 cows across most agro-ecological regions, except for the dry zone. Historically, the largest herds of cattle and buffaloes have been found in the dry and dry intermediate zones. The Dry Zone includes the Eastern, North, and North-Central province s. The Eastern Province, which includes the districts of Trincomalee, Batticaloa, and Ampara, holds a significant potential for dairy industry development. In the dry zone, herds tend to be larger, although they are mostly made up of indigenous animals with low milk yields (Hitihamu, et al., 2015).

Anuradhapura, a key district in Sri Lanka's dry zone, makes a significant contribution to the country's dairy industry, with an estimated daily cow milk production of approximately 85,117 liters (DAPH, 2016). Predominantly, smallholder farmers in the district typically manage herds of 5-10 milking cows, rearing both indigenous and exotic crossbred breeds, with Jersey crossbred cows being the most popular (Ibrahim et al., 1999). Despite their popularity, these cows often produce milk below their genetic potential in the dry zone, resulting in lower milk yields and poor milk composition, which negatively impacts farmer income and market demand. Environmental concerns, such as unpleasant odours from cow dung and urine, also persist.

Enhancing rumen activity through the use of Effective Microorganisms (EM), such as *Lactobacillus acidophilus* and *Lactobacillus plantarum*, can improve milk yield and composition while reducing odours by enhancing digestion (Sun et al., 2017; Uyeno et al., 2015). This approach offers a cost-effective solution to address both productivity and environmental challenges in the Dry Zone dairy farming sector (Mohamed et al., 2018).

In Sri Lanka, smallholder farmers play a crucial role in the dairy sector, especially in the dry zone, which includes key districts like Anuradhapura. Despite their substantial contribution to the rural economy and food security, local milk production meets only 40% of the national demand, necessitating substantial imports (Damunupola, 2022). Dry Zone dairy farms, typically managed extensively, face challenges such as poor genetic quality of animals, limited freshwater availability, and inadequate pasture quality. Jersey crossbred cows are prevalent but underperform in this region. Enhancing milk yield and composition through the use of effective microorganisms presents a viable solution to these challenges (Prasath, et al., 2023).

The Dry Zone (DZ) is a significant yet under recognized contributor to Sri Lanka's livestock sector, producing 64% of the national milk supply and 60% of ruminant meat, despite limited financial and infrastructural support. Holding the majority of the country's cattle, goats, and buffaloes, the DZ underperforms but has the potential to more than double its production (Gamage, 2011).

Dairy farming in Sri Lanka is predominantly managed by smallholder farmers practicing mixed crop-livestock farming (Bandara 2018). This integrated approach serves as a valuable income source for these farmers within the mixed farm system (Moran, 2009). However, the national dairy development programme has had limited success due to a lack of understanding of the ecological, socio-economic, and cultural constraints (Zemmelink et al. 1999). Identifying the features of cattle and buffalo mixed farming systems in the dry lowlands could boost national cattle and buffalo production, ensuring the long-term sustainability of livestock farming on the island. Moreover, understanding the key characteristics of cattle and buffalo farming systems would bolster regional dairy production (Vithanage, et al., 2013).

In the dry zone, approximately 400,000 hectares of natural grassland provide a primary source of feed for nearly all dairy farmers (Ibrahim et al 1999). According to Zemmelink et al. (1999) access to these external fodder resources is vital for economically viable dairy production. However, the production performance data indicate that feed intake was insufficient to meet the nutritional needs of livestock, particularly during the dry season, in both semi-intensive and extensive systems. Additionally, the lack of high-quality feed production throughout the year was a considerable challenge for smallholder dairy farmers, limiting their ability to accomplish profitable dairy production (Chandrasiri, 2002).

Despite ongoing technological advancements in agriculture, climate remains a critical limiting factor in farm production. Climate change is projected to result in drier, hotter summers and more frequent extreme weather events across Sri Lanka. Consequently, environmental considerations are gaining prominence on political, social, and economic agendas, especially in agriculture. It is well established that milk yield and composition are influenced not only by individual cow characteristics but also by environmental conditions, such as temperature, rainfall, and humidity.

The consumption for livestock products are increasing both locally and internationally. Livestock plays a crucial role in food security by providing essential nutrients such as protein, minerals, and vitamins through products such as milk, curd, meat, and other dairy items. For many rural smallholder farmers, livestock farming serves as a significant source of income.

The Department of Animal Production and Health (DAPH) promotes investment in dairy production, implements cattle import projects, and establishes milk chilling centres across the island to improve nutrition levels and address malnutrition.

1.4 Problem Statement

According to the Department of Animal Production and Health, approximately 0.4 million dairy farmers are involved in the milk production, with around one million people engaged in the industry as an income generating activity. Further, for 72,400 farmers', sole income generating activity is dairy farming. (Vidanaarachci, 2019). In addition, Perera and Jayasuriya (2008) further emphasized the importance of milk and milk products in ensuring food security, as they provide vitamins, minerals, proteins and calcium for a healthy population.

Further, Sri Lanka imported milk and milk products worth of 61.9 billion of Sri Lankan Rupees in 2020, representing a significant financial drain on the country. From both food security and economic perspective, the sustainable development of the dairy sector is therefore essential.

Sri Lanka dairy sector faces several challenges in the dairy production sector. Achchathan and Kajanathan, (2012), identify key constraints such as inadequate feed supply, lack of improved breeds, ineffective management, and insufficient veterinary and extension services. Additionally, sustainable dairy farming depends on well-functioning Farmer Managed Societies, effective herd management of herds, access to AI, and provision of low-cost, quality concentrate feed (Wijethilake, et al. 2018).

Further, Silva and Sandika (2012) clearly illustrated that access to credit, subsidies, extension services, and farmer training in dairy farming increases the income of the small holder farmer. In addition, common constraints in the dairy production sector include issues in herd development, low productivity, animal health issues, clean milk production, provision of natural and processed feed, high production costs, lack of quality and quantity of feed and inadequate livestock extension services (Ibrahim, 1999, Ranaweera 2006, Perera and Jayasuriya, 2008). All these issues are linked to the production inefficiencies in the dairy sector.

Given the challenges faced by dairy farmers, in optimally using available resources measuring dairy farm efficiency provides valuable insights into farm performance and the factors affecting production efficiency within existing resource constraints. Optimal resource use leads to more efficient dairy management, thereby safeguarding the economic and social well-being of both farmers and consumers.

According to Ibrahim et al. (1999), the majority of extensive type of dairy farmers are concentrated in the Dry Zone of Sri Lanka, particularly in the Northern, Eastern, North Western and North-Central provinces. Moreover, several studies have noted that cattle intensification is occurring in the wet zone, where farmers predominantly practice intensive and semi-intensive dairy farming systems. In addition, upgrading programmes are also ongoing in wet zone related areas. However, in most of the Dry Zone regions, dairy farming largely relies on extensive systems, with animals grazing on natural grasslands.

The use of grassland resources for livestock has a long tradition, with these grasslands exhibiting considerable diversity in terms of climate and vegetation. Livestock play a vital role in meeting the increasing protein requirements of a growing population. However, existing ecosystems have been severely limited due to various development activities including clearing for short-term cultivation, illegal burning, and extensive removal of herbages for fodder and over grazing. Therefore, there is a continuing need to implement a broad spectrum of production and conservation methods to ensure sustainable management of the grassland resource for the future (Premarathne et al. 2003). Furthermore, the absence of grassland maintenance programmes and mismanagement of these natural resources have led to the depletion of natural farming systems. In addition, these farming systems are vulnerable to the impacts of natural disasters.

Sri Lanka experienced a significant weather hazard in December 2022, caused by Cyclonic Strom Mandous. Four districts: Jaffna, Kilinochchi, Vauniya and Mannar were affected. In these districts, mainly the dairy farmers practice extensive management practices with locally available breeds. In addition, extensively managed goat farms also are common in this area. However, the occurrence of such climate has negatively impacted the dairy industry and the socio-economic status of dairy farmers in the region.

Due to sudden weather changes (cold shock) in the Northern Province, the Department of Animal Production and Health reported 939 cattle deaths and 332 goat deaths including milking animals. Moreover, 3159 poultry birds were also lost during this cold shock. Normally the average temperature in the Northern region ranges between 29°C to 33 °C, however, during the shock, it dropped to 17 °C. In addition, Northern part of Sri Lanka, which was affected by a civil war lasting over 30 years, has experienced limited focus on development activities.

Over the past 10 years, several projects and programmes have been implemented to develop the dairy sector in the region. However, these initiatives have not sufficiently emphasized the importance of transitioning dairy management systems from extensive to semi-intensive. Moreover, Hitihamu, et al. (2021) highlighted the need to transform buffalo farming systems into semi-intensive farming systems in the Dry Zone of Sri Lanka. which would improve resource use efficiency. Further, the Sri Lanka Council for Agriculture Research Policy has advocated for the transformation of dairy farming systems. Furthermore, Ranaweera (2006) explained that the existing smallholder dairy farming system is unable to meet the growing demand for dairy products, underscoring the necessity to explore new dairy farming strategies.

The Government of Sri Lanka has implemented several projects and programmes to enhance dairy development in the country, aiming to achieve self-sufficiency in dairy production. However, given the prevailing resource constraints, it is important to maintain the sustainability of the dairy industry, at a higher level of efficiency. Further, Ranaweera (2006) highlighted the importance of the farming system approach, noting that different farming systems have varying resources availability for dairy farming, which leads to different levels of efficiency.

Hence it is important to study production efficiency levels to increase the output of different dairy farming systems. However very limited studies have focussed on efficiency analysis of dairy farming in the Dry Zone of Sri Lanka. Therefore, analysing dairy production efficiency in Dry Zone is essential to inform policy strategies for more dairy farming.

1.5 Research Questions

1. What are the factors affecting technical efficiency of dairy production in different farming systems in the Dry Zone of Sri Lanka?
2. To what extent dairy technologies reach to the farmers?
3. What policy suggestions can enhance the dairy production in Dry Zone of Sri Lanka?
4. How can a results framework align outcomes and KPIs with policy recommendations?

1.6 Objectives

The overall objective of this study is to understand the factors affecting technical efficiency of dairy production in the Dry Zone of Sri Lanka. The specific objectives are as follows.

1. To determine the factors contributing to dairy production efficiency in Dry Zone of Sri Lanka;
2. To assess the level of technology adoption among dairy farmers and identify the constraints they face;
3. To provide policy guidelines to enhance dairy production in the Dry Zone of Sri Lanka, by improving the efficiency levels;
4. To develop a roadmap/results and resources framework with outcomes and key performance indicators aligned with policy recommendations.

1.7 Significance of the Study

This study will help to identify the inefficiencies that have contributed to the stagnation of production in the country. Sustainable dairy production encompasses economic, environmental and social sustainability. Under economic sustainability, this research will focus on evaluating the production efficiency of dairy farming systems by estimating their technical efficiency in the dry zone. Additionally, the findings will assist farmers to upgrading their farming practices by identifying and providing the required level of inputs to improve productivity and sustainability.

Furthermore, this study is important for the development of the dairy sector in Sri Lanka, as investigating the production efficiency of the Dry Zone dairy farming systems helps to identify the extent and sources of inefficiencies. Further, this detail analysis will provide opportunities to improve production efficiency and increase output. In addition, measuring the technical efficiency of dairy farming in these areas will help to identify the key factors contributing to production inefficiencies.

The socio-economic factors contributing to dairy production inefficiencies, along with technical issues such as feeding, breeding, farming methods and deficiencies in supporting services, can be identified through this study, providing valuable opportunities to develop effective policies to enhance the efficiency of the dairy sector.

1.8 Organization of the Report

This report is organized into five chapters: Introduction, Literature Review, Methodology, Results and Discussion, and Findings and Recommendations. The first chapter, Introduction, provides an overview of the study, including the background, problem statement, research questions, and objectives. The second chapter, Literature Review, presents a comprehensive review of the production efficiency in dairy farming, both in Sri Lanka and globally. It also discusses the theoretical framework of the study, supported by empirical examples. The Methodology chapter outlines the sample population, conceptual framework, and the rationale for sample selection.

The Results and Discussion chapter presents the socio-economic characteristics of the sample population and the features of dairy farming in the dry zone. Additionally, the chapter includes a discussion of the stochastic frontier model estimations, covering both efficiency and inefficiency models. Finally, the Findings and Recommendations chapter summarizes the key findings of the study and offers detailed recommendations.

CHAPTER TWO

Review of Theoretical Concepts and Empirical Models

The literature review comprises of two sections: the theoretical and empirical review. In the theoretical review, production efficiency and technical efficiency are described. In addition, Data Envelopment (DE) method and Stochastic Frontier Analysis (SFA) will be discussed in detail in this chapter. In the empirical literature review, the studies undertaken using these theories were analyse critically and the research gap for further study also explained

2.1 Review of Theoretical Concepts

Technical Efficiency (TE)

Technical efficiency (TE) is a critical concept in economics and production theory, reflecting the capacity of a firm, organization, or country to maximize output from a given set of inputs. The measurement of technical efficiency has significant applications in various fields such as agriculture, manufacturing, healthcare, and economics. Technical efficiency refers to the ability of a production unit to utilize its inputs in the most effective way, producing the maximum possible output given its resource constraints. This concept, initially developed by Farrell (1957), is often contrasted with allocative efficiency, which involves using the optimal mix of inputs based on their cost and the prices of factors of production.

Farrell's (1957) seminal work laid the foundation for efficiency measurement, distinguishing between technical inefficiency (the shortfall from the optimal production frontier) and random error (uncontrollable factors like weather conditions or technological shocks). Technical efficiency is typically quantified as the ratio of observed output to the potential maximum output that could be produced with the same input quantities. The measurement of technical efficiency has gained prominence due to its relevance in policy-making, resource allocation, and firm-level productivity analysis. Efficient firms are more competitive, leading to lower production costs and higher profitability, thereby contributing to overall economic growth. By identifying and addressing technical inefficiencies, policymakers and firms can optimize resource utilization, enhance competitiveness, and drive economic progress.

2.2 Production Function and Efficiency

There are two main methods to measure the efficiency and productivity that include parametric (economical) and non-parametric (mathematical petitioning). In Stochastic Frontier Analysis the frontier is stochastic, allowing noise to be separated from the effects of inefficiency. However, the statistical approach is parametric and requires the specification of functional form. This means that the structural restrictions are imposed and effects of misspecifications in the functional form might be confounded with inefficiency. The non-parametric approach is free from functional form misspecification and other structural restrictions, but it does not account for statistical noise and vulnerable to outliers (Zamanian, et al., 2013).

Furthermore, there are two primary methodological approaches to estimate efficiency: non-parametric models, particularly Data Envelopment Analysis (DEA) developed by Farrell (1957), and parametric models, including Deterministic Frontier Analysis and Stochastic Frontier Analysis (SFA), developed by Aigner et al. (1977) and Wim Meeusen and Julien van den Broeck, (1977). While SFA offers notable advantages, such as accounting for random shocks and measurement error, allowing structural analysis of the determinants of producer performance, and being grounded in stronger economic theory, it also has significant limitations. These include the need to make strong a prior assumption about production technology through functional form selection (like Cobb-Douglas or trans-log), despite unknown distributional characteristics, difficulties in specifying error structure which may introduce additional error sources, and potential approximation errors due to the assumption of continuity (Chefeebo, et al.(n.d.).

Production and productivity can be increased through two main methods. The first is by increasing the use of inputs and/or improving technology given a certain level of inputs. The second option is to enhance the efficiency of producers or firms, while maintaining a fixed level of inputs and technology. The production frontier describes the minimum input bundles required to produce a given level of output, or the maximum possible level of production from a given set of inputs. This is commonly referred to as technical efficiency.

Although there is a connection between production efficiency and technical efficiency, they are not the same. The key distinction is that production efficiency is about cost minimization by adjusting the mix of inputs, whereas technical efficiency emphasizes output maximization from a given mix of inputs (Wassie, 2014). In other words, production efficiency focuses on the optimal combination of inputs to minimize costs, while technical efficiency seeks to maximize output using a fixed set of inputs. By understanding and improving both production efficiency and technical efficiency, firms and policymakers can promote overall productivity and economic growth. Enhancing technical efficiency enables greater output with the same resources, while production efficiency ensures this output is achieved in the most cost-effective manner.

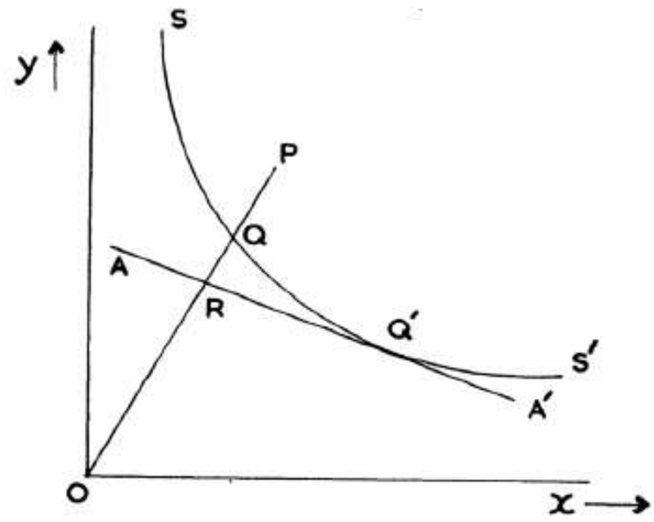
Neoclassical economics assumes that producers in an economy always operate efficiently. However, in real terms, manufacturers are not always fully efficient. This discrepancy can be explained both in terms of inefficiencies and unforeseen exogenous shocks beyond the producer’s control. The foundation of modern economic theory is based on the assumption of optimizing behaviour, either from a producer’s or consumer’s perspective. Economic theory explains that producers optimize both technically and economically. From a technical viewpoint, producers optimize by avoiding waste of productive resources, while from an economic viewpoint, they optimize by solving allocation problems involving prices (Kokkinou, 2010).

Furthermore, Shantha (2019) explains the theory of production, which refers to the relationship between increased output and the use of a given set of inputs. It describes the mathematical relationship between the production of goods and a specific combination of inputs under a given level of technology.

Additionally, in general, economic production efficiency refers to a level of maximum level of capability in which all resources are fully utilized to produce the most cost-efficient product possible. At this point of maximum production efficiency, an entity cannot produce additional units without drastically changing its production process. In agriculture, technical efficiency can be measured against a production frontier that represents optimal performance. A farm is considered technically inefficient if it operates below this frontier, indicating a suboptimal use of resources. To reach the frontier and achieve technical efficiency, farmers have two options: either increase output using the current level of inputs, or maintain current output while reducing input usage.

Technical efficiency increases as farms move closer to the production frontier. Productivity differences between farms can be attributed to four main factors: operational scale, technological choices, environmental conditions, and the effectiveness of management in utilizing resources. These elements collectively determine each farm's success in converting inputs into outputs (Masuku and Sihlongonyane, 2015).

Farrell's (1957) seminal research on productive efficiency measurement has transformed how economists analyze firm performance. His work challenged the prevailing neoclassical assumption that all firms operated at full technological efficiency. Instead, Farrell proposed an influential alternative: defining the production frontier based on the performance of the most efficient firms in the industry. This methodological innovation has led to numerous studies exploring best practice technology and efficiency measurement over the years. Figure 1 illustrates the core principles of Farrell's efficiency measurement framework (Chiona, et al., 2014)



Source: Chiona, et al. (2014)

Figure 1: Farrell's Measure of Technical and Allocative Efficiency

Farrell (1957) examined a firm employing two factors of production, X and Y, to produce a single product, P, under the assumption of constant returns to scale. This situation can be illustrated using an Isoquant diagram, where SS' signifies all efficient input combinations needed for one unit of output. Point P indicates the actual input combination the firm uses per unit of output, while the Isoquant SS' reflects the theoretical minimum input combinations that a perfectly efficient firm might use, forming the lower boundary for that output level.

Technical efficiency is illustrated by point Q, which represents an efficient firm using inputs in the same proportion as point P. The ratio OQ/OP measures technical efficiency, indicating that Q could produce the same output as P while using only a fraction (OQ/OP) of each input. The distance QP reflects technical inefficiency – the amount by which all inputs could be proportionally reduced without reducing output. A firm is technically efficient if OQ/OP equals 1, and inefficient if the ratio is less than 1.

Allocative efficiency is measured using budget line AA', whose slope equals to the input price ratio. The optimal point Q' occurs where isoquant SS' is tangent to budget line AA', representing both technical and allocative efficiency. At this point, allocative efficiency is measured by the ratio OR/OQ, indicating the firm's success in using factors of production in optimal proportions given their prices. At Q', the firm achieves maximum economic efficiency by optimizing its input mix considering both technical capabilities and input prices (Chiona et al. 2014).

2.3 Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a non-parametric method developed by Charnes, et al. in 1978 to evaluate the relative efficiency of decision-making units (DMUs) that transform multiple inputs into outputs, without requiring specified functional relationships between variables. There are two primary DEA models: the CCR model (Charnes, Cooper, Rhodes), which assumes constant returns to scale and measures overall technical efficiency, and the BCC model (Banker, Charnes, Cooper), which accounts for variable returns to scale and separates pure technical from scale efficiency. Originally created for non-profit assessment, DEA's ability to handle multiple variables in different units has made it valuable across various sectors, with the key distinction being that BCC model considers operational scale's impact on efficiency while the CCR model assumes proportional input-output relationships.

2.4 Stochastic Frontier Analysis

Stochastic Frontier Analysis (SFA) is a widely used econometric technique for measuring production efficiency across various sectors, including agriculture and milk production. It is especially valuable for identifying inefficiencies in production while distinguishing them from random noise. This review explores the application of SFA in the context of milk production, focusing on its theoretical framework, key findings, and its contribution to improving the efficiency of dairy farming operations.

The stochastic frontier production function indicates the existence of technical inefficiencies among firms producing a specific output. However, many theoretical models of the stochastic frontier production functions have not clearly specified the technical inefficiency effects using appropriate explanatory variables (Battese and Coelli, 1995). The stochastic frontier production function suggests the presence of technical inefficiencies among firms producing a particular output. However, most theoretical stochastic frontier production functions have not obviously expressed a model for these technical inefficiency effects in terms of appropriate explanatory variables (Bettese and Coelli, 1995).

Early empirical studies addressing the explanation of inefficiency effects adopted a two-stage approach, in which the first stage involves the specification and estimation of the stochastic frontier production function and the prediction of the technical inefficiency effects, under the assumption that these inefficiency effects are identically scattered. The second stage contains the requirement of a regression model for the anticipated technical inefficiency effects, which contradicts the assumption of identically distributed inefficiency effects in the stochastic frontier (Bettese and Coelli, 1995). The stochastic frontier production function incorporates two error terms such as random effect and technical inefficiency in production.

The stochastic frontier model was separately proposed by Meeusen and van den Broeck (1977) and Aigner, Lovell, and Schmidt t al. (1977). Many researchers have applied this model, which initially used cross-sectional data to quantify efficiency and a two-stage formulation in early empirical work. The one-step technique was used recently in empirical research to estimate efficiency. Technical efficiency can be estimated using the stochastic frontier model as follows:

y = $(x; \beta)$ ε and $\varepsilon = vi - \mu i$ .... (1)

In this function, y represents the maximum potential output, while x refers to the vector of the level of inputs utilized, and β refers to the unknown parameters and εi is the stochastic error. It is anticipated that the two halves of the constructed error term will be distributed equally and independently. vi is a symmetric normally disturbed error term captured output variations caused by factors that are beyond the control of the farmer. In contrast, μ refers to a one-sided error term representing the inefficiency of the decision-making unit. Moreover, as Masunda & Chiureshe (2015) states, the technical efficiency can be estimated as follows:

$TE = exp(xi\beta + vi - \mu i) \backslash exp(xi\beta + vi)$ .... (2)
$TE = exp(-\mu i)$ .... (3)

A production unit is considered efficient if the value of $\mu i = 0$, which implies that the actual output is equal to the potential output. In this case, production unit attains the production and is deemed technically efficient. And the parametric model is estimated in terms of its variance parameters as follows:

$\delta 2 = \delta 2\ v + \delta 2\ u$ .... (4)
$y = \delta 2 \backslash \delta 2$ .... (5)

Where, $0 \leq \gamma \leq 1$, it is an essential variance metric for assessing whether a stochastic frontier model outperforms the conventional average production function. The technical inefficiency model can only be calculated in the case of cross-sectional data if the inefficiency effects for μi's are stochastic. The most popular method for estimating stochastic frontiers is undoubtedly the maximum likelihood estimator technique, which requires specifying the distribution of the error terms employed in the model (Battese,1997).

Either the one-step technique or the two-step approach may be used to implement the stochastic frontier approach to econometric modelling of technological efficiency. The one-step method incorporates all variables into the maximum likelihood estimate and treats them as firm specific. Nonetheless, there are certain external factors over which the firm has little or no control. As a result, modelling these elements and including them in the maximum likelihood probability estimate might bias the technical efficiency measurement.

The two-stage method, which involves estimating the production function and producing levels of efficiency before regressing them against a different set of variables that are not firm-specific, is criticized for potentially introducing persistence bias into the second stage, which can affect the estimates of efficiency (Wang and Schmidt, 2002). The stochastic frontier modelling technique is used in this work to measure technical efficiency in two steps. This approach is employed because it separates stochastic effects from those related to the decision-making unit.

2.4.1 Cost Frontier Model

According to Nan Jiang and Basil Sharp (2014), the cost function can be estimated using micro data on observed operating cost, input prices and output quantity. The general form of the cost frontier model is:

$C_{it} \geq C(W_{1it}\ W_{2it} \dots \dots \dots .W_{kit}\ Y_{it}: \beta)$……………………….(1)
I = 1, 2,………………….N
T= 1,2 ………………….T

Where C_{it} represents the observed costs of i in period t, W_{kit} is the k^{th} input price, Y_{it} is the output volume, and β is a vector of technological parameters depicting the relationship between the input prices, the output, and the minimum cost of production. To be a cost-minimizing solution, the cost function, C(·), must be nonnegative, nondecreasing in input prices and output, homogeneous of degree one, and concave in input prices (Coelli et al. 2005). This cost function is deterministic because it ignores statistical noise such as measurement error and random shocks beyond the control of the operator. Such random shocks can have significant effects on agricultural production. A stochastic cost frontier model that incorporates statistical noise can be specified as follows:

$C_{it} \geq C(W_{1it}\ W_{2it} \dots \dots \dots \dots \dots .W_{kit}Y_{it}) \exp\{v_{it}\}$…………………………….(2)

Where V_{it} is an independently and identically distributed random error component that reflecting statistical noise, usually assumed to follow a standard normal distribution with a mean of 0 and constant variance, The actual cost can be greater than the stochastic minimum production cost due to inefficiency, in which case:

$C_{it} \geq C(W_{1it}\ W_{2it} \dots \dots \dots \dots \dots .W_{kit}Y_{it}) \exp\{v_{it} + u_{it}$ ……………………….(3)

Where u_{it} is a non-negative, producer-specific inefficiency error term that follows certain distributional assumptions? If a firm is 100 percent efficient, the inefficiency error term is 0, meaning the firm is operating on the stochastic cost frontier. Cost efficiency is measured by the ratio of the stochastic frontier cost to the actual cost.

$$CE_{it} = \frac{c(w_{1it}, w_{2it}, \dots, w_{Kit}, y_{it}; \boldsymbol{\beta}) \exp\{v_{it}\}}{c(w_{1it}, w_{2it}, \dots, w_{Kit}, y_{it}; \boldsymbol{\beta}) \exp\{v_{it}\} \exp\{u_{it}\}} = \exp\{-u_{it}\}.$$
……………… (4)

The parameters of the stochastic cost frontier can be consistently estimated using maximum likelihood, provided that v_{it} and u_{it} are homoskedastic and independently distributed independently from each other and from the regressors. Producer specific cost efficiency can be estimated using Battese and Coelli's (1988) point estimator:

CE_{it}=E$[exp - (u_{it})\,|v_{it} + u_{it}$ ………………………………… (5)

Relatively a few studies have involved empirical analysis of cost effeminacy due to a lack of data that include input prices paid by each firm and sufficient variation in those prices.

2.5 Empirical Review

2.5.1 Dairy Production Efficiency Studies Conducted in Sri Lanka

Bandara and Weligamage (2018) studied the technical efficiency and its determinants of dairy production under extensive management in Eastern Dry Zone of Sri Lanka. They concluded that milk production achieved an average technical efficiency of 49.6%. indicating a potential to improve technical efficiency by 50.4%. In the production frontier analysis, the number of milking cows in the herd and the use of improved breeds were significant factors.

Further, the age of the farmer, herd size and education level of the farmers also significantly affected efficiency. To increase the efficiency of production, the use of improved cows, availability of milking cows in the herd and farmer education on dairying should be enhanced. This study focused on the extensive system in the Dry Zone and other farming systems were not studied. Therefore, studying on production of dairy farming systems for sustainable production is important for sustainable production.

Wijethilake, et al. (2018) conducted a study on factors affecting production efficiency in the Uva Province and found that farmer training, proper culling and access to AI are crucial. However, the study focused only on the Uva Province, and studying milk production efficiency using a farming systems approach is also important.

Malcolm, et al. (2019) conducted a study to identify the socio-economic determinants and estimate the technical efficiency of buffalo farming in Uva Province in Sri Lanka. Variables used in the production function included breed, average birth weight, shed condition, grazing duration, labour power, frequency of water provision, and cost of farming and feeding. Breed, birth weight and labour power were significant in the Cobb-Douglas production function. Extension services and frequency of water provision had a strong impact on determining the efficiency of buffalo farms.

The average technical efficiency is 86.8%. Therefore, the milk production can be increased by 13.2% through better use of extension services, high yielding breeds, quality feed, and adequate labour power. However, this study did not compare or consider various farming systems. Furthermore, different management types were also not taken into account.

Sheromiha and Kularatne (2016) analysed the technical efficiency of smallholder dairy farmers and the factors causing technical in-efficiency. A stochastic frontier production function was estimated using data collected on the management practices and general information. The study found that the mean technical efficiency was 45%

with a range of 40% - 55%, indicating that the dairy farmers were not fully technically efficient.

Farmer's education level, extension services, years of farmer experience, main source of income, training received, and land utilized for fodder and milking frequency significantly influenced technical efficiency. This study concluded that small-scale dairy farming is technically inefficient and transforming these farms into commercial enterprises is important. This study focused only small-scale farming and management practices; medium and large-scale farms were not taken in different farming systems. This study aims to analyse the socio-economic characteristics of dairy farmers and factors affecting technical efficiency in Uva Province of Sri Lanka. The technical efficiency analysis revealed that inefficiency caused a 37.1% loss among intensive farmers and a 20% loss among semi- intensive farmers. Based on the results, it is concluded that sustainability dairy production depends on farmer training, farmer societies, culling unproductive male animals, increased access to extension services, low-cost quality concentrate feed, and other supplements. This study focused on the productive efficiency of intensive and semi-intensive systems in Uva Province, but a comparison of different farming systems was not conducted (Wijethilake et al, 2018). "Reasons for Variations in the Levels of Efficiency in Smallholder Dairy Milk Production in Sri Lanka: A Cross Sectional Data Analysis" was conducted by Edirisinghe (2010), who concluded that technology or knowledge transfer is critical. He found that the average efficiency in dairy production was 52%, and human capital development is key to improving efficiency.

In addition, planed extension and training programmes are beneficial in increasing efficiency. However, this study was confined to Kurunegala district, did not consider variations in dairy farming systems, and focused only on small-scale dairying without addressing differences in production and farming systems.

Serasinghe, et al. (2003) conducted a comparison of Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) to evaluate technical efficiency. The technical efficiency scores from the parametric SFA and DEA methods were compared using production data from cattle farming systems in the up-country wet zone. Further, maximum likelihood estimates of the stochastic frontier were obtain and tested for returns to scale. Both methods showed that the integrated vegetable-based system is more efficient compared to the milk-based system. This study focused on comparing technical efficiency using two efficiency measures, especially data envelopment analysis method

2.5.2 Dairy Production Efficiency Studies in the World

Yilmiz (2020) analysed dairy production efficiency using cross-sectional data and applied Stochastic Frontier Analysis. The mean efficiency of the farms was 0.55, with efficiency ranging from 0.3 to 1. Further, 97.3% of the variation was attributed to inefficient use of inputs, while random factors contributed only 2.7%. Without using additional inputs, milk production could be increased by 45%. Significant factors affecting efficiency include household size, total number of cattle, technological level, barn type and production of maize silage.

Masunda and Chiureshe (2015) empirically investigated farm level technical efficiency of production and its associated determinants using a stochastic frontier model. They found an efficiency level of 54.9%, noting that dairy farmers are far below their production potential.

Age, veterinary extension, gender, and farming experience positively affected efficiency. Zamanian, et al. (2013) estimated technical efficiency using both Stochastic Frontier Analysis (SFA) and Data Envelop Analysis (DEA) for the agriculture sector of 21 countries during 2007-2008. The findings indicate that the average DEA efficiency of BCC and CCR models were 0.770 and 0.744, respectively, while the SFA score was 0.479. Although the SFA scores are consistently lower than the DEA scores, both DEA methods show similar country rankings. It is assumed that SFA removes statistical noise leading to more accurate efficiency estimates.

A study conducted in 2010 across three districts of Khyber Pakhtunkhwa (Peshawar, DI Khan, and Mansehra) in Pakistan analysed the technical efficiency of milk production. Data were collected from 300 livestock farmers through multi-stage sampling, with 100 farmers from each district. The results indicate that milk production is influenced by herd size, dry fodder, green fodder, concentrate/oil seed cake, hired labour, permanent labour,

The technical efficiency was estimated at 0.70, suggesting that farmers could reduce their input use by 30% while maintaining current output levels with existing technology. Furthermore, the results revealed that increasing age of livestock farmers was associated with declining efficiency, while farmers with more experience demonstrated higher efficiency levels compared to those with limited experience. Additionally, higher education levels among farmers showed a positive correlation with technical efficiency.

Based on these findings, this study recommends that government policies should focus on attracting younger, more energetic individuals to the dairy business, while also emphasizing the importance of education in improving technical efficiency among farmers (Sajjad et al, 2013). Further, Majwa, et al. (2012) studied the milk production efficiency in Kenya, aiming to increase milk production among smallholder farmers using the stochastic frontier production analysis. The findings reveal that the average technical efficiency was 79%, with 21% of production lost due to inefficiency of input utilization. Land size, access to extension service, infrastructure and level of schooling were found to reduce inefficiency.

Masuku and Sihlongonyane (2015) studied the technical efficiency of dairy farming in Swaziland, revealing several key factors influencing farm performance. While increased access to market information improved efficiency, both the frequency of extension visits and farmer age were negatively correlated with technical efficiency levels.

The study found an average technical efficiency of 78.2% among dairy farmers, indicating a potential to improve efficiency by 21.8% through better resource utilization. Farmers faced several challenges, including limited access to grazing lands, high costs of animal feed, difficulty obtaining necessary inputs, insufficient water resources, and labour shortages. To enhance both productivity and technical efficiency in the dairy farming sector, the study recommends improving the quality and delivery of extension services, supporting the development of farmer cooperatives, and securing better milk prices for producers. These measures would help address existing constraints and enable farmers to achieve higher efficiency levels.

Uddin, et al. (2010) conducted a farm economic analysis of different dairy production systems in Bangladesh and stated that the potential availability of input and support services plays a significant role in reducing the costs, increasing returns and improving productivity (TIPI-CAL Analysis).

Further, Masunda and Chiweshe (2015) applied Stochastic Frontier Analysis to study farm level technical efficiency in Zimbabwe, focusing on smallholder dairy farms. Cross-sectional data was used to measure efficiency through a two-stage approach. Bandara and Waligamage (2018) also used cross sectional data, while Paul and Shankar (2017) employed an alternative specification for technical efficiency analysis to measure technical efficiency of dairy production.

Ali-Sharafat (2013) examined the technical efficiency of dairy farms in Jordon using a stochastic frontier application. The analysis of sampled dairy farms revealed a concerning level of technical inefficiency, with a mean technical efficiency of just 39.5%. This indicates that the average farm could potentially increase its milk production by 60.5% using their existing input quantities. Effectively, Jordan's dairy farms are operating at only 40% of the industry's potential frontier production levels, with technical inefficiency accounting for the 60% gap below the frontier.

To bridge this substantial efficiency gap, two key recommendations emerge: enhancing farmers' access to extension services and encouraging greater farmer participation in the extension process itself.

2.6 Empirical Gap

The literature review indicates that limited studies have been conducted on dairy production efficiency in Sri Lanka, mostly confined to small dairy farming pockets. Most of these studies focussed on small-scale dairy farmers. In this study, stochastic frontier analysis is applied in the Dry Zone across four districts, considering different dairy farming systems. According to Edirisinghe (2008) understanding the exogenic impact of the production environment is crucial for policymaking aimed at enhancing efficiency. Therefore, studying dairy production efficiency in four different districts in Dry Zone in this study is important and useful for effective policymaking. Furthermore, analysing technical efficiency of the Dry Zone provides opportunities to minimize the costs and improve knowledge on the sustainable utilization of inputs to achieve the highest possible milk production.

CHAPTER THREE

Methodology

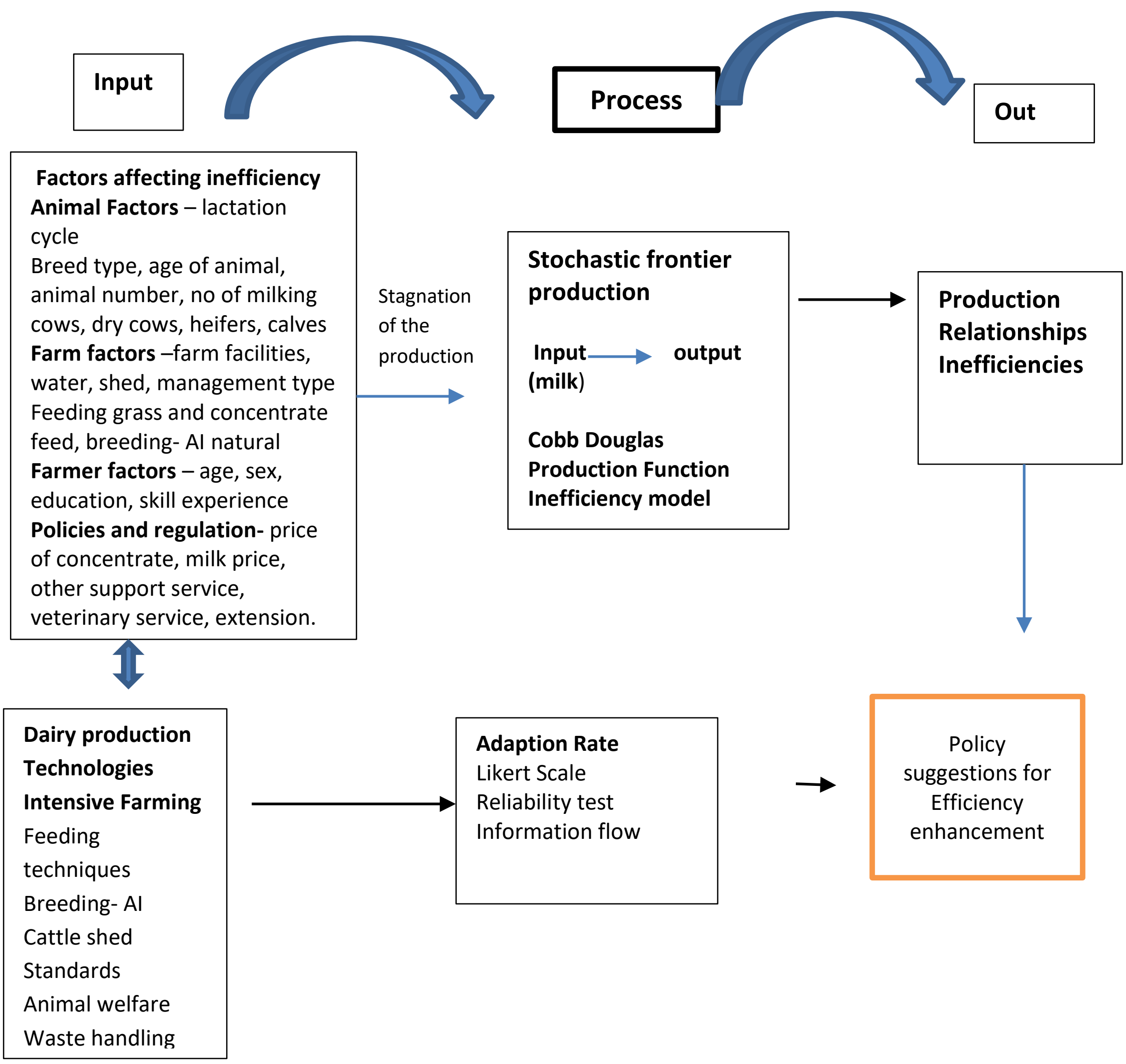
3.1 Conceptual Model

The conceptual framework explains dairy production efficiency using stochastic frontier analysis. It has been developed based on an input, process and output based approach. Accordingly, the input section of the framework describes the variations associated with dairy farming, including animal factors, farmer factors, farm factors, and regulatory and policy issues, all of which influence the stagnation of dairy production in farming systems of Sri Lanka.

Accordingly, the challenges and issues in the existing scenarios include high cost of production, lack of improved breeds, poor-quality concentrate feed and roughages, inadequate extension service, small herd size, inappropriate management practises and other infrastructure facilities. To estimate the technical efficiency of dairy production in different farming system Stochastic Frontier Analysis will be applied. This analysis will identify the factors contributing to milk production inefficiencies, focusing on dairy production-related factors, the farm-related factors and farmer-related factors.

Despite other outputs such as milk, manure and calves milk production can be considered the dependent variable. The independent variables, such as breed type, number of milking animals in the herd, herd size, feed cost, concentrate feed, grassland, veterinary cost, breeding cost, and labour hours per day are considered as firm-specific factors. Then, farm efficiency will be measured, and the farmer-specific factors - age, sex, education, training, and skills - will be regressed with the farm specific variables (Coelli et al. 2005)

Conceptual Framework



Source: Develop and adopted from (Rapsomanikis et al.2003)

Figure 2: Conceptual Framework

3.2 Objective One and Two – Estimation of Technical Efficiency and Determining Factors that Contributed to Dairy Production Efficiency in Different Farming Systems

The ultimate aim of this study is to propose efficient dairy production strategies for sustainable dairy development. The farming systems included in the study are from the Dry Zone. Accordingly, the Low Country Dry Zone, the Coconut Triangle, and the Jaffna Peninsula represent Dry Zone dairy farming systems and were selected for the study. Factors such as labour, medicine, technology, veterinary service, number of milking animals in the herd, breed type, management type (intensive, extensive and semi-intensive), and scale of production (small, medium and large scales) will be considered. The stochastic frontier analysis will be applied to measure efficiencies in dairy production. Data related to the characteristics of farming systems will be collected through key informant interviews and focus group discussions.

3.3 Theoretical Framework for the Technical Efficiency

The frontier production function can be defined as the maximum feasible or potential output that can be produced by a production unit, such as farm with a given level of inputs and technology. The actual production function (corresponding to the production unit's actual output) can be expressed as:

$Qi = f (Xi; \beta) \exp (-ui)$ and $0 \leq ui< \infty$; i= 1, 2...., n ………………. (1)

Where Qi represents the actual output for the ith sample (production) unit; Xi is a vector of inputs; and β is a vector of parameters that describe the transformation process; f (.) is the frontier production function and ui is a one-sided (non-negative) residual term. If the production unit is inefficient, its actual output will be less than the potential output. Therefore, we can treat the ratio of the actual output Qi to the potential output f(.) as a measure of the technical efficiency of the production unit. Using equation (1) above, we can express this measure as:

$TE = Qi / f (Xi; \beta) = \exp (-ui)$ ……………………………………………….(2)

It is noted that ui is zero if the production unit achieves the potential output with the highest technical efficiency and is greater than zero when production falls below the frontier (less than full TE). A random noise variable vi (independently and identically distributed normal with mean 0 and variance σv2) can be included in the equation (1) to capture the effect of other omitted variables that may influence the output, as:

$Qi = f (Xi; \beta) \exp (vi-ui)$ ………………………………………………… (3)

This new function is known as the individual-specific stochastic production frontier function. In order to estimate equation (3), a half normal distribution is assumed for ui (after empirical verification). The likelihood function for this model is:

$L = -N \ln \sigma$ - constant + $\sum [\ln \Phi (-\varepsilon i \lambda / \sigma) – 1 / 2 (\varepsilon i / \sigma 2)$ ……………. (4)

Where, λ = σu / σv, σ2= σv2 + σ 2, and Φ is the cumulative standard normal distribution function, and εi= (vi–ui). The maximum likelihood estimation (MLE) method can used to estimate the stochastic frontier production equation. The individual-specific TE is given by the conditional mean of exp (-ui), based on the distribution of the composite error term, εi.In addition, other important parameters of the model are: σ = √ (σu2+ σv2), λ = σu/σv(>0) and γ= σu2/σ2). A significant σ (and λ) would indicate the significant variations in the output levels. The λ term with value above one would indicate that output variations due to inefficiency are higher than that due to random factors. A zero value of γ would indicate that the deviations from the frontier are due entirely to the noise and, in this case, the ordinary least squares (OLS) estimates of the model are equivalent to the MLE results. A value of one would indicate that all deviations are purely due to differences in TE across farms.

3.4 Empirical Model and Data

This study uses the farming system data from the Dry Zone and dry part of the coconut triangle dairy farming system level data. Milk production data and factors affecting milk production in these specific farming systems will collect from the respective dairy farms. In this model, the empirical strategy consists of two stages. In the first stage, we estimate the stochastic frontier production function at the farming system level, district level and management level to assess technical efficiency for milk production. We began by considering various functional forms, such as transcendental logarithmic (trans log) function and Cobb-Douglas function, and found that the latter provides the best fit. Therefore, our stochastic frontier production function is given by:

ln Qi = β0 + βL ln L + βA ln A + βF ln F + vi –ui…………………… (5)

Where βi's are parameters to be estimated and Q,= milk production of the farm, and factors affecting milk production such as feed (Concentrate, Roughages), labour, breed type, management type, provision of water and other indicators can be identified. As mentioned before, the Maximum Likelihood Estimation (MLE) technique is used to estimate Equation (5). In the second stage, we estimate the determinants of TE by regressing socio-economic variables (listed below) against the TE values obtained from estimates of Equation (5). Since the estimated TE is bounded between 0 and 1, the model is specified as follows, using suggestions from the literature:

ln [TEi /(1-TEi)] = α0 + α1 X1 + α2 X2 + α3 X3 + α4 X4 + α5 X5 + ei ………………… (6)

Where, X1 is the age of the farmers X2 is the sex of the farmers, X3 is education level of the farmers, X4 is the dairy farming experience of the farmers, and other variables represent additional socio-economic indicators of the farmers.

3.5 Empirical Model Estimation

The Cobb-Douglass production Frontier Model is commonly used in a linear form by taking the logarithms of input and output quantities. The production function for each herd is as follows:

$$logy_i = logx + \sum_{j=1}^{m} \beta_j logx_{ij} + \Sigma_{k=1}^{2} \beta_k D_{kj} + \Sigma_{j=1}^{m}\Sigma_{k=1}^{2}\beta_{jk} D_{kj} logx_{ij} + e_j \;\ldots\ldots\; (7)$$

In the second stage analysis, the technical efficiency (TE) score estimates for i^{th} herd/farm obtained from the first step were regressed against selected farm and producer characteristics. The inefficiency model is given in the following equation:

$U_{i=}Z_i\delta + W_i$……………………………………………… (8)

U_1= Efficiency component of technical inefficiency

$\boldsymbol{Z_1}$=Vector of explanatory variables associated with the technical inefficiency effects

$\boldsymbol{\delta} =$ Vector of unknown parameter to be estimated

W_i= Unobservable random variables

3.6 Variables in the Efficiency and Inefficiency Models

Dependent variable **-** Milk production

Independent Variable (Farm Factors)	Measurement
Feed cost concentrate	Rupees
Pasture feed	Amount- kg- price
Milking cows/herd	Number
Herd size	Number
Milking at present	Number
Breed type	Improved, local
Animal breeding	AI, bulls
Pasture land availability	Yes, no
Veterinary cost	Rupees
Labour cost	Rupees
Type of management	Extensive, intensive, semi-intensive
Cattle shed availability	Yes, no
Farm infrastructure provision	Standard, lower standard
Extension provision	Type of extension received,
Role of private sector in extension provision	Production improvement support

3.7 Producer Specific Variables

Independent Variable (Farm Factors)	Measurement
Farmer’s age	Years
Sex	Male. Female
Education Level	Primary, secondary, GCE O/L, GCE A/L, Degree
Training received	Yes, no
Experience	Years
Member of farmer manage society	Yes, no
Skills	Yes, no

The dependent variable of the study was measured using average milk production litres per animals per day. Stochastic frontier analysis was applied to measure efficiencies in dairy production. Data related to the characteristics of farming systems were gathered through key informant interviews and focus group discussions.

3.8 Sampling Procedure

The stratified random sample method was used to select the sample. Accordingly, farmers were selected from different districts based on dairy management methods such as intensive, semi-intensive, and extensive systems to represent farming systems in the Dry Zone provinces of Sri Lanka. Based on the number of registered farmers in the Dry Zone, the representative sample was selected to the study.

Table 3.1: Sampling Procedure

Province	Districts	Farming System	Total Number of Dairy Farmers
Northern	Jaffna	Jaffna Peninsula	45
North Central	Anuradhapura	LCD	60
North Western	Kurunegala (dry part)	Coconut Triangle (CT)	65
Southern	Hambanthota	LCD	45
Total Number of Farmers			**215**

3.9 Objective Two – To Study the Level of Technology Adaption of Dairy Farmers

In Dry Zone dairy farming, the types of technologies used by farmers were identified using the Likert Scale method. Technologies related to dairy farming were measured using 5 scale Likert analysis. Dairy production efficiency-related technologies, such as feeding techniques, breeding techniques, manure management, forage production, mechanization, were assessed. The internal consistency of the data related to technology adoption was measured using a reliability test.

CHAPTER FOUR

Results and Discussion

The Results and Discussion chapter illustrate the socio-economic situation of the sample population, characteristics of dairy farmers, and the estimates from the stochastic frontier analysis. The first part of the chapter explains the characteristics of sample dairy farmers, including age, sex, scale of management, management methods, education level, experience, employment status, land ownership. In addition, breed types, their production performance, and the cost of production of one litre of milk will be discussed in detail. The dairy farming characteristics of the study area are also explained in this chapter. Moreover, the descriptive analysis of data and Stochastic Frontier Analysis are explained in detail.

4.1 Sample Distribution of the Study Area

Table 4.1 shows the representation of dairy farmers from different selected districts of Dry Zone of Sri Lanka for the study. Accordingly, 71 farmers from Kurunegala district were interviewed using a structured questionnaire. To represent other districts, 46 dairy farmers from Jaffna, 61 farmers from Anuradhapura and 38 farmers from Hambanthota were selected.

Table 4.1: Sample Distribution According to the Districts

District	Frequency	Percentage
Kurunegala	71	32.9
Jaffna	46	21.3
Anuradhapura	61	28.2
Hambanthota	38	17.6
Total	**216**	**100.00**

Source: Survey Data, 2023

4.2 Scale of Operation of the Sample Farmers

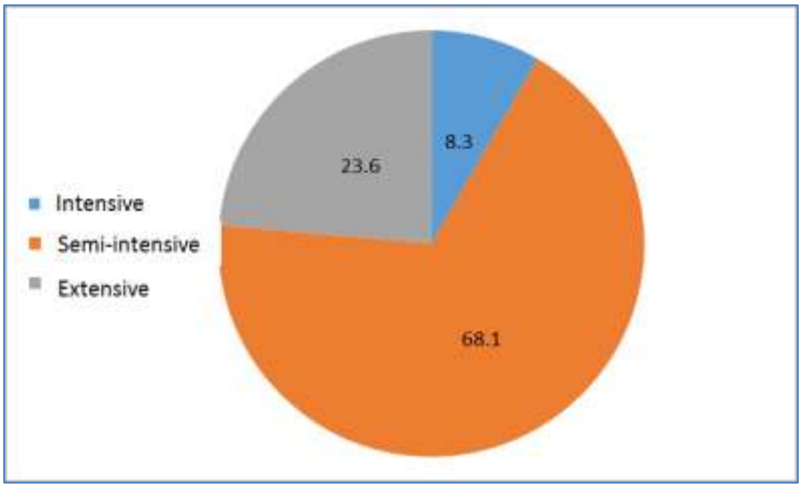
In the Sri Lankan context, the scale of dairy farming is categorized into three main groups: large scale with more than 50 milking cows; medium scale with more than 10 up to 50 milking animals and small scale as less than 10 milking animals in a herd. Accordingly, this sample consisted of 0.5% large scale farms, 46.3% medium-scale farms and 53.2 % small-scale farms.

Table 4.2: Scale of Operation of the Sample Farmers

Scale of Production	Frequency	Percentage
Large Scale (More than 50 Animals)	1	0.5
Medium Scale (10-50 Animals)	100	46.3
Small Scale (Less than 10 Animals)	115	53.2
Total	**216**	**100.0**

Source: Survey Data, 2023

4.3 Type of Dairy Management



Source: Survey Data

Figure 3: Dairy Management Systems of the Study Area

In general, dairy farming management in Sri Lanka can be classified into three main management types. Intensive management refers to cattle being reared inside the cattle shed with all inputs provided. Semi intensive management means providing inputs inside the cattle shed only during certain physiological stages and at night. Extensive farming refers to animals being allowed to graze freely with no inputs provided by the farmers. This sample comprises 8.3% intensive farmers, 68.1% semi-intensive farmers and 23.6% extensive farmers. According to the Figure 4.1, it is clear that the semi-intensive method of management is dominant in the area.

Table 4.3 illustrate the ethnicity of the dairy farmers in the study area. Accodingly, 76% of the farmers belong to the Sinhala ethnic group, followed by 23% Tamils and 0.5% Muslims. The Jaffna Pennisula predominantly represerents Tamil and Muslim farmers.

4.4 Age Level of Household

Table 4.3: Age Distribution of Farmers

Age Level of the Farmers	Frequency	Percent
<20	1	0.5
21-30	8	3.7
31-40	37	17.1
41-50	63	29.2
51-60	57	26.4
61-70	39	18.1
>70	11	5.1
Total	**216**	**100.0**

Source: Survey Data: 2023

It is noted that around 4.2% of the farmers in the sample are considered younger farmers. The age distribution shows that farmers between 31 to 50 years represent 46% of the sample. Further, it was found that 51 to 60 age group represents 26% of the farmers, while those aged 61 and above represent 23% of the total sample population.

4.5 Education Level of the Farmers

Table 4.4: Education Level of Farmers

Education Level of Head of the Household	**Frequency**	**Percentage**
Primary (up to grade 1-5)	19	8.8
Secondary (up to grade 6-10)	51	23.6
Up to G.C.E. (O/L)	49	22.7
Passed G.C.E. (O/L)	57	26.4
Up to G.C.E. (A/L)	23	10.6
Passed G.C.E. (A/L)	12	5.6
Degree	1	0.5
Diploma	2	1
No schooling	2	0.9
Total	**216**	**100.0**

Source: Survey Data, 2023

The table 4.5 illustrates the education levels of dairy farmers in the sample. Accordingly, it was clear that majority of the farmers have education ranging from secondary to GCE A/L. However, only around 5.6% of the farmers have passed GCE A/L. The sample also includes one degree holder and two farmers with diploma qualifications.

4.6 Employment Status of the Dairy Farmers

The research indicates that 88.4% of the farmers in the sample were employed, while the rest were not employed due to reasons such as age, retirement of formal jobs and severe illnesses. Further, it was found that for 72.2 % of the farmers dairy farming is the main occupation, while 16% are primarily engaged in crop cultivation. In addition, 3.6 of the farmers have their main occupation in government or private sector.

Table 4.5: Monthly Household Income

Primary Income Level of Households (Rs.)	**Percentage**
<10,000	2.6
10,001 – 25,000	12.4
25,001 – 50,000	27.8
50,001 – 100,000	26.3
100,001 – 200,000	21.1
200,001 – 500,000	8.2
>500,001	1.5
Total	**100.0**

Source: Survey Data, 2023

The survey indicates that, 2.6% of farmers earned less than Rs. 10,000, a month from dairy farming. Further,12.4% earned between Rs. 10,001 to 25,000.00. The majoriry of farmers, around 27.8% earned between Rs. 25,001 to 50,000. Additionally, 26.3% earned between Rs.50,001 and 100,000 and 21% earned Rs.100,001 to 200,000. Around 8.2% earned between 200,000 and 500,000 per month. Interestingly, about 1.5% earned more than Rs.500,000 from dairy farming.

Table 4.6: Land Ownership of the Farmers

Land Size(acres)	**Total %**
Less than 0.25	15.2%
0.25 - 0.5	3.3%
0.5 – 01	22.1%
01 – 02	29.9%
02 – 05	21.3%
05 – 10	5.8%
More than 10	2.3%
Total	**100%**

Source: Survey Data, 2023

The land ownership of the dairy farmers is described in table 4.6 , Accordingly,15% of the farmers owned less than 0.25 acres. Farmers who owned between 0.25 to 0.5 acres accounted for around 3.3%. In addition, 22% of the farmers owned 0.5 to 1 acre of land, while 29% owned 1-2 acres. About 21.3% of the farmers owned between 2 and 5 acres. Furthermore, to maintain a large scale farm with grazing land, a larger land size is essential. Accordingly, 6% of the farmers owned between 5 and 10 acres, and 2.3% owned more than 10 acres.

4.7 Avarage Milk Production by Breed Type in Dry Zone

Table 4.7 explains the average milk production by breed type in the Dry Zone of Sri Lanka. The main breeds found include: Jersy. Frisian and Jersey Friesian crosses. These breeds produce between 11 to 13 litres per day in Kurunagala and Anuradhapura districts. However, in the Jaffna and Hambanhota districts the average production is slightly lower, 8-9 litres per day. In addition, AMZ, AMZ-Jersey and Jersey-Sahiwal crossers produce around 10 litres per day. Further, it is also important to note that Murrach and Nili-Ravi breeds produces around 10 to 11 litres per day in all four districts and Surti animals yield about 8 litres per day in all four distrcits of the study area. Friesian and Jersey crosses produce an average of 8 litres per day in all four districts of the study area.

Table 4.7: Average Milk Production by Breed Type

Breed Type	Average Milk Production (Litres per day)			
	Kurunagala	**Anuradhapura**	**Jaffna**	**Hambantota**
Jersey	11	10	8	8
Jersey X Friesian	12	12	9	8
Friesian (F)	13	8	8	8
Sahiwal (S)	8	7	7	7
Sindhi (SN)	5	5	5	5
Hariana (HR)	6	6	6	6
AMZ	10	10	10	10
Indigeneous	3	3	3	3
Murrah (M)	10	10	10	10
Nili-Ravi (N)	11	11	11	11
Surti	8	8	8	8
Friesian X Sahiwal	8	8	8	8
ASF	10	10	10	10
Jersey X Sahiwal	10	9	9	9
Girilanda	8	6	6	6
Sahiwal X Girilanda	8	8	8	8
Sindhi X Sahiwal	6	6	6	6
ASF X Friesian	8	7	7	7
Ayarshier	9	9	9	9
Jersey Cross	8	8	8	8
Local	2	2	2	2
Friesian Cross	7	7	7	7
Sahiwal Cross	5	5	5	5
Mura Cross	9	9	9	9

Source: Survey Data, 2023

Table 4.8 illustrates the average, minimum and maximum milk production by breed type across different districts in the Dry Zone. Accordingly Jersey-Friesian crosses yield the highest average milk production in the Dry Zone. However, Jerset and Friesian breeds also provide higher milk yeilds under intensive management system. It is evident that the most suitable cattle breeds for the Dry Zone of Sri Lanka include Jersey, Jersey Friesian crosses, Jersey-Sahiwal crosses and Girilanda. Among buffalo breeds, Murrah and Nili-Ravi are identified as the most suitable for the region.

Table 4.8: Breed Type and Milk Production in Different Districts

Breed	Minimum Production (L)	Maximum Production (L)	Average Production (L)
Jersey (J)	1	14	4.52
Jersey X Friesian	2	12	7.44
Friesian (F)	0.67	16	6.30
Sahiwal (S)	0.67	10	4.61
Murrah (M)	1	1	1.00
Nili-Ravi (N)	0.4	0.4	0.40
Friesian X Sahiwal	1.5	10	4.25
ASF	1.25	12	5.07
Jersey X Sahiwal	0.75	13	4.07
Girilanda	2.5	12	7.25
Sindi X Sahiwal	6.2	6.2	6.20
Jersey Cross	0.38	9	3.79
Friesian Cross	6	6	6.00
Sahiwal Cross	7	7	7.00
Mura Cross	8	8	8.00

Source: Survey Data, 2023

4.8 Breed Type and Milk Production in Different Districts

Table 4.8 explaines the minimum and maximum milk production by breed type in the study area. Accordingly, Friesian cattle produced maximum of 16 litres per day, while Jersey cattle produced upto 14 litres per day. Jersey-Frisian crosses and Jersey-Sahiwal crosses also yielded around 12-13 litres per day. However, it is noted that Murrah and Murrah crosses produced 11 litres and 8 litres respectively, with both the minimum and maximum productions being the same for these breeds. The minimum production levels of some breeds are very low, which may be attributed to factors such as the age and lactation stage of the cow. Furthermore, in the Kurunegala district, the Girilanda breed recorded a maximum milk yield of 12 litres per day.

4.9 Cost of Production of Milk

Table 4.9: Cost of Production of Milk per Litre (Rs.)

District	COP With Family Labour	COP Without Family Labour	Cost per Animal per Day with Fixed Cost	Cost per Animal per Day without Fixed Cost
Kurunegala	290.84	116.78	500.00	202.09
Jaffna	256.91	127.11	763.97	388.54
Anuradhapura	427.75	108.08	522.29	154.55
Hambanthota	391.45	108.67	644.68	158.28

Source: Survey Data, 2023

Table 4.9 explains the cost of production of milk in study area. Excluding family labour, the cost of milk production in Hambanthota and anuradhapura was around Rs 108 per litre, whereas in Kurunegala it was approximately Rs. 116 and in Jaffna district it was around Rs. 127. The higher cost of production in Jaffna and Kurunegala is attributed to the fact that most farmers in these districts practice intensive farming methods and rely heavily on concentrate feed.

However, when family labour costs are included, the scenario changes. Anuradhapura and Hambantota districts show a higher total cost of production due to the significant contribution of family labour. Among all districts, Jaffna records the highest total cost per milking animal per day, while other districts report daily costs ranging between Rs. 500 and Rs. 644 per animal. Fixed costs—including expenditures on buildings, animals, and equipment—also contribute significantly to the total cost. As a result, the overall cost per animal increases when fixed costs are taken into account.

4.10 Descripive Statistics of Variables

Table 4.10 presents the descriptive statistics of the variables in this study. Milk production per month per herd is considered the dependent variable, while the other variables are treated as indipendent variables Further, the minimum, maximum, mean, and standard deviation values for each variable are presented.

Table 4.10: Descripive Statistics of Variables

Variables	Minimum Value	Maximum Value	Mean Value	Standard Deviation
Milk production litres per month	0	10,500	610	864
No. of milking animals	0	19	4	3.18
Age (HHH)	18	88	51.18	12.07
Experience of cattle farming	1	60	13.75	10.96
Total cost feed (per month) (Rs.)	651	225,000	34876	30,100
No. of animals	1	76	12	10
Labour cost (Rs.) with family labour) (per month)	0	105,000	42,524	13,178
Grass land management cost (per month)	0	45,000	5,666	7,696
Breeding cost (per month)	0	8,950	431	983.6
Water cost (per month)	100	12,000	1,741	1,965
Disease management cost (per month)	0	32,000	4,518	4,812.7
Insurance cost (per month)	0	1,667	14	127.72
Labour cost (Rs.) (without family labour) (per month)	0	45,000	3,517	10,763
Age of the cattle shed	1	34	7.23	6.14
Cattle shed cost	1,000	3,500,000	264,106	447,883
Cattle shed (per month)	0	10,714	1,804	2,246
Electricity expenses (per month)	0	15,000	2,571	2,279
Machinery expenses (per month)	0	80,000	6,800	12,214
Transport expenses (per month)	0	25,000	7,260	6,199

Source: Survey Data, 2023

Most of the minimum values are recorded zero, which reflects the reality that some extensive farmers in the Dry Zone of Sri Lanka do not use any inputs for milk production.. On the other hand, the maximum values are considerably high, indicating that some of the farms in the sample operate as large scale commercial enterprises.

The mean age of the sample dairy farmers was around 51 years, with the minimum age being 18 years and the maximum age was 88 years. The experience of the farmers ranged from one year to 60 years, whereas the mean experience of the farmers were 13.75 years. Some farmers use family labour for dairying, while other farmers use both family labour and hired labour for milk production. Therefore, labour costs with and without family labour per month was calculated seperately. The feed cost showed a minimum monthly cost of Rs. 651, whereas the maximum cost was Rs. 225,000. This means that even in extensive dairy farming, the feed cost holds a certain value, and the mean feed cost per month was Rs.34,876. This indicates that, on average, a farmer in the sample would spend around Rs.1,000 on feed costs.

4.11 Production Frontier Analysis

The Stochastic Frontier Production function was used to estimate the technical efficiency of different dairy farming systems in the Dry Zone of Sri Lanka. For this analysis, both farm-related factors and farmer-related factors were considered. Accordingly the following variables were used as farm and farmer factors for the Production Frontier Analysis.

In the technical efficiency calculation, variables such as the number of milking animals in the herd, amount of concentrate feed, amount of pasture, labour hours, frequency of water supply and the total number of animals in the herd were included in the maximum likelihood estimation. The results revealed a positive relationship between most variables and milk production, except for the total number of animals, which showed a negative relationship with milk output.

As described in Table 4.11, the number of milking animals and amount of concentrate feed per day exhibited a statistically significant positive relationship at 0.01 level of the P value. This implies that a 1% increase in the number of milking animal and the quantity of concentrate feed leads to 0.816 % and 0.799% litres increase to total milk output, respectively. Additionally, the frequency of water supply was significant at 0.025 level, indicating that a 1% increase in water supply frequency results in a 0.258% increase in milk production.

Except the total years of experience in cattle farming and the availability of a cattle shed, all other variables included in the inefficiency analysis exhibited a negative relationship with technical efficiency in the stochastic frontier analysis. Specifically, education level, age, membership in a farm society, and breeding method were negatively associated with milk production efficiency.

Table 4.11: Maximum Likelihood Estimates of the Cobb-Douglas Production Function of the Sampled Farmers

	Coefficient	Standard Error	P - Value	95% confident Interval	
Constant	4.81	0.24	0.000	4.3353	5.291556
No of milking animals	0.816*	0.577	0.000	7035438	0.929764
Concentrate feed per day	0.799*	0.208	0.000	.0391459	0.120725
Pasture per day	0.303	0.308	0.326	.0301523	.120725
Labour hours per day	0.166	0.560	0.767	.0301523	0.907586
Water supply frequency	0.258**	0.11	0.022	.0932377	.1264683
No. of animals/herd	- 0.012	0.207	0.951	0.4203345	0.3946536
Inefficiency model					
Constant	**1.44**	**2.413**	**0.549**	**3.282941**	**6.179626**
Educational Level	- 0.210	0.267	0.429	0.7345503	0.3123565
Experience of cattle farming	0.267***	0.138	0.054	0.3441286	1.292978
Gender	- 0.474	0.417	0.256	1.747429	0.6008499
Age	- 0.573	0.55	0.339	0.8788718	0.3947467
Farm Society Member	- 0.001	0.002	0.520	0.0065752	0.0033297
Method of breeding	- 0.281	0.372	0.444	1.014003	0.443798
Availability of Cattle shed	0.379	0.282	0.179	0.933746	0.1742621

Source: STATA Output, 2023

The experience of the farmer also affects their efficiency in dairy production in the study area. As the farmer's increases by one year, their efficiency also increases, showing a positive relationship between years of experience and certain aspects of farming efficiency. This may be the result of accumulated knowledge of farming practices over time, which can lead to improved decision-making, problem-solving, and overall efficiency.

4.12 Technical Efficiency Analysis

The sochastic frontier analysis explained that the average effiiciency of dryzone milk production was around 60%, whereas minimum efficiency was 15% and the maximum efficiency 92%. Depending on the district, the average, minimum, and maximum technical efficiencies of dairy production vary. Dry Zone dairy production was analyzed under different dairy farming systems, such as the dry part of Coconut Triangle, the Low Country Dry Zone, and the Jaffna Peninsula system. To represent Low Country Dry Zone, both Anuradhapura and Hambanthota districts were selected: to represent Coconut Triangle, Kurunegala district was selected; and to represent Jaffna Peninsula dairy farming system, technical efficiency in Jaffna district was calculated. Accordingly, the average efficiency in Kurunegala district was 77%, with a minimum of 65% and a maximum of 92%.

This indicates that, without changing or increasing the inputs in dairy farming, production efficiency could potentially be increased to 92%.The average technical efficiency of Anuradhapura district was 77%, with minimum and maximum efficiencies ranging between 72% to 81%. In Jaffna district, the average technical efficiency was 56%, with a minimum of 43% and a maximum of 64%. However, in Hambanthota district, the lowest average technical efficiency was observed, with a minimem efficiency of 15% and a maximum efficiency of 43%.

Table 4.12: Technical Efficiency-Average, Minimum and Maximum

District	Average Efficiency	Minimum Efficiency	Maximum Efficiency
Kurunegala	0.7716	0.6521	0.9293
Anuradhapura	0.7713	0.7278	0.8116
Jaffna	0.5677	0.4392	0.6492
Hambanthota	0.3290	0.1520	0.4301
Total	**0.6084**	**0.1520**	**0.9293**

Source: Frontier Output

According to the estimates of technical efficiencies of dairy production presented in Table 4.13, it is clear that in the Kurunegala district, milk production efficiency can be increased by 33% without adding any additional input. However, to reach the maximum efficiency level of 92% observed in the district, the existing resource utilization patterns must be managed more effectively. Similarly, in Anuradhapura district, efficiency can be increased up to 81% without changing the current resource levels. However, as explained in the frontier analysis, increasing the number of milking animals, the use of concentrate feed, and forage feed, and the frequency of water provision contributes to enhancing milk production.

In Jaffna district, the technical efficiency can be increased by 21% from the minimum level of 43% to the maximum of 64%, by improving input utilization. Efficiency of dairy production can be enhanced by simply applying correct concentrate and forage feeding practices, along with adequate water provision. The study also reveals that in Hambantota district, technical efficiency was at minimum level, as most farmers practice an extensive type of management. The maximum efficiency observed was 43%, indicating that appropriate utilization of inputs - such as increasing the number of milking animals, providing the correct amount of concentrate feed and roughages and improving the frequency of water supply - can significantly improve milk production efficiency.

4.13 Level of Technology Adaption of Dairy Farmers

In this study, several factors were considered to understand the level of technical adaptation among dairy farmers. These included the practice of artificial insemination (AI), provision of concentrate feed, availability and presentation of roughages, proper feeding frequency, use of machine milking, availability of cattle sheds and the adoption of certain practices to manage environment changes. Accordingly, 90% of the sample farmers provided concentrate feed to their animals. However, 10% did not, and these were mainly farmers practicing an extensive type of management.

Some farmers stated that they could not afford concentrate feed due to its high cost. Additionally, a few reported that the concentrate feed had used did not lead to an increase in milk production.

Grassland availability is a crucial factor for dairy development and, data indicate that 72% of the farmers maintained their own grassland, while 28% relied on road side grasses and other natural resources. However, the research also shows that 70.5% of the farmers owned less than 2 acres of land, making it difficult for many to maintain dedicated grasslands. Despite these limitations, maintaining a grassland is important, especially in the dry zone, where natural grasses become scarce during the dry season due to seasonal changes.

Maintaining a bio gas unit provides energy solutions to both the household and dairy activities. However, only 19% of the farmers had biogas units. This indicates that 81% of the farmers did not have a biogas unit on their dairy farms, mainly due to lack of financial constraints. In addition, the lack of proper waste disposal mechanisms and small-scale of many farmers from establishing biogas units. Cattle shed provides a comfortable environment for animals, which helps enhance milk production efficiency. In the total sample, only 18% of farmers did not own cattle shed. Most of these farmers reported that they lacked the funds to build one. However, even among farmers who have cattle sheds, many do not meet the required standards.

Water provision is also very important for milk production. When animals need to drink, having water freely available water is essential to enhance production efficiency. Depending on the physiological status of the animal, water plays a crucial role. This study found that 66% of the farms provide water at all times, while the rest supply water three times a day, twice a day or once a day. AI is practiced by 96% of the farmers in the sample, while the rest rely on natural breeding. Due to AI, the new generation of animals is more advanced compared to their mothers and F1 generation possesses improved milk-producing genes. Furthermore, machine milking has become increasingly popular in dairy farming. Most dairy development institutes provide financial support to higher-producing farms. This study confirms that 22% of the farmers own a milking machine. In addition, silage production is also developing in dry zone. This study found that around 18% of farmers produce silage in their farms. Silage production ensures a reliable feed supply in the Dry Zone and contributes to enhancing milk production efficiency.

4.14 Summary of the Chapter Four

This chapter examined dairy farming in the Dry Zone of Sri Lanka, focusing on milk production, technical efficiency, and the extent of technology adoption among farmers. In the analysis, monthly milk production per herd was used as the dependent variable, while farmer demographics, input costs, and farm characteristics served as independent variables. Descriptive statistics indicated that the average age of farmers was 51 years, with an average of 13.75 years of experience in dairy farming.

Monthly milk production ranged from 0 to 10,500 litres, with a mean of 610 litres, reflecting a wide disparity between smallholder and large-scale commercial farms. Feed costs varied significantly, ranging from Rs. 651 to Rs. 225,000, with an average of Rs. 34,876. Labour costs also showed substantial variation depending on whether family labour was included, indicating diverse management practices across farms.

To assess technical efficiency, the study employed a stochastic frontier production function. The results showed that the number of milking animals, the quantity of concentrate feed, and the frequency of water supply were positively associated with milk production. In contrast, a larger total herd size was negatively related to output, suggesting that merely increasing the number of animals does not necessarily lead to higher productivity. Variables such as pasture availability and daily labour hours did not show significant effects. Among the inefficiency-related variables, only the farmer's years of experience had a statistically significant positive influence, indicating that more experienced farmers tend to manage their operations more efficiently.

There was considerable variation in technical efficiency across the regions studied. On average, farms operated at 60.8% efficiency, indicating substantial room for productivity improvement without additional inputs. District-wise analysis revealed that Kurunegala and Anuradhapura performed the best, each with average efficiencies of approximately 77%, with Kurunegala reaching a maximum of 92%. Jaffna recorded a moderate average efficiency of 56%, while Hambanthota had the lowest at just 33%, reflecting low input use and predominantly extensive farming systems. These findings highlight the potential to improve dairy productivity, especially in underperforming districts, through better resource utilization.

In terms of technology adoption, 90% of farmers provided concentrate feed, although some were deterred by high costs or doubts about effectiveness. Grassland management was practiced by 72% of farmers, but land scarcity posed a constraint, as over 70% owned less than two acres. Biogas units were present on only 19% of farms, mainly due to financial and infrastructural limitations. Additionally, 18% of farmers did not have cattle sheds, and many existing sheds were substandard. Nonetheless, access to drinking water was relatively good, with 66% of farms providing unrestricted availability, which is crucial for maintaining milk yield. Artificial insemination (AI) was widely adopted, with a 96% usage rate, contributing to genetic improvements in dairy herds. Machine milking was practiced by 22% of farmers, while 18% engaged in silage production. These technologies are gradually gaining traction and are vital for enhancing feed availability and milk production during dry periods. Overall, the study underscores the importance of improving input management and encouraging the adoption of appropriate technologies to enhance milk production efficiency in Sri Lanka's dry zone.

CHAPTER FIVE

Findings, Recommendations, Resources Framework and Conclusions

5.1 Findings

1. **Dairy Farming Systems**
   In the study area, dairy farmers operate under three main management systems: 8.3% practice intensive farming, 68.1% follow semi-intensive methods, and 23.6% use extensive farming. Semi-intensive dairy farming is the most commonly adopted system in the Dry Zone.

2. **Demographic Profile of Farmers**
   The sample comprised predominantly male farmers (93%), with only 7% female participation. Age distribution revealed that 4% were under 30 years, 77% were in the 30–60 age group, and 22% were over 60 years old. In terms of education, 82% had studied up to GCE (O/L), 11% had passed O/L, and the remaining had completed A/L, diplomas, or degrees.

3. **Farming Experience and Occupation**
   Dairy farming was the primary occupation for 72% of the sample, while 16% were primarily engaged in crop farming. More than 60% of the farmers had over 15 years of experience in dairy farming, reflecting a highly experienced farming community.

4. **Forage Sources**
   A majority (72%) of farmers relied on roadside and naturally available grasses to feed their cattle. Only 28% owned dedicated grasslands for forage production, indicating a heavy dependence on communal or naturally occurring grass resources.

5. **Farm Scale Distribution**
   The study found that 53.2% of farms were categorized as small-scale, 46.3% as medium-scale, and only 0.5% as large-scale operations. This distribution, along with the dominance of semi-intensive practices, highlights the smallholder nature of dairy farming in the region.

6. **Key Production Factors**
   Milk production was significantly influenced by several farm-level factors, including the number of milking cows, quantity of concentrate and pasture feed per day, water supply frequency, and the availability of cattle sheds. Farmer-related factors such as training and years of experience also played a critical role in productivity.

7. Impact of Input Variables on Milk Yield

Statistical analysis indicated that both the number of milking animals and the amount of concentrate feed had a strong positive correlation with milk output at a 0.01 significance level. A 1% increase in milking animals and concentrate feed led to a 0.816% and 0.799% increase in milk output, respectively. Water supply frequency also had a significant positive impact at the 0.025 level, contributing to a 0.258% increase in milk yield per 1% improvement. Although pasture supply and labour hours were not statistically significant, they still showed positive trends in milk production. Interestingly, a 1% increase in total herd size resulted in a slight decline in milk yield (0.012 liters), indicating possible overcrowding or resource strain.

8. Technical Efficiency

Overall technical efficiency in the Dry Zone was estimated at 60.2%, suggesting that milk production could be increased by 40% through better use of existing inputs. District-level efficiency varied, with Kurunegala and Anuradhapura achieving 77%, Hambantota 55%, and Jaffna the lowest at 32%. The low efficiency in Hambantota was attributed to the widespread use of extensive farming methods.

9. Technology Adoption and Water Management

Most farmers had adopted basic dairy technologies; however, approximately 50% did not consistently provide adequate feed or 24-hour water access to milking animals. According to the Stochastic Frontier Analysis, continuous water availability alone could enhance milk production by 25% using existing resources.

10. Cost of Milk Production

The average cost of milk production, excluding family labour, was Rs. 103.20 per liter. By district, the costs were Rs. 100.73 in Kurunegala, Rs. 101.75 in Anuradhapura, Rs. 105.85 in Hambantota, and Rs. 104.78 in Jaffna. Feed costs accounted for about 70% of the total cost, and the average daily cost per animal was Rs. 225, underscoring the financial burden of feed procurement.

11. Dairy Breeds and Productivity

The primary dairy breeds observed in the area included Jersey, Friesian, Jersey-Friesian crosses, and Jersey-Sahiwal crosses. These breeds recorded milk yields ranging from 12 to 20 litres per day, reflecting moderate to high productivity potential under improved management conditions

5.2 Recommendations

1. **Strengthen Farmer Knowledge and Capacity**
   To improve dairy productivity, it is essential to conduct regular training programmes for farmers on proper concentrate feeding, the importance of 24-hour water provision, efficient pasture use, and proper cattle shed management. These trainings should be delivered through farmer field schools and local extension officers, with a special focus on areas like Hambantota and Jaffna where technical efficiency is low. Additionally, greater participation of women and youth should be encouraged through inclusive capacity-building initiatives

2. **Improve Feeding and Watering Systems**
   Feeding remains one of the largest costs and constraints in dairy farming. To address this, support should be provided for developing community-based feed production units for silage and concentrate feed. Promoting the cultivation of improved grasses on communal or private lands can also help reduce dependence on roadside and natural grasses. In parallel, infrastructure such as water tanks and pipelines should be subsidized to enable 24-hour water access, a key factor shown to significantly increase milk yield.

3. **Enhance Infrastructure and Farm Management**
   Improving farm infrastructure particularly cattle sheds play crucial role in increasing milk production and animal welfare. Financial and technical assistance should be offered to help farmers upgrade or construct proper sheds. Furthermore, farmers currently practicing extensive systems should be encouraged and supported to transition towards semi-intensive or intensive models, which have demonstrated higher efficiency and productivity.

4. **Improve Breeding and Herd Composition**
   To boost milk yields, efforts should be made to promote the use of high-yielding breeds such as Jersey, Friesian, and their crossbreeds with Sahiwal. Support for mobile artificial insemination (AI) and veterinary services is necessary to improve genetic quality and reduce downtime due to reproductive or health issues. Farmers should also be trained on effective breeding and herd management practices to ensure long-term productivity.

5. **Strengthen Technical Efficiency and Data Use**
   Enhancing technical efficiency, currently at 60%, requires better use of farm data and advisory tools. Introducing digital recordkeeping systems and benchmarking tools can help farmers track inputs and outputs more effectively. Advisory services should guide farmers on optimizing feeding, water use, and herd size to improve returns from existing resources without expanding herd numbers unnecessarily

6. **Empower Farmer Organizations and Cooperatives**
Local dairy farmer societies can play a central role in improving service delivery, collective input purchasing, and milk marketing. Support should be provided to establish and strengthen such organizations at the village level. Training on cooperative governance, milk quality assurance, and business planning will enable these societies to operate effectively and represent farmer interests in the dairy value chain

7. **Reduce Cost of Production and Increase Profitability**
To reduce production costs, particularly feed-related expenses, which account for 70% of total costs, group purchasing mechanisms should be promoted. Farmers should also be encouraged to produce feed on-farm and utilize agricultural by-products like coconut poonac and maize bran. Additionally, promoting value addition through curd, youghurt, and ghee production can help increase farmer income per litre of milk and make the sector more economically viable.

5.3 Resources Framework

Table 5.1: Resource Framework for Increase Farmer Income

Objective	Verifiable Indicators	Means of Verification	Assumptions / Risks
Outcome 1: Increase Farmer Income	1. Changes in household (HH) expenditure	DCS Surveys	Assumption: No market for milk
	2. High nutrition levels of HH members	DCS Surveys	Risk: Market limitations for milk
Output 1: Increase in Milk Yield per Animal	1. Enhanced technical efficiency (TE)	Estimates using DAPH data, sample surveys	Risk: Diseases, limited availability of concentrates, and water
Output 2: Farmer Training	1. Number of Farmer Business School (FBS) sessions	DAPH records	Assumption: Availability of extension officers
	2. Number of visits to farmers	DAPH records	Risk: Limited allowances for extension officers
Output 3: Loans to Build Sheds and Buy Concentrates	1. Initiate a loan system with banks	Bank records	Assumption: Availability of low-interest loans
	2. Number of farmers receiving loans	Bank records	Risk: High-interest rates from banks
Output 4: Improved Milk Collection Method	1. Dairy companies linked to farmers	Dairy company records	Assumption: Private sector participation

Output 5: Transition Small-Scale Farmers to Medium-Scale Farmers	1. Number of farmers shifted from small-scale to medium-scale	DAPH farm records	Assumption: Provision of high-yielding animals and sufficient inputs
			Risk: Limited access to inputs or funding
Output 6: Facilitate 24-hour Water Provision	1. Increase farmer knowledge of water provision and animal well-being	Surveys and DAPH Veterinary office data	Assumption: Availability of funding and infrastructure
	2. Improved water availability	DAPH Veterinary office level data	Risk: Limited assets and infrastructure
Output 7: Empower Farmer Organizations (FOs)	1. Number of functioning farmer organizations	DAPH records	Assumption: Increased farmer awareness and willingness to organize
	2. Exchange of knowledge and resources between organizations	DAPH records	Risk: Farmer resistance or lack of participation
Output 8: Access to Improved Technologies	1. Increase in knowledge and access to new technologies	DAPH, Technology provider reports	Assumption: Availability of technology partners and funding
	2. Number of farmers adopting new technologies	DAPH reports, technology providers	Risk: Limited funds and training opportunities

The table 5.1 illustrate the primary objective of the programme is to increase farmer income. This will be monitored using two main indicators: changes in household expenditure and improvements in the nutritional levels of household members. Data will be collected through surveys conducted by the Department of Census and Statistics (DCS). Achieving this outcome assumes there is a viable market for milk, but a key risk is the possibility of limited market access, which could prevent income gains despite increased production.

To support this objective, several key outputs have been identified. First, increasing milk yield per animal is crucial and will be assessed through improvements in technical efficiency, using data from the Department of Animal Production and Health (DAPH) and sample surveys. However, this could be affected by risks such as livestock diseases, limited availability of concentrates, and water shortages.

The programme also emphasizes farmer training, especially through Farmer Business School (FBS) sessions and farm visits. The number of sessions and visits will be tracked using DAPH records. This output relies on the availability of extension officers, while limited travel allowances for these officers could pose a risk to consistent farmer engagement.

Another essential component is providing loans to farmers for building sheds and purchasing feed. The success of this intervention will be measured by the establishment of a loan system with banks and the number of farmers receiving loans, verified through bank records. This assumes the availability of low-interest loans, though high interest rates may deter farmers from applying.

Improving the milk collection process is also a priority, aiming to link dairy companies directly with farmers. Dairy company records will be used to verify progress. This output assumes active participation from the private sector, which is critical to its success.

The framework further aims to support the transition of small-scale farmers to medium-scale operations. This will be monitored through the number of farmers shifting to larger-scale production, as documented by DAPH. The success of this output depends on the availability of high-yielding animals and adequate inputs, with risks including limited access to necessary resources or funding.

Ensuring 24-hour access to water for livestock is another output, with indicators focused on increased farmer knowledge about water's importance and actual improvements in water availability. These will be measured using DAPH veterinary office data and surveys. However, the availability of infrastructure and financial support is a key assumption, and a lack of these could limit impact.

The programme also seeks to empower farmer organizations (FOs). Indicators include the number of active organizations and their engagement in knowledge and resource exchange, verified through DAPH records. This relies on farmers being aware and willing to organize, but risks include possible resistance or low participation.

Lastly, enhancing access to improved technologies is vital. This involves tracking increases in farmer knowledge and the adoption of new technologies through reports from DAPH and technology providers. The effectiveness of this output depends on partnerships with technology providers and adequate funding, though limited training opportunities and funds may hinder adoption.

5.4 Conclusions

This study concludes that, based on the Stochastic Frontier Analysis (SFA), the number of milking animals, the amount of concentrate feed, and the frequency of water provision are significant factors that positively influence milk production in the Dry Zone of Sri Lanka. Despite the widespread adoption of certain dairy technologies, many farmers still fall short in implementing optimal practices—particularly in terms of balanced feeding and ensuring 24-hour water availability for milking animals. Dairy farming in the Dry Zone is predominantly carried out by small- to medium-scale farmers under semi-intensive management systems. Most rely on roadside and natural grasses, and many possess more than 15 years of experience in the field. However, technical efficiency across the region averages only 60.2%, suggesting that milk production could potentially be increased by 40% if available resources were used more effectively. Notably, there are significant district-level disparities in technical efficiency: Kurunegala and Anuradhapura demonstrate higher efficiency at 77%, while Hambantota and Jaffna lag behind at 55% and 32%, respectively largely due to the prevalence of extensive farming methods and limited resource optimization. The high cost of production, particularly due to feed expenses which account for 70% of total costs, continues to constrain profitability. Moreover, farmers lack consistent access to improved breeds, infrastructure, and organized support systems. These challenges highlight the urgent need for location-specific interventions, targeted farmer training, improved access to inputs and water, and the strengthening of local dairy farmer organizations. With coordinated efforts in policy implementation, infrastructure investment, and capacity building, there is significant potential to improve milk yield, reduce costs, and ensure a more sustainable and profitable dairy sector in Sri Lanka's dry zone. Strengthening technical efficiency and farmer support systems can ultimately contribute to national milk self-sufficiency and improved rural livelihoods.

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