Strengthening resilience and food security through the development of agroforestry in post-war Kilinochchi, Sri Lanka

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

Kilinochchi is the largest agrarian region found in Sri Lanka. It is an area that has been greatly affected by three decades of civil war, which led to the mass disruption of lives and livelihoods within this region. It is estimated that over 300 000 individuals were displaced during the years of war, and returning only now to their places of origin. Inadequate land policies along with the lack of transparency relating to land administration have made inhabitants within the Kilinochchi district apprehensive about their land ownership, and the security of their livelihoods. Farming is the dominant form of livelihood within Kilinochchi. Farmers in this region primarily cultivated paddy fields using extensive amounts of mineral fertilizers, pesticides, and herbicides. Usage of agrochemicals deviates from their traditional forms of cultivation prior to the onset of conflict between the separatist Liberation Tigers of Tamil Eelam (LTTE) and the Sri Lankan army. This extensive use of agrochemicals within the region coupled with severe droughts has contributed to the loss of nutrient resources in the soil, and has diminished food security within the region. Sustainable land-use systems such as agroforestry can help to decrease farmer dependency on agrochemicals for bountiful harvests, improve soil fertility and soil water retention, and also increase food security within rural communities found in the district. This study conducted a baseline survey to determine soil physical and chemical properties in order to implement agroforestry systems in Kilinochchi's dry zone climate. Implementation of the recommended agroforestry model is an attempt to enhance livelihoods and food security for resource-poor farmers and their families living in the region. The results indicated that the soils within the research site were low in soil organic carbon, total nitrogen, organic matter, and have near neutral to alkaline soils, and slightly compacted soils, which signify low levels of fertility. The vegetation survey indicated only 17 tree species existed on the research site. The low number of

tree species at the research site is evidence of the massive deforestation events that occurred during three decades of civil war. In addition, a qualitative study was conducted with farmers living on land surrounding the research site in the villages of Kanakambikaikulam, Thiruvaiyaar, Bharathipuram, and Malaiyaalapuram. The interviews revealed a wide variety of factors and constraints that affected land management practices and strained farmers' livelihoods, all of which impacted food security in Kilinochchi. These constraints included limited or no access to agricultural inputs (seeds and capital), lack of land tenure, water scarcity and poor soil fertility, inability to hire laborers due to monetary limitations, inaccessible markets, and external exports competing with local markets. There is presently no available information on the potential of agroforestry practices to ensure long-term food security within the region of Kilinochchi. There is also very little knowledge about integrating the rich traditional ecological knowledge (TEK) of the farmers with agroforestry practices. The collected data aims to fill these gaps in knowledge. Essentially, the results from the baseline soil survey will be used to design a model agroforestry system as a recommendation to help regenerate soil fertility, and help farmers create sustainable agro-ecosystem management plans. The model agroforestry system will be designed to increase crop yield without compromising the integrity of the agricultural fields for long-term food security and livelihoods in Kilinochchi, Sri Lanka.

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DEDICATION

This research has been life-changing for me. Sri Lanka is my homeland, and it pains me to see how difficult life has become for farmers living in the north within Sri Lanka's post-war context. In that sense, I dedicate my entire research to all the farmers in Kilinochchi in hopes that it can be used to improve soil infertility and alleviate food insecurity within their communities. Farmers are the backbone of our societies, where would we be without them?

TABLE OF CONTENTS

Contents

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

1. Background

Three decades of civil war in Sri Lanka have many adverse impacts on the environment and people in this region. Civil war within the region degrades the surrounding land through activities such as deforestation, shelling, and bombings resulting in massive environmental damage (McNeely 2012). Degradation of land through warfare results in marginalized soils hampering agricultural productivity and food security in the region. One of the agricultural systems most impacted by the war is paddy cultivation.

Rice paddy cultivation is the main agricultural sector in the country, and is mainly cultivated in the Northern Province of Sri Lanka. The Northern Province of Sri Lanka includes the regions of Jaffna, Kilinochchi, Mannar, Mullaithivu, and Vavuniya, and is further separated into the Vanni region. The Vanni region was once the northern stronghold of the separatist Liberation Tigers of Tamil Eelam (LTTE), and encompassed parts of the districts of Kilinochchi (to the north), Mullaithivu (east), Mannar (west), and Vavuniya (south) (Human Rights Watch 2008). Within the Vanni region, rice paddy cultivation is most dominant in the Kilinochchi district, which is known as the largest agrarian region found on the island (Government of Sri Lanka 2012). However, three decades of civil war has severely affected the rice production within the Kilinochchi district, which is responsible for nearly 12% of all paddy contribution to the Sri Lankan economy (Sarvananthan 2007).

Farmers in this region are known to cultivate paddy fields using extensive amounts agrochemicals, deviating from their traditional forms of cultivation prevalent before the onset of the civil war. Extensive use of agrochemicals within the region along with severe droughts has contributed to the loss of nutrient resources in the soil, and led to the degradation of soil biological, physical and chemical properties. Furthermore, in communities that rely on subsistence agriculture, degenerated soil decreases local food availability and increases food insecurity in the locality (Vermeulen et al. 2012). As a result, there is a need to expand our current knowledge on tropical soil management and conservation so that appropriate technologies and alternative land-use systems can be developed to improve soil fertility and food security for the Kilinochchi district.

Currently, quality of soil is declining globally at a rapid rate, and is directly related to agro-ecosystem management practices (Khumalo et al. 2012; Frageria 2002). Additionally, maintaining soil quality in tropical regions can be difficult due to climate variability, plant types found in the region, and human disturbances, all of which would impact soil fertility. As a result, it is important to implement land management practices that protect soil resources, which can then be used to improve crop productivity (Arshad and Martin 2002). Sustainable agricultural land management practices can be considered as an option that can be used to enhance agro-ecosystem resilience and improve soil fertility (Vermuelen et al. 2012). Sustainable land-use systems such as agroforestry, defined as the deliberate integration of woody species with agricultural crops on the same land unit (Nair 1993), have the potential to regenerate soil fertility and improve food security within the Kilinochchi region. Remediating degraded soils has other environmental benefits that include improved soil water holding capacity, improved floral biodiversity, and enhanced soil quality (Vermuelen et al. 2012); all are factors that contribute to sustainable crop productions and food security in Kilinochchi. Since suitable new lands for crop production are scarce in many tropical countries, regenerating soil fertility of existing arable lands is important for sustainable crop production (De Costa and Sankarra 2005).

Soil quality, defined as "the capacity of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Schoenholtz et al. 2000), is an important indicator of the soils ability to withstand climate perturbations, such as drought, in the environment (Schoenholtz et al. 2000). In a study by Fonte et al. (2010), it was found that implementing an agroforestry system in the dry forest zone of Central America improved soil aggregate stability, soil organic matter (SOM), nitrogen and phosphorous availability, which helped to improve soil fertility in the region. As a result, agroforestry would be a method to regenerate marginalized soils to improve soil infertility in order to alleviate food insecurity in the region of Kilinochchi.

Thesis Outline

This thesis is arranged into six chapters. It begins with the introduction, literature review, and chapter two the regional context and experimental plots in the study area. The remaining chapters three, four and five look at baseline soil survey, tree inventory and biodiversity, and interviews with agrarian households living in the Kilinochchi region. The last chapter presents recommendations for agroforestry designs based on the preceding chapters' findings, overall conclusions, and future research ideas.

Chapter 1: Introduces the relevant literature related to agriculture, food security and land use topics in Northern Sri Lanka. It includes research on agricultural practices and food systems, war and land degradation, the role of agroforestry practices in tropical biomes, and lastly land rights, policy, legislations that affect farmer's access to arable lands in the research region.

Chapter 2: Provides a description of the research site, and includes the experimental design, soil and climate details, and regional context of the site.

Chapter 3: Examines soil chemical and physical quality within the research site to develop a baseline soil survey.

Chapter 4: Inventories trees found in the research site and home gardens of agrarian communities of the surrounding villages of the research area.

Chapter 5: Examines current agricultural practices, land degradation, agroforestry practices, and struggles faced by farmers around food security living in communities surrounding the research site.

Chapter 6: Based on the preceding chapter's findings recommends agroforestry systems that will help remediate degraded soils and alleviate food insecurity in the region, and provide overall conclusions to the thesis.

CHAPTER 1: Literature Review

1.1 Introduction

This literature review documents the changes in dominant agricultural practices throughout the Northern Province of Sri Lanka in the last forty years. The Northern Province includes the districts of Jaffna, Kilinochchi, Mannar, Mulaitthivu, and Vavuniya. It is further sectioned into the Vanni region that includes districts of the Northern Province except Jaffna. Kilinochchi, located in the Vanni region of the Northern Province is an agrarian community largely focused on the production of rice in paddy fields to supply its income and food for the area (Vhrukumu et al. 2012). Rice paddy cultivation (herein referred to as paddy cultivation) as well as home gardens represent two of the major agricultural practices in Kilinochchi that will be discussed in section 1.1. In addition, in section 1.2 it will examine the historic and current data on agroforestry systems and its role on the remediation of degraded soils in war impacted areas focusing on the Vanni region in Sri Lanka. Prior to war, Kilinochchi was still the agrarian hub of Sri Lanka, and was known for its historic cultivation of rice (*Oryza sativa*), onions (*Allium cepa*), eggplants (*Solanum melongena*), and green chilli (*Capsicum annuum*) (Yatawara 2013). During the civil war from 1983 to 2009 and after its termination, hardly any research studies were conducted on agriculture. This has led to a large knowledge gap on land use, migration of farmers, impact on crops, crops sown, food security issues during and post-war times. The limited academic literature on agricultural practices in northern Sri Lanka is largely due to the previous inability of academics and researchers to obtain access to the northern regions of Sri Lanka during the period of conflict. What little information that is found on agriculture in the Northern Province state that Kilinochchi's agricultural community and practices were severely impacted by war (Vhurumuku et al. 2012; MRG 2011; WaronWant 2014). Section 1.3 examines literature on current land allocation policies in Sri Lanka focusing on how it affects agricultural land use, how it in turn affects agrarian livelihoods, and how accessibility to farmland affects the farmer's ability to secure food for themselves and their families in post-war Sri Lanka.

1.2 Agricultural Practices in Northern Province of Sri Lanka

The Northern Province of Sri Lanka is predominantly an agrarian economy that is dependent upon its agricultural outputs for provincial economic stability (Sarvananthan 2007; Domros 1979). The Northern Provincial district of Kilinochchi, found within the Vanni region, is one of the largest agrarian hubs on the island of Sri Lanka (GoSL 2012). The Kilinochchi district is comprised of many rural villages that practice small-scale farming and, until the start of civil war in 1983 that ended in 2009, utilized a very traditional form of agriculture (Petersson et al. 2011).

1.2.1 Traditional Farming Practices of Sri Lanka

Self-sufficient traditional forms of farming were prevalent throughout Sri Lanka until the British colonization of the island in the late 1700s (Dharmasena 2010). The traditional farming methods practiced by farmers in Sri Lanka ensured prolonged land fertility and pest protection for their crops. These methods included, i) cultivation of traditional rice varieties, ii) use of organic fertilizer (straw, green manure, cow dung, poultry feces, liquid fertilizers) on their fields, ii) natural weed management through hand weeding and bio-pesticides, iii) maintaining existing biodiversity, and iv) managing water without creating moisture stress (Dharmasena 2012). Furthermore, farmers also incorporated agroforestry practices such as silvopastoral systems with their traditional agricultural practices. A silvopastoral system is defined as land-use systems where both trees and livestock are combined on the same tract of land (Nair 1993). After the harvest, the use of livestock on paddy fields allowed farmers the opportunity to naturally control weeds in their fields. In addition, the grazing cattle also excreted dung and urine on the land which helped to fertilize and enrich the soil for the next growing season (Dharmasena 2010).Essentially, traditional farming practices were low-input systems that optimized the use of internal inputs (on-farm) resources and reduced the use of external (off-farm) resources (i.e. pesticides and fertilizers). The strong focus on internal and on-farm inputs benefitted the farmers and helped to maintain land integrity through lowered production costs and pollution of water, reduced pesticide residues in food, reduced farmer's overall monetary risk, and augmented both short and long-term profitability of the farm (Poux 2008). However, external factors such as globalization, civil war, open-economic policies, and inadequate agricultural policies has forced farmers in Sri Lanka to become more reliant on external inputs for crop production (Dharmasena 2010). This type of farming system that relied on external inputs for production of crops will be hereafter referred to as modern agriculture.

In essence, traditional farming systems throughout Sri Lanka were divided into two main sectors referred to as chena and paddy cultivation (Sandika and Withana 2012). Chena cultivation, also known as shifting agriculture, was used extensively within the dry zone of Sri Lanka (Sandika and Withana 2012; FAO 1999). This type of cultivation was dependent on rain for irrigation, and involved the process of clearing forested land for crops (Ratnasinghne 2002; Dharmasena 1994). It was believed that nearly 18% of Sri Lanka's land area was under chena cultivation, and about 250 000 farming families depended upon it for their livelihoods (FAO 1999). However, the extent of chena cultivation in the Northern Province is still unknown. It was believed that chena cultivation was the precursor to more modern agriculture practices including traditional home gardens and rice paddy cultivation, which was the dominant form of agriculture within the

Kilinochchi district (FAO 1994). Details on how farmers practiced agriculture during war were largely missing, and therefore the impact war had on famers' livelihoods presents a gap in our current knowledge.

1.2.2 Traditional Livelihoods: Home gardens

The cultivation of home gardens was one of the oldest forms of agriculture to spread throughout the Asian continent, and was depicted as an agroforestry system that had many ecological and social values (Kumar and Nair 2006; Linger 2014). Home gardens refer to traditional land-use systems found around a human settlement where various plant and tree crops were grown by homeowners to meet the food requirements of that household (Devi and Das 2012; Kumar and Nair 2006; Galhena et al.. 2013). Home gardens were usually arranged in a particular order based on practical considerations about the crops' specific sunlight and soil requirements (Devi and Das 2012). Home gardens can be classified as mixed, kitchen, backyard, farm yard, compound, or homestead plots (Galhena et al. 2013). Essentially, home gardens were important food systems that combat food insecurity in many tropical countries around the world. In addition, these gardens alleviated micro-nutrient deficiencies and provided families living in rural communities with a diverse range of fruits and vegetables, which may be inaccessible to them due to their limited income and distance to food markets (FAO 2010). According to the Centre for Disease Control and Prevention (2014), micronutrients are essential vitamins and minerals required by the body for development and disease prevention, and are only obtained from the diet. Iron, vitamin A, folate, iodine, and zinc are considered to be essential micronutrients. Therefore, micronutrient deficiencies are the lack of these vitamins, which result in malnourished, unhealthy, and impoverished communities (Caulfield et al. 2016). In addition, home gardens have many socio-economic benefits that have contributed towards nutritional security, food security, energy requirements, and income generation even within densely populated regions (Landreth and Saito 2014; Kumar and Nair 2006). Additionally, home gardens were remarkably flexible. Their structure and composition can be modified to meet the different livelihood needs of rural farmers regardless of the size of their property (household consumption vs. commercial good) (Peyre et al.. 2006). The ability to modify home garden cultivation to meet the various household needs of rural communities was important to maintain food security in individual households (Kumar and Nair 2006).

Currently, many rural areas in Northern Sri Lanka have undergone major changes within their agricultural sector (Karunaratne 2003). Specifically, commercialization and globalization of Sri Lanka's economic market resulted in a farming system that was dependent upon machinery and external inputs for viable profit (Kumar and Nair 2004; Karunaratne 2003; Landreth and Saito 2014). Furthermore, the Northern Province's economic market had evolved to a predominantly service-oriented sector where, prior to the war, agriculture had the greatest contribution to the gross domestic product (GDP) of Sri Lanka's economy (Sarvananthan 2007; Karunaratne 2003; Department of Census and Statistics Sri Lanka 2011). This service sector has contributed over 44% of total employment in Northern Sri Lanka, which had resulted in changes to traditional family-run farming systems including home gardens within this region (Department of Census and Statistics Sri Lanka 2011). Even though 35% of households within the Kilinochchi district, in the Northern Province, cultivated home gardens, the rapid increase of employment in the service sector raises serious questions about the permanence of these home gardens and food security for households living in the area (FAO 2011; Kumar and Nair 2006). Moreover, the three decades of civil war impacted agriculture and traditional agricultural practices, and led to substantial negative impacts on the once thriving food systems.

1.2.3 Traditional and Modern Practices of Rice Paddy Cultivation

Rice was and continues to be the most traditional and important economic agricultural crop for the national market in Sri Lanka (Domros 1979). In Sri Lanka, cultivation of this grain began ~ 800 B.C, and has continued to play a significant role in the country's agricultural economics since then (Jeyawardene 2003; FAO 1999). Sri Lanka was estimated to have about 2,800 different cultivars of rice that grow on a wide variety of soil, and were naturally tolerant to iron toxicity and pest infestation (FAO 1999). Sri Lankan soils, especially within the dry zones have a natural abundance of iron that was already present in the ground, which often led to iron toxicity (Wickramasinghe and Wijewardena 2003). Iron toxicity is caused by the excessive amount of soluble Fe^{2+} (reduced iron) that accumulate in flooded soils (Becker and Asch 2005). In addition, it is a problem that was normally associated with lateritic soils (Audebert et al. 2006), such as Ferric Lixisols (ISRIC 2014), and therefore considered a serious issue for the production of paddy fields in lowland areas (Becker and Asch 2005; Saharawat 2006; Audebert et al. 2006). Consequently, iron toxicity in paddy fields damage the cell structural components and impair the physiological processes of rice development (Becker and Asch 2005; U.S Environmental Protection Agency 2003), which could decrease rice harvests by 12-100% (Becker and Asch 2005; Sahrawat 2006), and therefore impact food security with the dry zone regions.

There were two paddy cultivation seasons known as *Sirupoham* and *Perumpoham*, which were concurrent to the two monsoons that occur in Sri Lanka. *Sirupoham* (Yala) occurs during the months of mid-March and early May during the First Inter Monsoon rains and *Perumpoham* (Maha) occurs during the months of mid-September/October and continues up to late January/ February during the North-East Monsoons (Department of Agriculture Sri Lanka 2014). In the 1980s, the Northern and Eastern Provinces generated nearly one-third of the rice production in

Sri Lanka, yet only 15 % of the nation's population lived in these two provinces (Sarvananathan 2007). Currently 33 % of all individuals who live in Sri Lanka are employed in the agricultural sector (Department of Census and Statistics Sri Lanka 2011), and predominantly within paddy cultivation. However, to date there is currently no published data on the percentage of farmers who are employed in agriculture within the Kilinochchi district. Paddy cultivation was a significant source of livelihood for people living in the Northern Province, and had shaped Sri Lanka's economy, society, culture, and religion (Jeyawardene 2003; IRRI 2014). However, due to war present levels of paddy cultivation in the Northern Province led to a decline in rice production. Rice production in the Northern Province made up nearly 12% of the national production levels in the 1980s but only accounted for 2% of total outputs in 2005 (Sarvananthan 2007) (Table 1.1).

Table 1.1- Paddy production between the years of 1980 to 2012 in the Northern Province and districts of Sri Lanka

Metric tons	1980	2000	2005	2010	2011	2012
Sri Lanka	2,134,000 (100.0)	2,861,000 (100.0)	2,013,000 (100.0)	4,300,600 (100.0)	3,874,801 (100.0)	3,845,944 (100.0)
Northern Province	248,000 (11.6)	84,000 (2.9)	168,000 (8.3)	110,600 (2.6)	210,126 (5.4)	259,937 (6.8)
Jaffna	65,000 (3.0)	21,000 (0.7)	14,000 (0.7)	20,000 (0.5)	20,381 (0.5)	20,611 (0.5)
Kilinochchi		N.A	53,000 (2.6)	3,000 (0.1)	45,998 (1.2)	73,884 (1.9)
Mannar	115,000 (5.4)	19,000 (0.7)	38,000 (1.9)	44,000 (1.0)	48,706 (1.3)	67,630 (1.8)
Mullaithivu	33,000 (1.5)	22,000 (0.8)	34,000 (1.7)	15,000 (0.3)	27,666 (0.7)	36,232 (0.9)
Vavuniya	36,000 (1.7)	22,000 (0.8)	29,000 (1.4)	28,000 (0.7)	67,375 (1.7)	61,580 (1.6)

Source: with permission from the author, Dr. Muttukrishna Sarvananthan, Point Pedro Institute, Sri Lanka 2014.

Prior to the Green Revolution, rice was cultivated using long growing season indigenous varieties, which were grown during a single season without the use of mineral fertilizers, pesticides, or herbicides (Jeyawardene 2003). As a result, Sri Lanka was able to sustain the rice consumption of its population as well as export it to foreign countries. However, with population growth the demand for rice amplified, which resulted in a trend to increase rice production (Herath 1981). By the late 1960s, with the Green Revolution in full swing, high-yielding varieties (HYV) of rice were developed and implemented mostly by farmers in dry zone Sri Lanka to increase total rice outputs (Herath 1981; Jeyawardene 2003). During this period, the Sri Lankan government encouraged farmers to use expensive mineral fertilizers and encouraged mechanization for rice production (Jeyawardene 2003). Furthermore, the cropping of HYV and subsequently of new improved rice varieties (NIV) resulted in monoculture paddy fields (Jeyawardene 2003). Consequently, the monoculture rice plantations caused problems with pests, such as bacterial blight (*Xanthomonas citri),* gall midge (*Feltiella acarisuga*), and blast (*Pyricularia grisea*), which increased the use of pesticides and herbicides in the field (Jeyarwadene 2003; Pimentel 1996). The increased use of agrochemicals also led to the degradation of soil quality and eventually decreased rice productivity within the dry zone of Sri Lanka (Pimental 1996). In addition, the Green Revolution transformed the agricultural landscape, affecting the natural biodiversity of rice in addition to increased farmer dependency on agrochemicals for crop production, and contributed to the loss of traditional farming knowledge (Shiva 1993; FAO 1999). Farmer dependency on expensive and highly unaffordable agrochemicals, coupled with three decades of war and degraded land has severely impacted traditional livelihoods and food security of people living in the Northern Province of Sri Lanka.

1.3 War and Land Degradation in Northern Sri Lanka

McNeely (2003) and Vanasselt (2003) stated that many underlying stress factors caused by social and economic disparities between ethnic groups can cause friction within a society and can lead to war. Along with the destruction of human lives and livelihoods, war posed a serious threat to land integrity. Land integrity is defined as an ecological system that is complex, intact, and able to sustain itself and its biotic community (Leopold 1966). War degrades land integrity by reducing its resilience to environmental stress through reducing natural biodiversity, deforestation and harmful contamination of land and water, thereby negatively influencing natural ecosystem structure and function.

1.3.1 Ecological Effect of War on Forests and Biodiversity

Prior to war, Northern Sri Lanka was characterized by its self-sustaining way of life and self-sufficient livelihoods. This self-sufficiency was threatened by the loss of land integrity. Modern warfare negatively impacted ecosystems through reduced biodiversity and compromised soil fertility. The negative impacts of war on biodiversity included, deforestation, soil erosion, land and water pollution, habitat destruction, and forced migration of people to marginal lands (McNeely 2003). These factors contributed to land degradation throughout the region. Furthermore, prolonged periods of war lead to deforestation and habitat destruction causing soil erosion and chemical contamination of soil and water (McNeely 2003). In addition, war disrupted, displaced, and dislocated people who were forced to flee and take refuge in camps or are forced to construct makeshift homes on marginal lands outside the war zone. This mass movement of people from one region to another influenced forest ecosystems and their biodiversity as people re-built their lives and livelihoods in a war-torn landscape (Human Rights

Watch 2008; McNeely 2003). As a result, the self-sustaining lifestyle was replaced with socioeconomic infrastructure defined by a 30-year long civil war.

Prior to the civil war Sri Lanka was already affected by land degradation issues caused by deforestation. This dates back to the time of British colonization of the island. Forests covered 84% of Sri Lanka, which started to rapidly decline between the years of 1880-1990 when deforestation of the island began (MEPA 1991). By the 1900s, forest cover had dropped to 70% and 44% by 1956 (MEPA 1991).The island experienced near eradication of its forests during the years of civil war, which led to large-scale deforestation of Northern Sri Lanka (Wanasundera 2006).In the early 1980s and early 1990s, government soldiers cleared the Northern dry forests of Sri Lanka because they believed it served as camouflage for the rebel forces (Pathmanathan 2014 pers. comm.). While there may be several documented impacts of war on people's lives and livelihoods in Sri Lanka, there is very little analysis about the impact of the civil war on Sri Lanka's northernmost dry forests other than what was previously documented by Mongabay (2006). Apart from forest clear-cutting, heavy aerial bombardments by government forces into perceived rebel territories resulted in the further loss of forests in the Vanni region of Sri Lanka (Suthakar and Bui 2008). In 1989, six years after the start of the civil war, only 24% or 1.58 million ha of land remained under natural forests (MEPA 1991). The consequence of this rapid rate of deforestation caused by warfare resulted in the loss of many endemic biotic species and decreased soil fertility in many regions of Northern Sri Lanka (MEPA 1991).

1.3.2 Role of Trees on Soil Integrity

Sustainable food production in rural communities was dependent on a stable environment and availability of arable lands to produce high yielding crops (FAO 2014). War inevitably destroyed these two very important components of sustainable food production, and led to an overall degradation of land and human livelihood. At a local and global level, trees played an important role in maintaining soil integrity. According to the FAO (2014), trees prevented soil erosion, stabilized hillsides, retained moisture in soil, and helped protect the productivity of agricultural lands.

Soil erosion is a major agricultural problem in many countries around the world. It is estimated that each year 75 billion metric tons of soil is lost due to wind and water erosion, and the loss of this soil makes agricultural lands unproductive (Pimental et al. 1995; Lal and Stewart 2013; UNCCD 2014). About 80% of the world's agricultural land is affected by moderate to severe soil erosion, caused by improper agro-ecosystem management practices and the loss of vegetative cover (Pimental et al.1995; Khumalo et al. 2012; Frageria 2002). Declined number of trees in active war zone accelerated soil erosion, resulted in land degradation, and was the important environmental and economic issue in sub-humid, semiarid, and arid environments (Lal and Stewart 2013) such as those found in Northern Sri Lanka. Furthermore, soil degradation made it more difficult to achieve food security and alleviate poverty in subsistent farming communities, because of the strong connection between erosion and desertification of land (FAO 2014; Lal and Stewart 2013).

In addition, trees affected climate and water availability, which are both vital to agriculture (Stapleton 2014). Trees provided valuable ecosystem services. The presence of trees within an environment improved the function of watershed, and also helped to maintain water quality, which is necessary for agricultural production (Stapleton 2014; Lal and Stewart 2013). In addition, landscapes with trees had the ability to store large amounts of water that was used by other hardy vegetation or released slowly into streams and rivers (FAO 2014). The loss of trees, limited the ground's capacity to store water which resulted in water shortage during the dry seasons and destructive floods in the wet season (FAO 2014). In both cases, the soil was unable to absorb and retain water resulting in soil erosion. Though information was available on the impact of war on soils in a global context (Berhe 2007; Briggs et al. 2009), there are gaps in the literature on how civil war impacted the integrity of soils in Kilinochchi, Sri Lanka. What little that was found was inferred from literature on war-induced deforestation of the land and its impact on the surrounding environment (Khumalo et al. 2012; McNeely 2003; Frageria 2002; Hecht et al. 2006; Alvarez 2008).

The negative impact on the environment caused by the civil war was enhanced by unsustainable farming systems found in the region. Farmers in the region shifted from traditional to modern forms of farming that were dependent upon large inputs of agrochemicals which had resulted in there degradation of soil chemical, physical and biological characteristics. As a result, the long-term dependency on agrochemicals led to a decline in soil organic matter (SOM), and thereby decreased the availability of nutrients in the soil for sustainable crop production (Eluyodin and Wokocha 2010). The lack of fertile soils in Kilinochchi posed a serious problem for communities that relied on subsistence agriculture for their livelihoods. Thus, there was and continues to be a need to expand current knowledge on tropical soil management and conservation so that appropriate technologies and sustainable land-use systems can be developed to improve soil fertility and food security.

1.4 The Role of Agroforestry Practices in Tropical Biomes

Agroforestry is a form of sustainable land management practice that enhances agricultural land's resilience to improve food security. Agroforestry is defined as the deliberate integration of woody species with agricultural crops on the same land unit, and encompasses three major principles of productivity, sustainability, and adoptability (Nair 1993). Agroforestry systems have the potential to regenerate soil fertility and improve food security for rural communities living in Kilinochchi. Hence, agroforestry systems implemented in tropical biomes can help to increase and improve crop yields, reduce external agricultural inputs, sustain and conserve soil productivity for agriculture in the future, and conform to existing and local farming practices in the region (Nair 1993; Raintree 1986). Furthermore, the FAO (2014) stated that the more closely an agricultural system mimicked a natural forest's canopy cover and understory vegetation, the less chance of soil erosion. Decreased soil erosion and enhanced soil fertility has other environmental benefits which include enhanced soil water storage, increased soil biodiversity, and improved soil aggregate stability (Vermuelen et al. 2012; Lal and Stewart 2013), which are all factors that could contribute to sustainable crop production and food security in the region of Kilinochchi, Sri Lanka.

1.4.1 The Role of Agroforestry for Food Security in War-Impacted Populations

General consensus in the literature stated that implementing agroforestry systems in war-torn and land degraded regions can greatly improve food and nutritional security (Lal 2004; Godfray et al. 2010; Garrity et al. 2010; Sanchez et al. 1997; Mokgolodi et al. 2011; Tscharntke et al. 2014; Magcale-Macandog 2010). Food security can be defined as an individual's ability to physically and economically access sufficient, safe, and nutritious food to meet their dietary preferences and maintain a healthy and active life (World Health Organization 2014; Magcale-Macandog

2010). Based on this definition, food security in the Northern Province had been strongly hindered by the civil war. War and civil strife led to the continuous underproduction of food and food insecurity in the affected regions (Messer et al. 2002). Long periods of war have many direct impacts on agricultural outputs in the affected areas.

A majority of inhabitants who lived in the Northern Province of Sri Lanka and in the Kilinochchi district depended on agriculture as their main form of household income (Vhurumuku et al. 2012). Rice was the main cultivation crop within the region. However, farmers faced major setbacks cultivating paddy due to various land-related issues, such as lack of land, lack of ownership, inaccessible land, and lack of affordability of land prices (Vhurumku et al. 2012). Those farmers who were able to obtain land for cultivation were unable to obtain good crop yields due to poor soil conditions caused by the civil war, current unsustainable agro-ecosystem management practices, and lack of socio-economic infrastructure that supported farming. The inability of farmers to produce and sell their products at a profitable price led to economic instability for them and their families (Misselhorn 2005). These issues prevented resettling families the ability to achieve food security within their communities. Furthermore, food insecurity in Kilinochchi is amplified by Sri Lanka's political instability and poor governance, which resulted in poor land allocation policies and increased inequality between the different ethnic groups in the country (Messer et al. 2000). Therefore, it was believed that implementing agroforestry systems in rural Kilinochchi can greatly enhance the fertility of existing agricultural fields, increase economic stability of agrarian communities (Sanchez 1997; Garrity et al. 2014; McGinty 2008), and improve food production and food security within the rural communities of Kilinochchi.

1.4.2 Maintaining Integrity and Conservation of Dry Land Forests through Agroforestry

Eleven percent of all tropical forest types are made up of dry land forests or dry forests (Gascon et al. 2004), and was the largest contributor to the world's supply of food crops and livestock (Centre for Biological Diversity 2013). Dry forests are typically found in regions that have less than 100 mm of rain over a 5-6 month period, and annual rainfall that is less than 1600 mm (Pennington and Ratter 2006). During the civil war, large tracts of dry forests were cleared by warring factions, and resulted in the near eradication of hundreds of valuable indigenous tree species (Centre for Biological Diversity 2013) in Northern Sri Lanka. The elimination of these dry forests resulted, not only in the loss of trees, but also the associated ecosystem services. Dry forests were crucial for the sustainable food production and economic stability of poor rural communities who lived in tropical countries (Pimental et al. 1997; Centre for Biological Diversity 2013). Agroforestry systems, integrated in everyday farming practices of agrarian households promoted food security, and also re-introduced local and indigenous tree species within farming fields, and further developed the stability and productivity of the agro-ecosystem (Kindt et al. 2005; Atta-Krah et al. 2004). Leakey (1998) stated that, the incorporation of trees in farming fields through agroforestry practices re-establishes the complexity and integrity of a natural ecosystem within that landscape. Intact ecosystems were essential for productive agriculture and provided a variety of vital resources such as soil organisms important for soil fertility, structure, quality and health (Thrupp 2000). Increased biodiversity on farmland encourages species richness on the landscape (Backes 2001), adding to the integrity of dry land forests. This species richness is maintained and increased by rural community members who possess a wealth of indigenous knowledge (Alao and Shuaiba 2013), and those that used to manage the trees on their land. In a study conducted by Thrupp (2010), it was discovered that the

Tzeltal Mayans of Mexico can recognize more than 1200 species of plants and trees, and use that knowledge to select specific tree species most suitable to the diverse soil types found in the region. This knowledge is further integrated in agroforestry systems to increase the quality and number of tree species found on the landscape. The implementation agroforestry systems in war affected regions could help to restore and conserve natural dry forests found in the area. The re-establishment of these forests on farm lands could promote critical ecosystem services, such as watershed management (BISE 2014; Bond et al. 2009), that could help to improve food security for community members and biodiversity in the area (Kindt et al. 2005).

1.5 Land rights, Policy, and Legislations in Northern Sri Lanka

Despite the end of three decades of civil war, land continues to be a contentious topic in the Northern Province of Sri Lanka, specifically with regards to landlessness, land tenure and ownership, and competing allegations for acquisition of land for public purposes (Fonseka and Raheem 2011). Inadvertently, these issues associated with land ownership also impact the livelihoods of communities found in these regions, of which 56% is agrarian (Sarvananthan 2007). In 2008 Human Rights Watch estimated that over 300,000 inhabitants, or 70 %, of the total civilian population in Vanni were internally displaced people (IDP), and were now attempting to return to their places of origin. However, upon their arrival they were faced with inadequate legislative framework and policy that does not help original property owners to reclaim their land and thereby rebuild their livelihoods (Fonseka and Raheem 2011). The historic and current administration of the constitution’s thirteenth amendment does not distribute land decision making power equally among all government stakeholders.

1.5.1 Land Policies and the Thirteenth Amendment

There are many laws and amendments within Sri Lanka's constitution which state the government's position and management of land, but these laws are also incomprehensible (FAO 2014). According to these laws, land can be private properties or held by the State. Land that was considered as private was governed by various tenure regimes whereas state owned land could be given away through grants, permits or leasing schemes, and usually under the Land Development Ordinance (1935, as amended), the State Lands Ordinance (1949), and the Land Grants (Special Provisions) Act (1979) (FAO 2014). However, land laws in Sri Lanka are not cohesive. Furthermore, the power to grant land to citizens can only be given by the State even though the thirteenth amendment was created to devolve land powers to all elected Provincial powers. According to the thirteenth amendment to the constitution (1987), land is a Provincial Council Subject and that the:

> *"Government shall make available to every Provincial Council State land within the province required by such Council…[and] the Provincial Council shall administer, control and utilize such State land, in accordance with the laws and statutes governing the matter."*

This amendment allowed the Provincial Councils certain land powers and decision making with regards to rights over land, land tenure, transfer and alienation of land, land use, land settlement and land improvement (Fonseka and Raheem 2010; Fonseka and Jegatheeswaran 2014).However, land continues to be held tightly by the State despite this law which is meant to transfer land powers to local governments to meet the needs of the province and the people. Basically, State land continued to be the property of the Republic and can be transferred by the Central Government at will and on the recommendation of the relevant Provincial Council to any individual or organization (Fonseka and Raheem 2010; Fonseka and Jegatheeswaran 2014). However, the thirteenth amendment (1987) also directly prohibited the Provincial Council from disposing and allocating land to citizens without the direct approval of the President, which indicated that the State was the dominant power in all decision-making processes with regards to land. Furthermore, the thirteenth amendment also called for the establishment of a National Land Commission (NLC), which would be responsible for developing the National Land Policy for state land (Fonseka and Raheem 2011). However, no such NLC was created and as a result Sri Lanka does not have any sort of comprehensive national policy on land (Fonseka and Raheem 2011).The failure to fully implement the thirteenth amendment raised serious concerns about the Central Government's level of commitment to create a democratic nation with devolved powers to every elected Provincial Council, as well as the livelihoods of people living within the region of Vanni caught between these complex laws (Angel 2008; Fonseka and Raheem 2011).

In the absence of these policy reforms, the Sri Lankan government had chosen an unconventional approach to solve a wide variety of land problems in northern Sri Lanka. Most of these issues are addressed using the cabinet passed Memorandum (Memo) and Land Circular documents produced in July 2011. The primary aim of the Memo and Land Circular was to identify any issues associated with land ownership and competing land claims, and accelerate the process of finding a solution for these problems (MLLDS 2014). In addition, the Land Circular also aimed to establish a process to examine land claims, and prioritizes the distribution of lands to individuals who were displaced from their places of origin during the war (MLLDS 2014). However, the Memo and Land Circular does not recognize land documentations that were provided by the de-facto LTTE administration during the war periods, which led to landless people within the Vanni region (Fonseka and Raheem 2011; MLLDS 2014). In addition, the process of land resettlement and distribution had become a method that was highly militarized, reflected in the Land Circular document, and allowed members of the Sri Lankan army the authority to be involved and even supersede civil administrative bodies on land-related issues (Korf 2004, Saparmadu and Lall 2014; Fonseka and Jegatheeswaran 2014). The military's active role in land administration made it harder for local governments to perform their duties without deferring to higher-level government authorities, which added to the existing trend of bureaucratizing and aggravating land issues (Fonseka and Raheem 2011). As a result, local provincial and district governments, who had no real power over land policies, were involved in resolving competing land claims, unable to provide a solution to the problem. This lack of organization and transparency regarding land administration as well as inadequate land legislations and policies made many inhabitants within the Vanni region apprehensive about the future of their land and the security of their livelihoods (Fonseka and Raheem 2011).

1.5.2 Landlessness, Land Tenure, and Ownership

Landlessness was a persistent problem in the Northern Province of Sri Lanka. It was not just a problem for IDPs but also for all inhabitants who did not have complete legal ownership and control over their land, including individuals whose lands were occupied by the Sri Lankan army (Fonseka and Raheem 2011). In Sri Lanka, 84% of all land was owned by the State owns while the remaining 16% was held in private hands (Bastian 2009) (Table 1.2). Furthermore, the portion of State owned land varied throughout the districts of the Northern Provinces. For example, land within the Jaffna district was predominantly held in private hands whereas land in the Kilinochchi district was mostly owned by the State (Fonseka and Raheem 2011).

Table 1.2 –Percentage share of State and privately owned land and their uses in Sri Lanka (adapted from Bastian 2009)

Category	Area (mill ha)	Share (%)
Total area	6.57	100
State owned	5.50	84
• **large inland waters**	1.20	18
• **forests and reserves**	2.18	33
• **agricultural land**	1.72	27
○ **under LDO lease(a)**	0.82	13
○ **under LRC (b)**	0.41	6
○ **tree crop plantations**	0.25	4
• **other**	0.40	6
Privately owned	1.07	16
Urban area	0.21	3

(a) State owned land given to small-holders under the Land Development Ordinance (LDO) permit which is renewed regularly
(b) Land acquired by the State under the Land Reform Law (1972) and held under the Land Reform Commission
(c) Land used for plantation crops. These plantations are now privately owned and managed. The land for the plantations is acquired from State under long-term lease.

It was within the Kilinochchi region where individuals have found themselves contesting with government officials over land ownership. This problem was further exacerbated by the different factions who administered land in the North over the three decades of conflict. With the disturbance of the civil war, many of the government enacted laws regarding land regularization and ownership were not reinforced especially in areas that were controlled by the Liberation Tigers of Tamil Eelam (LTTE). In these areas, the LTTE acted as the de-facto government, and along with the civil administration at the time provided land documents for particular plots of land without any regard for whether it was State or private land (Fonseka and Raheem 2011; Bastian 2009; World Bank 2008). Those practices were accepted and even normalized in the areas held by the LTTE. However, government officials have challenged the validity of these documents, which officially brands the contesting individual as an encroacher on State land.

Those deemed to be seen as encroachers on State land find themselves stripped of any right to land and property. In fact, regardless of their status as IDPs or previous residents of the North, these people became without voice, security, and the ability to take any sort of action on their lands to improve their livelihoods (World Bank 2008) regardless of previous land ownership claims. In these instances the people became landless and found themselves without home, land tenure, and livelihoods, forcing them into poverty, insecurity and at times migration. This forced poverty only added to the existing poor already living in the Northern Provinces, which is estimated to be about 85% of the population and predominantly of Tamil heritage (Sarvananthan 2007; GoSL 2002). In addition, many people who lived in the Northern Province of Sri Lanka had no awareness about land rights and ownership within their province (Fonseka and Raheem 2011; Klopp 2002). A frequent problem in the Northern Provinces was associated with people's belief that living on the land was proof of ownership as it was provided to them by the different authorities who administered land in the area during the war (Fonseka and Raheem 2011). This belief along with the other issues faced by the returnees placed them in a delicate and precarious position, which threatened their access to sustainable livelihoods and household food security.

1.5.3 Competition for Land with the Nation State

Sri Lanka's numerous land related issues around the topic of land ownership for returning community members of the North was only further aggravated by the States' own agenda to obtain land for military and cultural colonization as well as infrastructure development (Klopp 2002).

Despite five years since the end of the civil war, military occupation in the Northern Provinces of Sri Lanka continued to be exceptionally high (Sarvanathan 2007; MRG 2011). It was estimated that the ratio of military personnel to civilians was 1:3 in the Vanni region, which was considerably higher than the 1:11 ratio found in the Jaffna Peninsula (MRG 2011). Furthermore, the military was rapidly taking over civil administrative procedures in the North and had replaced many authoritative positions with retired high-ranking military personnel's, who are mostly of Sinhala descent (MGR 2011; ICG 2012). This resulted in the militarization of civil administration in such a manner that local government authorities had lost control over every-day decision-making especially with regards to the re-allocation of land to returning Tamil people. Moreover, the increased military presence in the Vanni region resulted in a culture of fear. Many villages were kept under the tight vigilance and scrutiny of the army, and any civil activity, such as farming, could not take place without permission from the army (MGR 2011; Fonseka and Jegatheewaran 2014). The increased military presence in Vanni also resulted in another much larger issue of land appropriation. In the Kilinochchi district, many public and private properties were seized and used by the military to build camps and other structures for their use (Fonseka and Raheem 2011). In many cases the military acquired these lands after they drove off original land owners despite the fact that they possessed legal deeds (Senathirajah 2014). In other situations, the army actively grabbed fertile agricultural land to build their military bases and deprived farmers of their livelihoods (Halliday 2014; Linberg and Herath 2014). In addition, the government started to grab land for infrastructure development in the North, which fell under the umbrella term of "high security zones (HSZ)." High Security Zones were highly restricted military buffer zones that were formed on the basis that they were strategic military positions during war (Fonseka and Raheem 2011). Even in the aftermath of the war, the government continued to sanction HSZs in the North even though these areas were not legally established (Fonseka and Raheem 2011). Many of these HSZs in the North have been were placed on some of the most fertile agricultural lands and were highly barricaded by military checkpoints. People were unable to access these lands or use it to farm without permission from the army (Lindberg and Herath 2014). It was estimated that over 26 000 people were unable to return to their lands because of military occupation or because of government-instigated development projects (Lindberg and Herath 201). As a result, Tamils still continued to struggle to reclaim their lives and livelihoods in the North (ICG 2012

1.6 General Research Objectives

The short-term objective for this study was to collect baseline information on the current condition of a site previously degraded due to warfare in the Kilinochchi region. This baseline information included a thorough investigation of soil chemical and physical characteristics. The collected information was used to determine suitable agroforestry practices for the alluvial landscape of this research site. The long-term objective of this project was to recommend several future agroforestry research endeavors that can be demonstrated on site. The ultimate aim is to aid local and regional subsistent farmers to initiate agroforestry practices that are most beneficial and applicable to their specific circumstances based on results derived from agroforestry research endeavors. A mosaic of agroforestry systems adopted by local communities in the region will enhance the environmental services provided by the land, improve soil and crop productivity, and eliminate food insecurity issues in the region. This research is unique because there are no published studies that investigate land previously occupied by warfare, and the potential of agroforestry practices to rehabilitate marginal land for agriculture production in Kilinochchi, Sri Lanka.

CHAPTER 2: Regional Context of the Study Area and Experimental Plots

2.1 Regional Context and Study Area

The district of Kilinochchi (9.3833° N, 80.4000° E), situated in the north of Sri Lanka (Figure 2.1), covers a total area of132 499 km^2 (FAO 2002). It is a region classified as having reddish brown earth soils or Lixisols (Jayawardane and Weerasena 2001; FAO 2014). The region is dominated by a mix of tropical savannah, moist deciduous and dry-evergreen forests (Illangasinghe et al. 1999). The Kilinochchi district is divided into four sub-divisions of Pachchilaippali, Kandavalai, Karachchi, and Poonakari (Department of Statistics Sri Lanka2014) (Figure 2.2).

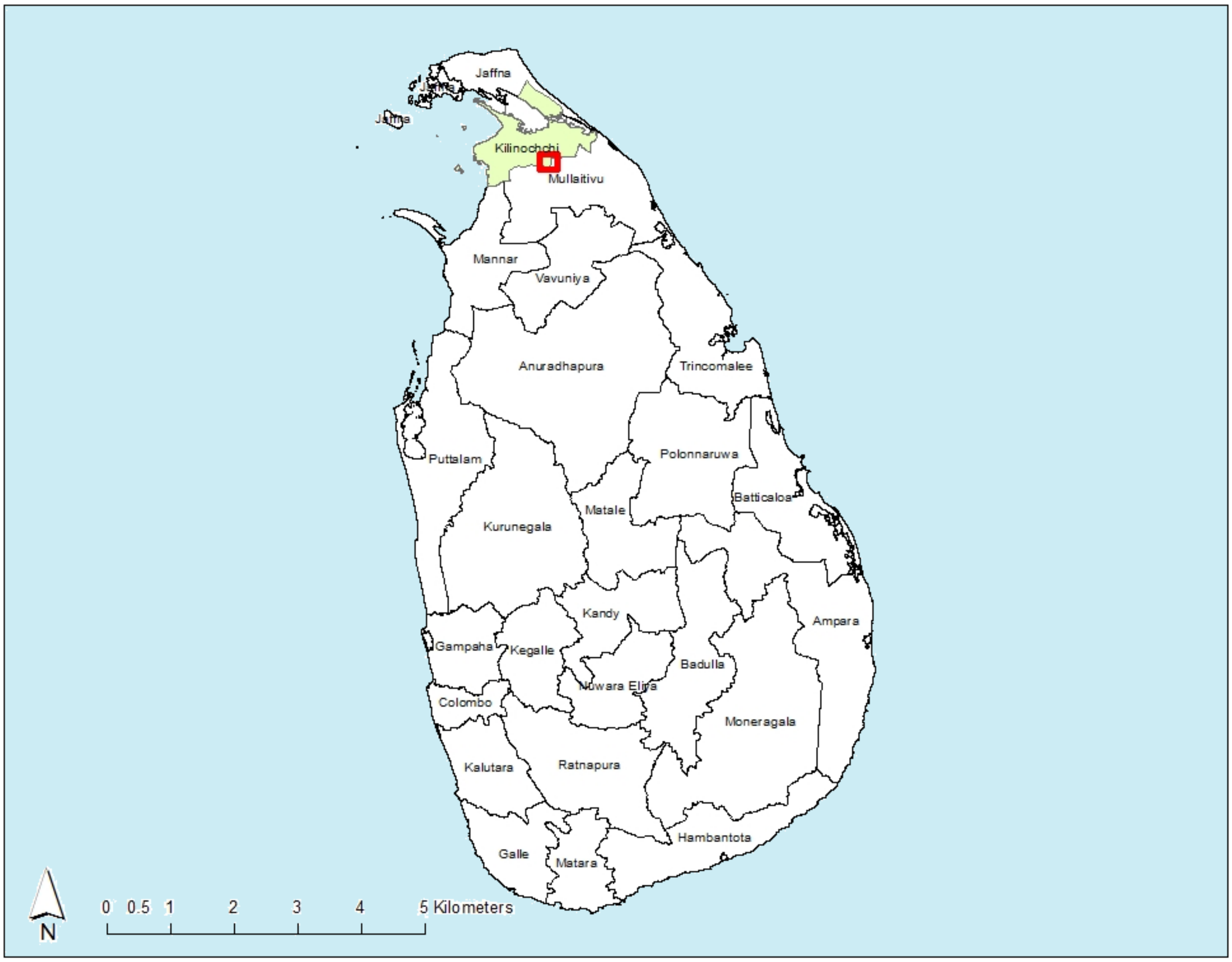


Figure 2.1- The district of Kilinochchi (9.3833° N, 80.4000° E) situated in the north of Sri Lanka

According to the Department of Agriculture (2014), Kilinochchi is located in the low country agro-ecological zone classified as the dry zone (Figure 2.3). As a result, regions categorized as being part of the low country are distinguished as having an elevation below 300 m. Moreover, Kilinochchi is known to have fluctuating temperatures. The average maximum temperature ranges from 32-35°Cwith the highest degree recorded during the months of February to early March. The average minimum temperature ranges from 22-24°C with the lowest degree recorded during the months of December to February. The dry zone has an annual average rainfall less than 1,750 mm with a distinct dry period from May to September (Punyawardena 2004; Domros 1974).

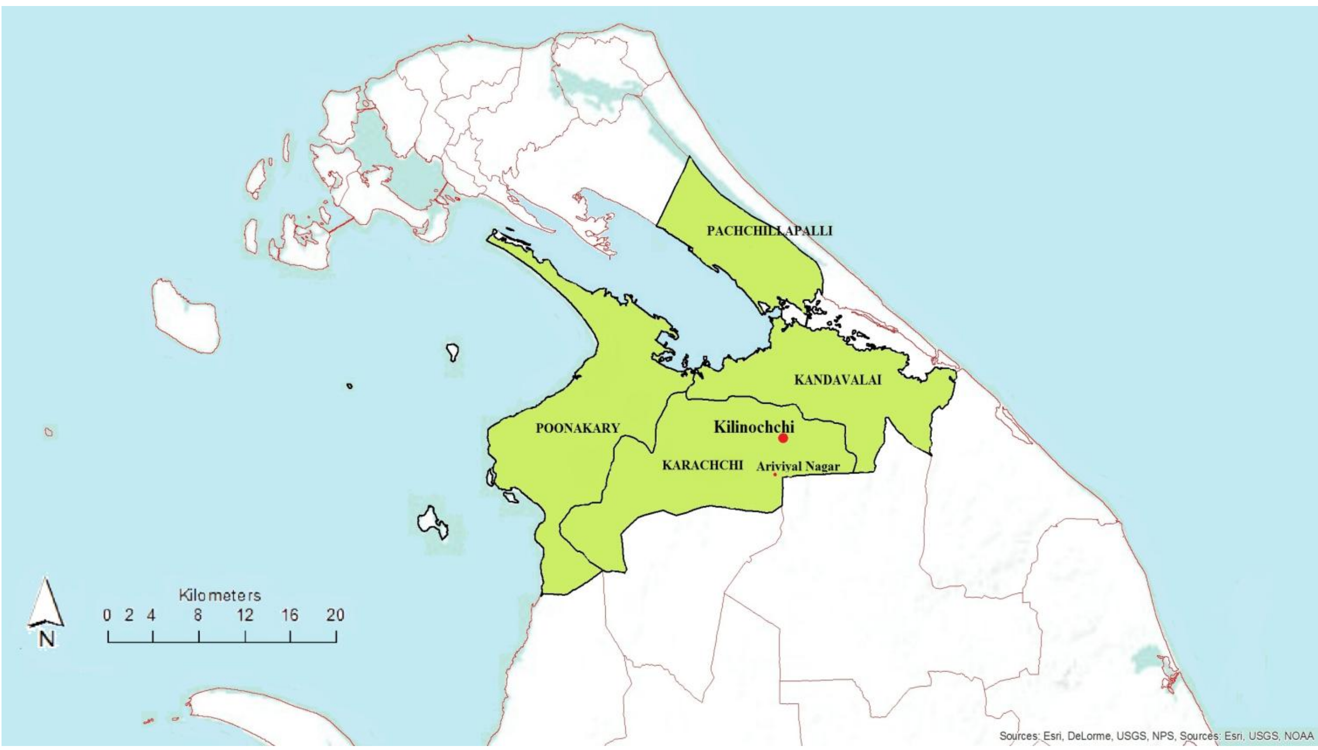


Figure 2.2- Map of Kilinochchi district showing the town of Kilinochchi and Ariviyal Nagar research site within the district's four sub-divisions of Pachchilaippali, Kandavalai, Karachchi, and Poonakari

Rainfall quantity can vary depending on the season. Maximum rainfall quantity for the entire wet season can reach up to 3 200 mm, while minimum rainfall quantity can go as low as 100 mm (Department of Meteorology Sri Lanka 2012). The dry zone has usually experienced most of its rains during *Perumpoham* or the Second-Inter-Monsoon.

According to the Department of Agriculture Sri Lanka (2014), there are two consecutive growing season in dry zone Sri Lanka. These growing seasons are called *Sirupoham and Perumpoham*, and usually coincide with the Second-Inter-Monsoon (*Perumpoham*) between the months of March to early May and October to November. The *Sirupoham* is considered to be a minor growing season in the region. Major crops typically cultivated during the growing season are rice (*Oryza sativa*) onions (*Allium cepa*), and green chilli (*Capsicum annuum*) (Sarvananathan 2007). However, most of the revenue obtained during the growing season is derived from rice cultivation than any other crops (Sarvananthan 2007).

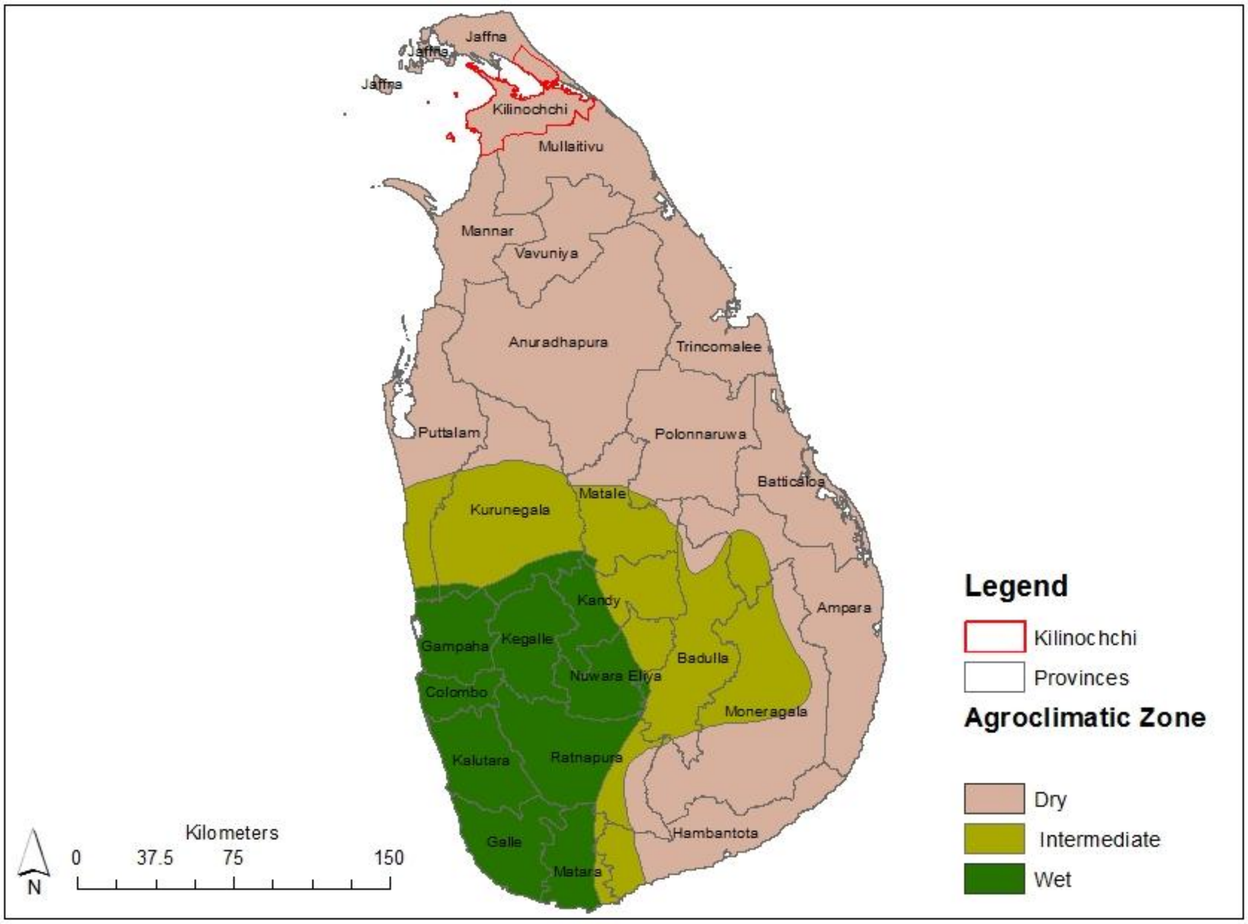


Figure 2.3 –Location of Kilinochchi in the low country agro-ecological zone classified as the dry zone (adapted from Geekiyanage and Pushpakumara 2013)

2.2. Study Site

The Ariviyal Nagar study site (9.3176° N, 80.3999° E) was located within the sub-division of Karachchi in the Kilinochchi district (Figure 4). The research took place on a section of land adjacent to the newly built University of Jaffna Agricultural campus (9.3176° N, 80.3999° E). The study plot was a section of abandoned pastureland 844.41 ha in size (Figure 2.4).

Figure 2.4- Ariviyal Nagar research site and vegetation found within the dry zone region of Kilinochchi , Sri Lanka, 2012 (photo: Pathmanathan 2012)

Since the research site falls within the northern region of Sri Lanka, rainfall within the study area is identical to that experienced by the district (Department of Agriculture Sri Lanka 2014). In addition, the research site is also comprised of Lixisols (FAO 2014). Lixisols are characterized as being the most widespread soil group in Sri Lanka (Panabokke 1996). Lixisols are primarily made on residuum or rocks that had been weathered through extensive chemical and physical changes but not displaced from its place or origin (USDA 2014), and colluviums or parent materials that accumulate at the base of a steep slope through gravitational force (Bauziene et al. 2008), obtained from intermediate and basic Precambrain rocks (Panabokke 1996). According to (Panabokke 1996), the upper part of the soil profile is made from recent colluvial material while the lower soil profile is derived from residual materials. Lixisols are also composed of highly weathered soil where the clay has been removed from the upper horizon down to the lower horizon (ISRIC 2014; Spaargaren 2008). These soils are reddish to reddish brown in color, and are usually found in the well-drained upper and mid slopes of undulating landscapes (Jayawardane and Weerasena 2001; Panabokke 1996). Additionally, soils in the region are large and strong, and are extremely hard when they dry (Panabokke 1996). The soils are predominantly made up of clay, which are mostly koalinite and smectite (Panakabokke 1996). Kaolinite clays are made up of silica/oxygen and alumina/hydroxyl sheets that interact with other soil components to create stable soil columns that are non-expanding (Miranda-Trevino and Coles 2003). Conversely, smectite clays are not as stable as kaolinites, and have smaller crystal sizes which have a large chemically active surface size and the unique ability to modify the movement of soil through the ground (Odom 1984). Furthermore, the natural vegetation in the research is comprised of dry mixed evergreen trees and low lying herbaceous species typical (Panabokke 1996; Sathurusinghe 2014) (Figure2.5). Currently, this site is not under any form of management and is free of herbicides, pesticides, and other forms of chemical fertilizers.

Figure 2.5- Aerial view of the Ariviyal Nagar study area showing the seven research sites (Source: Google Earth, December 2014)

The study site was already divided into seven unequal plots of land with the largest segments in the west-side of the research area. The study used randomized design with seven plots (Figure 2.6). Plots with a larger area contained five randomly located 10 m x 10 m quadrats and plots with a smaller area contain three randomly located 10 m x 10 m quadrats.

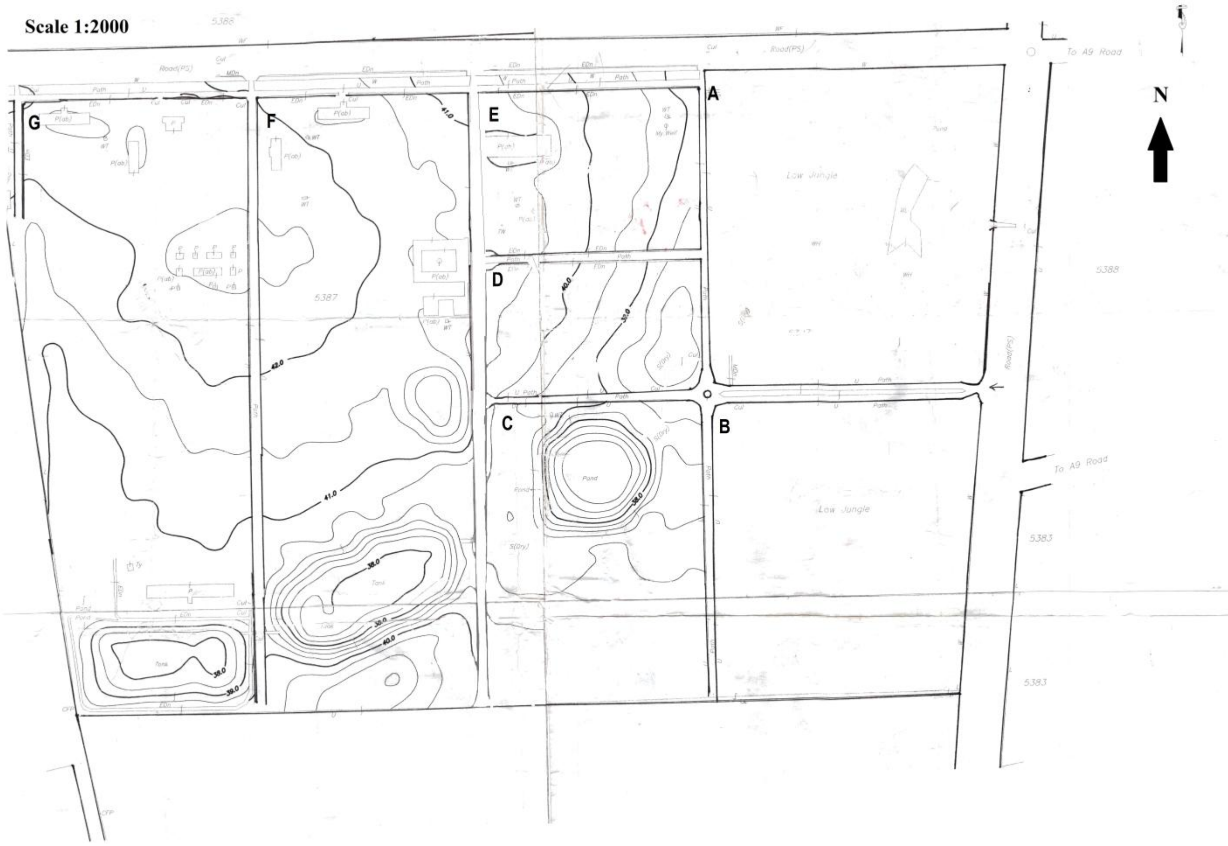


Figure 2.6- Land form map of the Ariviyal Nagar study area with labeled with seven plots A, B, C, D, E, F, and G, Kilinochchi, Sri Lanka (Source: Sri Lanka Survey Department 2013)

The area for the seven research plots are shown in Table 2.1, and was calculated using the scale Survey Department of Sri Lanka's map scale of 1:2000 where 1 cm is equivalent 2000 km. Within each quadrat, five random soil samples were extracted to a depth of 0-10 and 10-20 cm using a soil corer with a 5 cm inner diameter.

Table 2.1- Area of research plots found at the Ariviyal Nagar research site based on scale of 1:2000

Plot	Area (ha)
A	136.29
B	111.96
C	101.64
D	46.49
E	57.02
F	200.60
G	190.41

Soil samples were composited according to their depth increment and from each 10 x 10 m quadrat per plot. The collected soils were air-dried and sieved to 2 mm, and prepared for transport to Canada. In Canada, soil samples were divided into sub-samples for chemical and physical analysis (see Chapter 3).

All the soil data were examined using one-way ANOVA analysis for unbalanced completely randomized design to determine statistical significance between plots and amongst subplots. At the same site, a vegetation survey was conducted to account for the different flora that currently existed on this site. The methodology on the vegetation survey is described in detail in Chapter 4. Qualitative data for the research was collected using semi-structured interviews of farming families in four different villages, Kanakambikaikulam, Malaiyaalapuram, Bharathipuram, and Thiruvaiyaar, near the research site. Methodology on the semi-structured interviews is elaborated in chapter five.

Chapter 3: Soil Physical and Chemical Characteristics

3.1 Introduction

According to Sathurusinghe (2014) most of Sri Lanka's geologic foundations were composed of metamorphic Precambrian rocks, which were grouped into the Highland and Vijayan series. Furthermore, of the fourteen major soil groups found in Sri Lanka only two types were found extensively throughout the island. Historically, the major soil type classified for the Northern Province and the district of Kilinochchi was Lixisol (USDA: Reddish Brown Earths) (FAO 2010; Sathurusinghe 2014; Achchuthan and Kajananathan 2012; maps from Survey Department Ceylon 1967) (Appendix 1).

Though this was the historic classification, these soils became degraded due to poor land management practices and war impacts. Lixisols are known to have high base status at certain depths caused by the increased presence of ammonium, calcium, magnesium, and sodium cations within the soils (FAO 2006; ISRIC 2014), that result in high pH values (Valentine and Laykulich 2014; Juo and Franzluebbers 2003). In addition, the high base status of these soils is caused by low leaching from the top soil (ISRIC 2014). Many Lixisols have top soils that were comprised of sandy loam or sandy clay loam textures (Kaufe et al. 1998; Wickramasinghe and Wijewardena 2003). Furthermore, these soils had soil structures that are unpronounced and poorly developed (Kauf et al. 1998). Lixisols with degraded surface soils have decreased aggregate stability that is more susceptible to erosion caused by the direct impact of raindrops (FAO 2006). Soil aggregate stability is important for good soil structure, water infiltration, soil aeration, and resistance to erosion (FAO 2006). Moreover, the soils of Kilinochchi were further categorized as Ferric Lixisols (ISRIC 2014).

Clays found in the upper horizon of Ferric Lixisols were made up of 60% kaolinite, some mica, goethite, and hematite (Oorts et al. 2000), and therefore able to stabilize soil organic matter through the development of organo-mineral bonds (Wattel-Koekkoek and Buurman 2004). Furthermore, the associated carbon: nitrogen (C/N) ratio was higher in ferric soils that were undisturbed. The C/N ratio of organic material found in soils influences the rate of decomposition of organic matter, and therefore the mineralization or immobilization of soil nitrogen (USDA 2011). In addition, the topsoil of Ferric Lixisols were usually thin with low organic content, which is prevalent in regions that have pronounced dry periods (Kauf et al. 1998), such as northern Sri Lanka. As a result, these soils were prone to degradation, and therefore it was important to conserve its surface soils (FAO 2006).

Kilinochchi was a predominantly a rice-growing region. However, low soil fertility caused by decreased levels of soil organic matter limits rice production in the region (Wickramasinghe and Wijewardena 2003).This infertility and loss of soil nutrients was further exacerbated by extensive use of urea (Wickramasinge and Wijewardena 2003), and annual tillage using heavy machinery (Bationo 2007; FAO 2006), which has impacted food security in the area. Studies on soil fertility indicate that in continuous cropping systems, soil organic matter can be maintained through crop rotation, fertilizing the land using manure, and cattle penning (process of tying cows to graze in a harvested field) (Bationo 2007). As a result, it was important gauge the degree of soil degradation in the region.

The purpose of this study was to conduct a physical and chemical analysis of the soil properties, which will allow for the assessment of the level of degradation, as well as define the possible management regimes necessary to remediate the soils and improve their fertility and stability. A quantitative analysis of the existing soils will specifically help determine the soil nutrient availability for plant growth, creating a baseline data of soil condition to further determine the requirements to improve capacity to grow the desired crops for this region.

3.1.1 Research Questions and Objectives

3.1.1.1 Research Questions

1) What is the level of soil degradation within the Ariviyal Research site, and how does it impact crop productivity?
2) What sort of remediation effort can be taken to improve soil infertility in the region?

3.1.1.2 Research Objectives

1) A baseline survey of soils of the Ariviyal Nagar research study site will include the physical and chemical analysis of pH of each of the seven plots, soil organic carbon, soil organic matter, C/N ratio, and N contents in soils, bulk density and soil porosity.

3.2 Materials and Methods

3.2.1 Experimental Plot and Sampling Design:

The study site is located in Ariviyal Nagar on the University of Jaffna, Kilinochchi Campus. The plot was located on the west side of highway (A9) (Figure 3.1)

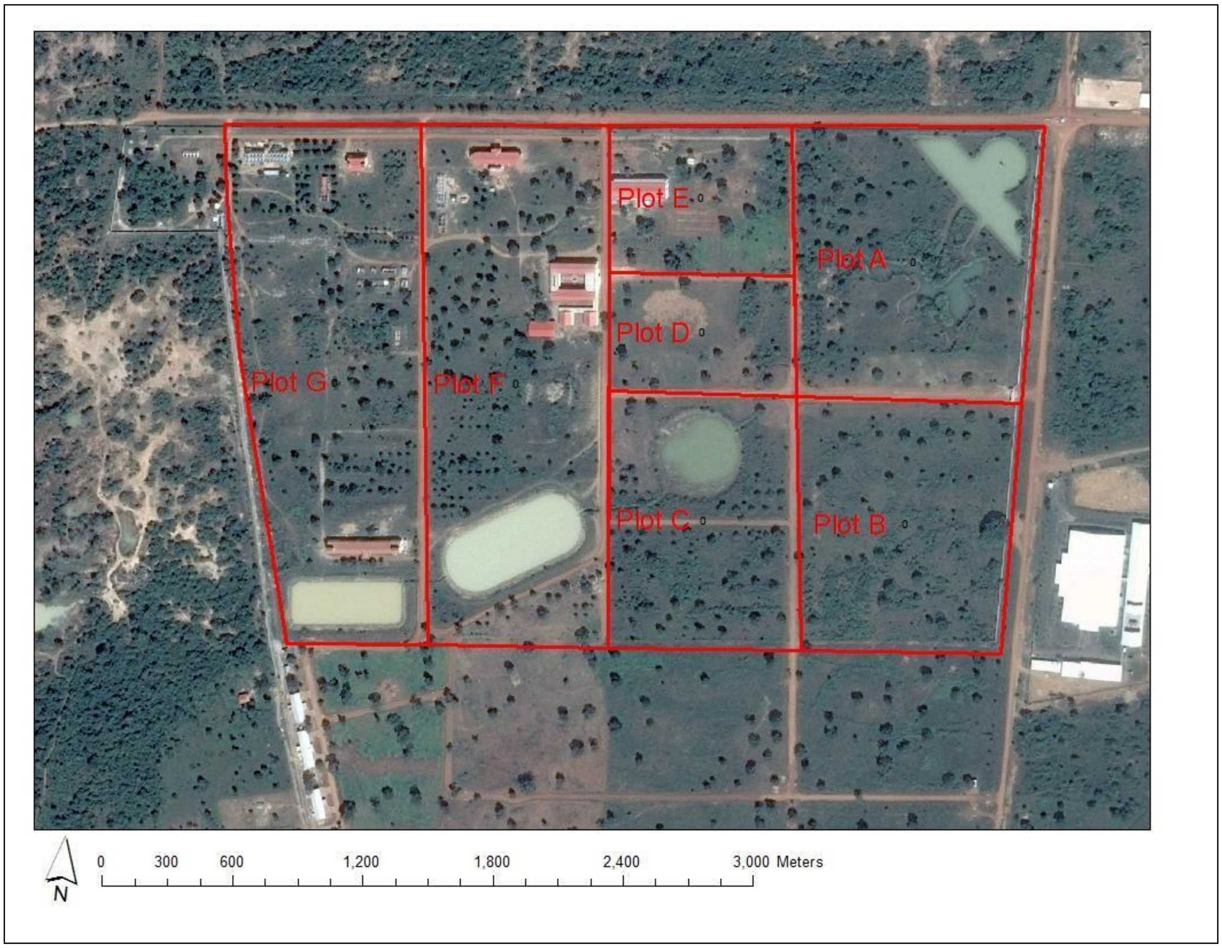


Figure 3.1: Study area plot locations in Ariviyal Nagar, University of Jaffna, Kilinochchi Campus.

The study area was divided by roads that separated each plot. Within each plot subplots were randomly chosen and tagged and a 10 m x 10 m sampling area was established. Five samples were taken from each subplot.

3.2.2 Soil Physical and Chemical Characteristics

Soil pH: Soils for pH analysis was collected from one depth at 0-20 cm. The procedure for measuring soil pH was determined by mixing 20 g of soil with 50 mL of water (1:2.5 ratio) (Anderson and Ingram 1989) in 50 ml snap-cap containers. The mixture was stirred with a glass stir stick for 10 minutes, left to stand for 30 minutes, and then stirred again for 2 minutes. The pH was measured/ read immediately using the ACCMT BIOBAS AB15B pH Kit by inserting the pH electrode into a mixed suspension

Bulk density: The bulk density of each sample was calculated using the inner diameter (3.8 cm) and length (4.9 cm) of the soil corer as well as the oven dry weight of the soil. The dry weight and moisture content of the soil sample was determined by oven drying 20 g subsamples at 105°C for 48 h. The oven dry soil mass was determined by subtracting the oven dried weight of the soil (g) and the weight of the can(g) from the wet soil weight collected and measured in the field (g). The determined values were then used in a formula to determine bulk density (p_b).

$$P_b = \frac{\text{oven dry soil mass (g)}}{\text{core volume (cm}^3\text{)}} \qquad \text{Equation 3.1}$$

Soil porosity: Soil porosity characterizes the area of the soil's volume that is not occupied by solid material, and is dependent on packing density, breadth of the particle size distribution, shape of the particles, and cementing (Nimmon 2004) for its value. The percentage ratio of soil porosity to soil solid is estimated to be 50:50 in soils that are idealized and not compacted (Nimmon 2004).Bulk density (BD) was used to calculate soil porosity (soil pore space) using the equation:

$$\%\ \text{porosity} = 100 - \left(\frac{BD}{2.65}\right) \times 100 \qquad \text{Equation 3.2}$$

Soil Organic Matter, Soil Organic Carbon and Nitrogen: Soil organic carbon (SOC) concentration, which is the measure of soil carbon attributed to the organic carbon derived from the flora and fauna, was measured in g/kg. The value was divided by 10 and multiplied by 1.724 to determine percentage soil organic matter (%SOM) content. The Costech Elemental Analyzer was also used to measure soil total nitrogen (TN) concentration, simultaneously. The soils contained carbonate, which was removed, prior to analysis, by adding 150 mL HCl (0.5 *M*) to 2 g of sieved (<2 mm) air dry soil (Dyer et al. 2012) in a 500mL beaker. This mixture was stirred with a glass stick, 3 times in 24 hours. After 24 hours, the soil was allowed to settle and the solution was washed, to remove the acid, by pipetting off the supernatant solution above the settled solid content and adding an equivalent amount of ultrapure water. This washing procedure was repeated once a day over a 4 day period. The soil was then dried in an oven at 40°C for 2 days (Midwood and Button 1998). Once the soil was thoroughly dried, it was ground in a Retsch ball mill, and 15mg was measured and analyzed for total organic C and N in the Costech Elemental Analyzer.

Soil Texture: Soil texture was estimated by using a soil texture methodology that does not require sieves (Colorado State University 2011). This methodology utilizes the rates of settlement of soil particles in water and soap solution. First, all non-soil components, such as rocks and roots were removed from the sample. The soil was broken up loosely, using a mortar and pestle. The ground sample (180g) was placed into a slender jar (1119.63 cm^3) until it was ¼ filled, the remaining ¾ was filled with water. One teaspoon of non-foaming dishwasher detergent was added to the jar and shaken by hand for 10-15 minutes, to mechanically disperse the soil aggregates into its mineral constituents. After shaking, the soil suspension was allowed to sediment out so that the particles settled according to size. After one minute, the jar was marked at the depth to which the sand sized particles (mm) had settled. After 2 hours, the jar was marked again to determine the depth at which the silt-sized fraction was taken to have settled. Finally, the jar was set aside, from disturbance, for 2 to 3 days to allow the clay particles to settle and to determine the clay content from the depth of particle settlement. The thickness of the sand, silt, clay, and total sediment depth was recorded. These values were used to estimate the percentage of sand, silt, and clay using the following formula (Colorado State University 2011):

$$\frac{\text{clay thickness}}{\text{total thickness}} \times 100 = \%\ \text{clay} \qquad \text{Equation 3.3}$$

$$\frac{\text{silt thickness}}{\text{total thickness}} \times 100 = \%\ \text{silt} \qquad \text{Equation 3.4}$$

$$\frac{\text{sand thickness}}{\text{total thickness}} \times 100 = \%\ \text{sand} \qquad \text{Equation 3.5}$$

3.3 Statistical Analysis

Stata v11.2 was used to conduct all the statistical analysis of the data. The Shapiro-Wilk test was used to determine if the data had a normal distribution, while the Levene's test was used to examine if the data was homogeneous. All data were normally distributed and homogeneous. Two-way ANOVA was conducted for bulk density and soil porosity data at the two sampling depths of 0-5 cm and 10-15 cm to test for significance of difference between plots and subplots. In addition, two-way ANOVA were conducted on pH, SOC, TN, and SOM, which served as dependent variables in separate analyses. The independent variables for all of these analyses were plots; A to G respectively making seven levels, and the second independent variable was subplots with twenty nine levels to test if there was a significant difference between plots and subplots. For all tested variables the differences within subplots were not significant, but were significant between plots. The Bonferonni post-hoc was performed to determine which plots were significantly different from each other at $p<0.05$. The Bonferonni post-hoc test was chosen because there was only seven means for comparisons, and because the sample sizes were uneven.

3.4 Results

3.4.1 Soil pH

The soil pH ranged from 6.8-8.3 for all plots (Table 3.1), and signified that the soils are near-neutral to alkaline. Statistical analysis indicated that the pH values did not vary within subplots but did vary between plots. Plot C (pH 8.3) varied significantly ($p<0.05$) from all other plots at the Ariviyal Nagar research site.

Table 3.1- Mean soil pH with standard error values for plots at the Ariviyal Nagar research site, Kilinochchi, Sri Lanka. Standard errors are provided in parentheses.

Plot	pH at 25°C
A	6.78 (0.10)
B	6.73 (0.04)
C	8.30 (0.04)
D	7.60 (0.05)
E	7.40 (0.14)
F	6.93 (0.05)
G	7.51 (0.13)

3.4.2 Bulk Density

The bulk density values for the six plots to a 5 cm depth ranged between 0.85 g/cm^3 to 1.60 g/cm^3 and for the deeper depths of 10-15 cm between 0.66 g/cm^3 and 1.62 g/cm^3. Bulk density was slightly higher at the 0-5 cm depth of each sample in comparison to the values found at the 10-15 cm levels. However, bulk density values at the two sample depths 0-5cm and 10-15cm within each plot did not differ significantly from one another. Furthermore, bulk density did not differ within subplots but did differ between one or more of the plots ($p<0.05$) (Table 3.2). The bulk density values differed significantly from plot A and all other plots. This indicated that plot A has the highest levels of compaction. The bulk density values of the remaining plots were lower.

3.4.3 Soil Porosity

Soil porosity was slightly lower at the 0-5 cm depth of each sample in comparison to the values found at the 10-15 cm levels. Soil porosity mean values at the two sample depths 0-5 cm and 10-15 cm did not differ significantly within the subplot. Soil porosity values indicated that the soils were well aerated in all plots. Soil porosity value differed significantly between plots (Table 3.2).

Table 3.2- Summary of bulk density (gm/cm^3) and soil porosity % at two sampling depths (0-5cm and 10-15cm) at the Ariviyal Nagar Research Site, Kilinochchi, Sri Lanka. Standard errors are provided in parentheses.

Plot	Bulk Density (0-5 cm)	Bulk Density (10-15 cm)	Soil Porosity (0-5 cm)	Soil Porosity (10-15 cm)	Subplot (n)
A	1.49 (0.02)	1.36 (0.03)	43.85 (0.60)	48.53 (1.11)	5
B	1.06 (0.02)	1.09 (0.02)	59.88 (0.85)	58.96 (0.82)	5
C	1.13 (0.01)	1.08 (0.01)	57.60 (0.45)	59.48 (0.26)	3
D	1.07 (0.03)	1.01 (0.03)	59.66 (1.32)	61.88 (1.06)	3
E	0.95 (0.01)	0.95 (0.01)	64.19 (0.44)	64.24 (0.24)	3
F	0.82 (0.01)	0.79 (0.02)	68.98 (0.37)	70.09 (0.59)	5
G	0.90 (0.02)	0.89 (0.00)	65.99 (0.64)	67.85 (0.39)	5

3.4.4 Soil Organic Carbon, Soil Organic Matter, Total Nitrogen and C/N ratio

The values of soil organic carbon was generally low in all the plots found in the Ariviyal Nagar research site (Table 3.4) with the lowest percentage in plot C (0.26%). The highest percentages were found in plots E and F (1.25 % and 1.35 %, respectively). Soil organic carbon values varied significantly between plots. Soil organic matter (SOM) percentages followed the same pattern as that of the soil organic carbon concentration for each plot, with plot C having the lowest value of 0.46 % and plots E and F having the highest percentages of 2.15% and 2.31% respectively

(Table 3.3). Soil organic matter varied significantly between plots. The total nitrogen concentration in all plots were below 1% and ranged from 0.009 % plot C to 0.087% in plot F. Total nitrogen values varied significantly between plots. The C/N ratio is above 20 for two plots C and D at 28.89 and 23.03 (Table 3.3). Plot G had the lowest value of 11.67.

Table 3.3- Soil organic carbon, soil organic matter, total nitrogen and C/N ratio values for plots A-G at at the Ariviyal Nagar Research Site, Kilinochchi, Sri Lanka. Standard errors are provided in parentheses.

Plot	Soil Organic Carbon (%)	Soil Organic Matter (%)	Total Nitrogen (%)	C/N ratio	Sub plots (n)
A	0.76 (0.02)	1.31 (0.14)	0.062 (0.01)	12.25 (0.72)	5
B	1.03 (0.04)	1.77 (0.11)	0.079 (0.01)	13.04 (0.33)	5
C	0.26 (0.10)	0.46 (0.35)	0.009 (0.02)	28.89 (3.31)	3
D	0.76 (0.02)	1.30 (0.22)	0.033 (0.01)	23.03 (1.71)	3
E	1.25 (0.01)	2.15 (0.21)	0.083 (0.01)	15.06 (2.26)	3
F	1.35 (0.06)	2.31 (0.20)	0.087 (0.01)	15.52 (1.04)	5
G	0.91 (0.06)	1.56 (0.20)	0.078 (0.01)	11.67 (1.00)	1

3.4.5 Soil Texture

The soil texture in the research site varied from clay to loam soil types that combined a mixture of clay, sand, and silt (Table 3.4). Nearly 33% of the entire site was composed of sandy clay loam, and was the most common soil texture in the research site.

Table 3.4- Soil Texture Analysis of Plots in Kilinochchi Research Site

	Plots						
Percentage	A	B	C	D	E	F	G
Clay	18	21	52	31	44	31	17
Silt	27	4.8	11	18	0	26	41
Sand	56	74	37	51	55	43	41
Soil Texture	Sandy loam	Sandy clay loam	Clay	Sandy clay loam	Sandy clay	Clay loam	Loam

3.5 Discussion

3.5.1 Soil pH

Soil pHs for the seven plots were slightly neutral to alkaline, which indicated that the soils were still capable of supporting production of certain crop species (Hazelton 2007). According to McKenzie (2010) and UNIDO (1998), crops grow best between soil pH of 6.0-7.5. Hence, most of the soils within the research site were conducive to plant growth as most subplots had pH that ranged between 6.0 and 7.5. In addition, above neutral pH values were typical in regions that had bare soil systems or minimum ground vegetation cover (Burle et al. 1997), as seen in Ariviyal Nagar research site (Figure 3.2). Furthermore, arid regions were expected to have near neutral or alkaline pH values over long periods of time (Dregne 1976; UNIDO 1998), which impacted soil vegetation type and plant growth. Plots C and D had the highest pH values of 8.3 and 7.6, respectively. As a result, these areas had reduced plant growth because alkaline soils diminished the solubility of macronutrients such nitrogen, phosphorous, and potassium (UNIDO 1998) that were necessary for plant growth. In addition, alkaline soils also decreased the availability of trace elements or micronutrients such as zinc, copper, boron, and manganese (Miller 1998). A deficiency in one or more of these micronutrients results in the decline of crop yield and quality

(Hodges 2010), and impacts the availability of food for agrarian communities. As a result, soil pH is an important chemical factor that impacts the solubility of nutrient compounds (UNIDO 1998), and influences the rate of availability and immobilization of macronutrients for plant intake (Recous et al.., 1999).

Lixisols are classified as having high soil pH values, which were also indicated by the results. However, soil that was collected from plot C showed the highest pH (8.3) because it was originally soils that were excavated from an adjacent plot and discarded into the area. This influenced the existing soil as the deposited soils contained higher clay content, and therefore impacted the type of trees and vegetation that can grow on those soils (Campbell et al. 1994; Aarrestad et al. 2010)

Figure 3.2 – Limited dry forests vegetative cover in the dry zone region of Ariviyal Nagar, Kilinochchi (source: Pathmanathan 2013)

3.5.2 Bulk Density and Soil Porosity

According to the values derived for bulk density, the soils at the Ariviyal Nagar research site were only slightly compacted. Values for bulk density were higher in the 0-5 cm depth than in the lower depth, which indicated that compaction occurred in the upper layer of the soil, especially in plot A. However, bulk density values are dependent on multiple factor, such as soil organic matter, soil texture, and current land management practices (Hazelton 2007), which all impact the level of compaction in soils. During the soil collection period, the Ariviyal Nagar research site was under heavy construction developing the new University of Jaffna agricultural campus. As a result, heavy machinery and equipment were seen moving over the land. The movement of heavy construction machinery over the research site created mechanical stress on the land, and compacted the soil (Keller and Hakansson 2010; Matangaran and Kobayashi 1999), which had resulted in the higher bulk density values in the upper soil surface (Pires et al. 2009). In addition, the Ariviyal Nagar research site had been a combat zone over a thirty year time period, which may have contributed to the compaction levels in the upper layer of the soil. In addition, plot A had the highest bulk density value (1.49 g/ cm^3), which was above the critical bulk density value of 1.3 g/ cm^3 (Pabin et al. 1998; Hazelton 2007). This can be attributed to the fact that construction of the administration block was most actively occurring on plot A (Figure 3.2).

Figure 3.3- Soil compaction in plot A due to active construction at the Ariviyal Nagar research site (source: Pathmanathan 2012)

Furthermore, bulk density was strongly related to soil organic matter content in the soil (USDA 2014). Increased soil organic matter would decrease soil bulk density value, because organic matter improves the structure of the soil (Six 2002; Dexter 2004). Soil bulk density was lowest in plots E, F, and G, which were also the regions that had the least amount of construction, and most amount of vegetation. Increased vegetation and tree litterfall adds organic matter into the soil, which reduces its compressibility (Ruehlmann and Korschens 2009), and therefore makes the soil more pliable for plant growth. In addition, presence of soil organic matter within the ground creates better soil structure (Perie and Ouimet 2007). Improved soil structure indicates that the soils have better aggregate stability and impacts soil pore space, which signify that are able to retain more soil organic carbon (Zhang et al. 2014), and thereby increase soil fertility (Six et al. 2004). Soil bulk density values could also be used to determine soil porosity, and is essential for soil management strategies (USDA 2014). High bulk density or compaction indicates decreasing porosity (Zhao et al. 2008), which is evident in plot A. In addition, soil porosity is impacted by soil texture (Kay and VandenBygaart 2002). Soils that were clay or loam-based had higher soil porosity and lower bulk density, and were therefore more aerated than their sand and silt -based counterparts (Reichert et al. 2009). As a result, these soils were better able to support root and plant growth (Dexter 2004; Zou et al. 2001), as seen in all plots, excluding plot A. Therefore, soil porosity values for all plots except plot A indicated that, overall, these plots had good aeration and were well drained (Nimmo 2004).

3.5.4 Soil Organic Carbon, Organic Matter, and Total Nitrogen

Generally, the soils in the sample plots were low in soil organic carbon (>1.5%) (SOC), soil organic matter (>2.5%) (SOM), and soil nitrogen (>1%) (N). These values indicated that the research site had "poor to moderate structural condition and slightly degraded surface soils" (Hazelton 2007). However, within the given range, plots E and F had the highest SOC, SOM, and N. Both SOC and N are essential for plant growth and nutrient uptake (Mingzhu et al. 2014; Bationo et al. 2005). Higher levels of SOC and N indicated that the soils found in those plots were more likely to support plant growth (Bationo et al. 2005). The field observation made in the Fall of 2013 showed that these plots also had the most number of species and tree counts when compared to other plots. As a result, there was more input by the existing vegetation to ground litterfall. Increased litterfall contributed to SOM, and increased the presence of SOC in the soil (Department of Agriculture Australia 2014; Berg 2000), which helped to mineralize available N for plant uptake in the ground (McKenzie 2010; Kaur et al. 2000) (see Chapter 4 for further discussion). In addition, SOC, SOM, and N are indicators of soil fertility (Teakle et al. 1951). A study conducted in West Africa by Bationo et al. (2005) indicated that SOC is a source and sink for nutrients, including nitrogen, which plays an important role for maintaining soil fertility, and crop production in the region. They stated that due to the arid conditions of the region and relatively low SOC in the soils, similar to Ariviyal Nagar, the cation exchange capacity of the soil depends heavily on SOC. Cation exchange capacity of soil is the ability of a soil to adhere to positively charged ion, and influences soil structure stability, nutrient, and soil pH (Hazelton ad Murphy 2007). As a result, degraded land such as those found in Ariviyal, have low cation exchange capacity, which impacts the soils ability to retain nutrients. The inability of soil to retain nutrients affects crop production on that land, which impacts the ability of small-scale farmers to produce sustainable yields for household consumption.

3.5.5 Soil Texture

Soil texture also influences the amount of SOC, SOM, and N present in the ground (Bationo et al. 2005). Light textured soils such as sandy loams would have poor water holding capacity and as a consequence under non-irrigate or poor and untimely rainfall conditions can be a challenge for plant establishment (Shober 2008). This is most true in plots A to D. In addition, sandy-textured soils were naturally infertile while clay soils had higher fertility (Shober 2008). Loam soils are perceived to be the ideal soil type for agriculture. Almost all of the soils in the area are loam based, and are conducive for plant growth because finer soil textures retain minerals and nutrients that are readily available for roots to absorb (Perie and Ouimet 2007).

3.6 Conclusion

Overall, pH indicated that the soils found on the research site are near neutral to alkaline but still capable of supporting plant growth except for plot C. In addition, bulk density and soil porosity for the study site indicated that the soils are slightly compacted in the upper layer, especially in plot A, but still aerated, and well drained, which signified that the plots could still support root growth. However, soil organic carbon, soil organic matter, and nitrogen values all indicated that the soils of the Ariviyal Nagar research site were degraded due to the lack of proper vegetative cover in the region caused by the three decades war. Therefore, this baseline assessment of the soils in the study area of Kilinochchi confirmed that the soils need to be improved, and still had the potential to support agriculture to improve food security in the region. However, it must be noted that the exact impact of warfare on the research site could not be accurately quantified. Regardless, soil fertility can be improved by adapting various agroforestry systems that incorporate nitrogen-fixing trees, salt and drought tolerant trees species, which could ameliorate soils from degraded conditions in a sustainable manner.

CHAPTER 4: Tree Survey at the Ariviyal Nagar Research Site and Agrarian Households

4.1 Introduction

Dry monsoon forests dominate 88% of Sri Lanka's forest vegetation (Jeyawardene 2004). The dry zone areas typical of Northern Sri Lanka were classified by its dry mixed evergreen forests or dry monsoon forests, and only receive rain during the northern monsoon (Sathurusinghe 2014). According to Stapleton (2014), dry zones were classified as areas where the amount of water lost by evaporation or used by plants and animals surpass the amount of precipitation that falls in the region. Currently, Kilinochchi's land area is covered by 32 373 km^2 of dry monsoon forests, 312 km^2 of mangroves, and 6 042 km^2 of sparse forests, and results in a total area of 38 727 km^2 covered by natural vegetation (World Bank 1996). The study site in Ariviyal Nagar is comprised of dry monsoon forests and thorny shrub-lands.

Dry forests are characterized as occurring in regions that experience five to eight months of dry period (Nelson 2003). They are composed of deciduous tree species that remain leafless during the dry season (Nair 2004). The trees species that constitute the overstorey of dry forests do not exceed more than 20 m in height, and the understorey is made up of woody climbers, shrubs and herbaceous ground flora (Jeyawardene 2006; Nair 2004). Dry forests typically include tree species that belong to the genera of *Acacia, Albizia, Borassus, Butea, Caesalpinia, Cassia, Corypha, Dalbergia, Dichrostachys, Feronia, Garuga, Homalium, Lannea, Melia, Schleira, Stereosprermum, Tectona,* and *Tetramele* (Nair 2004). Furthermore, dry forests provide important sources of food and livelihood for rural communities living in the region (Stapleton 2014).

In addition, the dry monsoon forests of Sri Lanka have a high degree of endemic tree species, which are threatened by recurring droughts, lack of alternative food source for local people, agricultural encroachment, and high demands of people and livestock (Nair 2004; Stapleton 2014).The International Union for Conservation of Nature (IUCN) (2014) defined endemism as a state where species are restricted or native to a specific geographical region, and may become vulnerable to extinction if their habitats were to be eliminated or severely disturbed. Endemic trees are vital components of their ecosystems because they are strongly adapted to the dry zone environment (Ceballos and Garcia 1995), and provide important ecosystem services and functions (Colding and Folke 1997). Ecosystem services, such as food, fuel, and fodder, provided by these trees are essential for agricultural production. However, a recent study by Miles et al. (2006) indicated that dry forests are at high risk to be converted to agricultural lands. The loss of these trees poses a threat to the integrity of the environment, ecosystem services, and the ability of rural communities to maintain their current agrarian livelihood (FAO 1987). Furthermore, the roles endemic tree species play in their environment are still unknown (Werff and Consiglio 2004). As a result, it is pertinent that these species are conserved within their native ranges so that further studies on the ecology of these trees can be conducted to determine their importance to their locality, and to the agrarian communities who are most dependent on their function in the environment (Miles et al. 2006; Werff and Consiglio 2004).

Furthermore, home garden tree species can contribute to replenish soil nutrients and maintain soil fertility (Thrupp 2000) with the added benefit of providing communities with readily available food and nutrient resources, as well as augment family income (Magcale-Macandog et al. 2010). Additionally, home gardens are important places for *in situ* conservation of local plant diversity, and can act as gene pool reserves for declining indigenous tree species (Das and Das

2005). Moreover, incorporating these trees species in agricultural fields can create agroforestry systems that increase dry zone forest biodiversity, provide necessary ecosystem services that increase crop yields, and help to stabilize micro climate variability on land (Sunderland 2011), which all benefit farmer livelihoods in the Kilinochchi region.

The purpose of this study was to inventory the current dry forest tree species that exist on the Ariviyal Nagar research site. In addition an inventory of home garden tree species was also conducted in the villages of Kanaikambikaikulam, Bharathipuram, Malaiyaalapuram, and Thiruvaiyaar during the farmer interview phase of the project (refer to chapter five for more details). The inventoried data will be used to recommend the tree species employed in designing the agroforestry systems most suited to remediate soils and alleviate food insecurity in the Kilinochchi region (refer to chapter six for more details).

4.1.1. Research Questions and Objectives

4.1.1.1 Research Questions

Would increasing tree cover in farm fields and the research site improve soil fertility and food security in the region?

Two sub-questions for this research were:

1) What are the current dry zone tree species in Kilinochchi?
2) What home garden tree species provides the most benefit to agrarian households?

4.1.1.2 Research Objectives

The main objective of this chapter was to conduct an inventory the tree species found in the Ariviyal Nagar research site and the home gardens of agrarian households living in Kanakambikaikulam, Bharathipuram, Malaiyaalapuram, and Thiruvaiyar.

The specific objectives of this chapter are:

1) To determine the relative frequency and density of dry zone tree species found in the Ariviyal Nagar research site.
2) To determine the relative frequency of home garden tree species in the four villages.

4.2 Materials and Methods

Field work occurred between the months of November and December 2013. The 10 m x 10 m subplots were determined subjectively so that the entirety of vegetative flora in the area was surveyed at the Ariviyal Nagar site. Five subplots were established in plots A, B, F, and G because they were the largest in the research site. Only three subplots were created in the smaller plots, C, D and E. The established subplots were used to determine plant species composition and abundance in each plot (A, B, C, D, E, F, and G). The survey was conducted using the handbook for tropical species and a local field vegetation guide. Only hardy perennials above the height of 1.3 m were considered for the vegetation survey (Wilson et al. 1990). The vegetation data was organized in a chart with the most common tree species found in the Dry Zone of Northern Sri Lanka. Relative density and relative frequency (Jasyasingam and Vivekanantharaja 1993) were also quantified for each species at the research site to determine canopy cover and species richness per plot. The trees in the home gardens were determined by asking the farmers to list all the current species planted in their homesteads.

$$\text{Relative density} = \frac{\text{number of trees per plot}}{\text{total number of plants in all plots}} \times 100 \qquad \text{Equation 4.1}$$

$$\text{Relative frequency} = \frac{\text{number of plots a species is present}}{\text{total occurence of all species in all plots}} \times 100 \qquad \text{Equation 4.2}$$

4.3 Results

There were 17 dry zone tree species inventoried in the sample plots at the research site in Ariviyal Nagar, Kilinochchi (Table 4.1). None of the tree species occurred in extremely high densities or frequencies at the research site. However, Plot E and F had the most number of tree species per plot, and was therefore the most species rich (Figure 4.1). The results indicated that *Rhizophora mucronata* (10%), *Manilkara hexandra* (12%), and *Albizia lebbeck* (13%) were found in high densities and occurred in more plots than the other inventoried tree species at the research site. Furthermore, *Rhizophora mucronata* (20%), *Melia dubia* (10%), *Morinda tinctoria* (20%), *Chloroxylon swientenia* (20%), *Syzgium cumini*(15%), *Albizia saman* (10%), *Bauhinia racemosa* (15%), *Manilkara hexandra* (25%), *Bauhinia tomentosa* (10%) , *Albizia lebbeck* (20%), *Azadirachta indica* (20%), *Limonia acidissima* (15%) were the most frequently occurring tree species throughout the area of the research site (Table 4.2). Plot F had the most number of trees in all the plots, which indicated that it had the most amount of biodiversity (Figure 4.2). The most common uses for the trees inventoried at the Ariviyal Nagar research site are presented in Table 4.3.

Table 4.1- Dry zone tree species found in the Ariviyal Nagar research site, Kilinochchi

Common Name	Local Name	Botanical Name	Family
Morinda Tree	Manja vanna	*Morinda tinctoria*	Rubiaceae
Ceylon ironwood	Paalai maram	*Manilkara hexandra*	Sapotaceae
East Indian Walnut	Vaaghai	*Albizia lebbeck*	Fabaceae
Bauhinia	Othi	*Bauhinia racemosa*	Fabaceae
Ceylon satinwood	Muthirai	*Chloroxylon swietenia*	Rutaceae
Jambul	Naaval	*Syzygium cumini*	Myrtaceae
Neem Tree	Vembu	*Azadirachta indica*	Meliaceae
Yellow Bauhinia	Thiruvathi	*Bauhinia tomentosa*	Fabaceae
Buddha Tree	Eluppai	*Polyalthia longifolia*	Annonaceae
Beed tree	Malai vembu	*Melia dubia*	Meliaceae
Crown flower	Erukkalai	*Calotropis gigantean*	Asclepiadaceae
Loop-root mangrove	Kondal	*Rhizophora mucronata*	Rhizophoraceae
Rain Tree	Nilal vaaghai	*Albizia saman*	Fabaceae
Wood Apple	Vilaa maram	*Limonia acidissima*	Rutaceae
Mahogany	Mahogany	*Swietenia mahogany*	Meliaceae
Arjun Tree	Marutha maram	*Terminalia arjuna*	Combretaceae
Cluster Fig	Aththi	*Ficus racemosa*	Moraceae
Mango Tree	Maa maram	*Mangifera indica*	Anacardiacea
Banyan Tree	Aala maram	*Ficus benghalensis*	Moraceae
Teak	Taekku	*Tectona grandis*	Lamiaceae

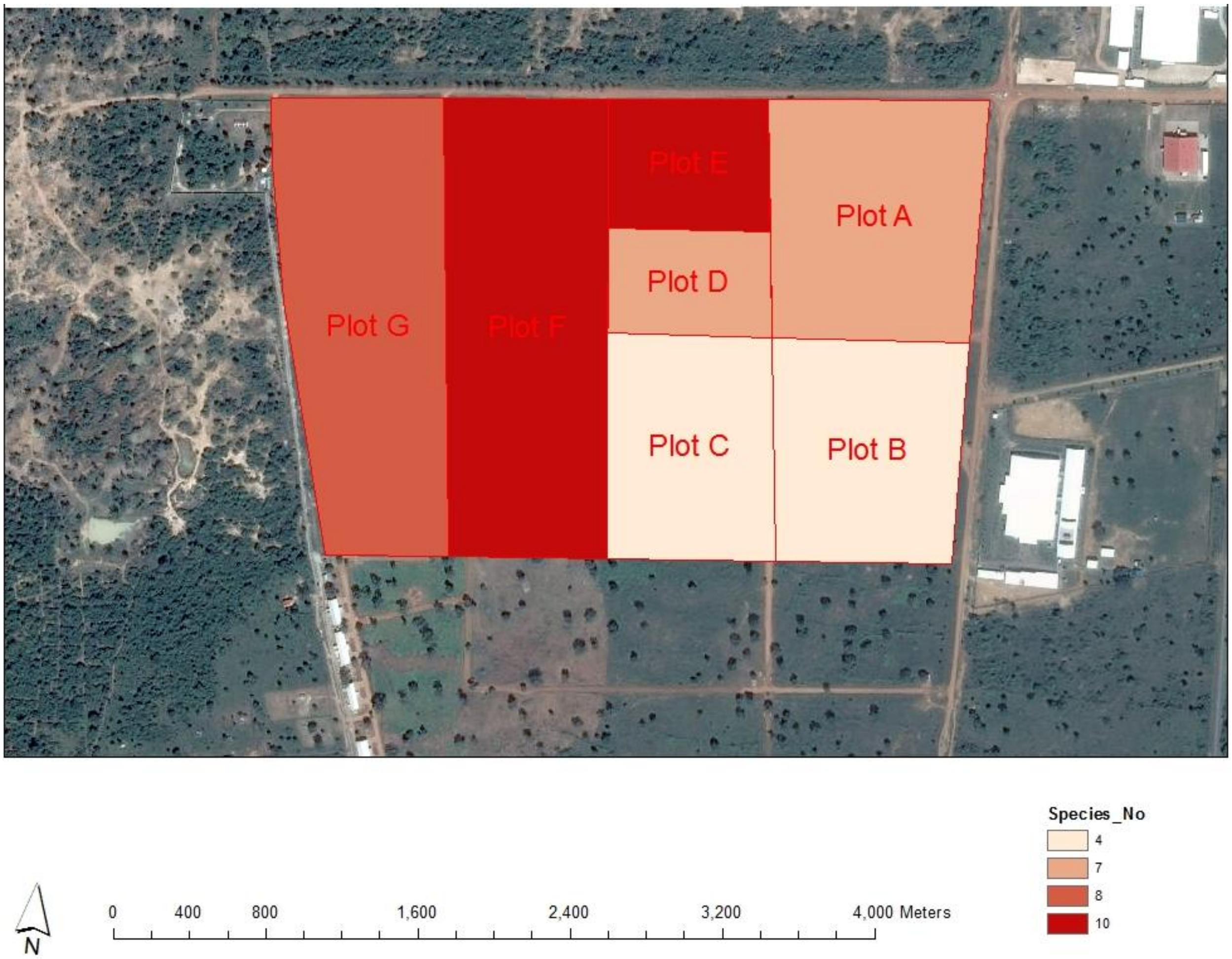


Figure 4.1- Number of tree species per plot at the research site in Ariviyal Nagar, Kilinochchi, Sri Lanka, 2014

Table 4.2- Relative frequencies and densities of dry zone tree species found in the Ariviyal Nagar research site

Tree Species	Relative Frequency (%)	Relative Density (%)
Albizia lebbeck	20	12.95
Albizia saman	10	2.88
Azadirachta indica	20	8.63
Bauhinia racemosa	15	4.32
Bauhinia tomentosa	10	4.32
Calotropis gigantean	5	0.72
Chloroxylon swientenia	20	7.19
Ficus benghalensis	5	1.44
Ficus racemosa	10	5.76
Limonia acidissima	15	1.44
Mangifera Indica	5	0.72
Manilkara hexandra	25	11.51
Melia dubia	10	2.88
Morinda tinctoria	20	7.91
Polyalthia longifolia	5	0.72
Rhizophora mucronata	20	10.07
Swientenia mahogany	5	1.44
Syzgium cumini	15	4.32
Tectona grandis	5	2.16
Terminalia arjuna	5	8.63

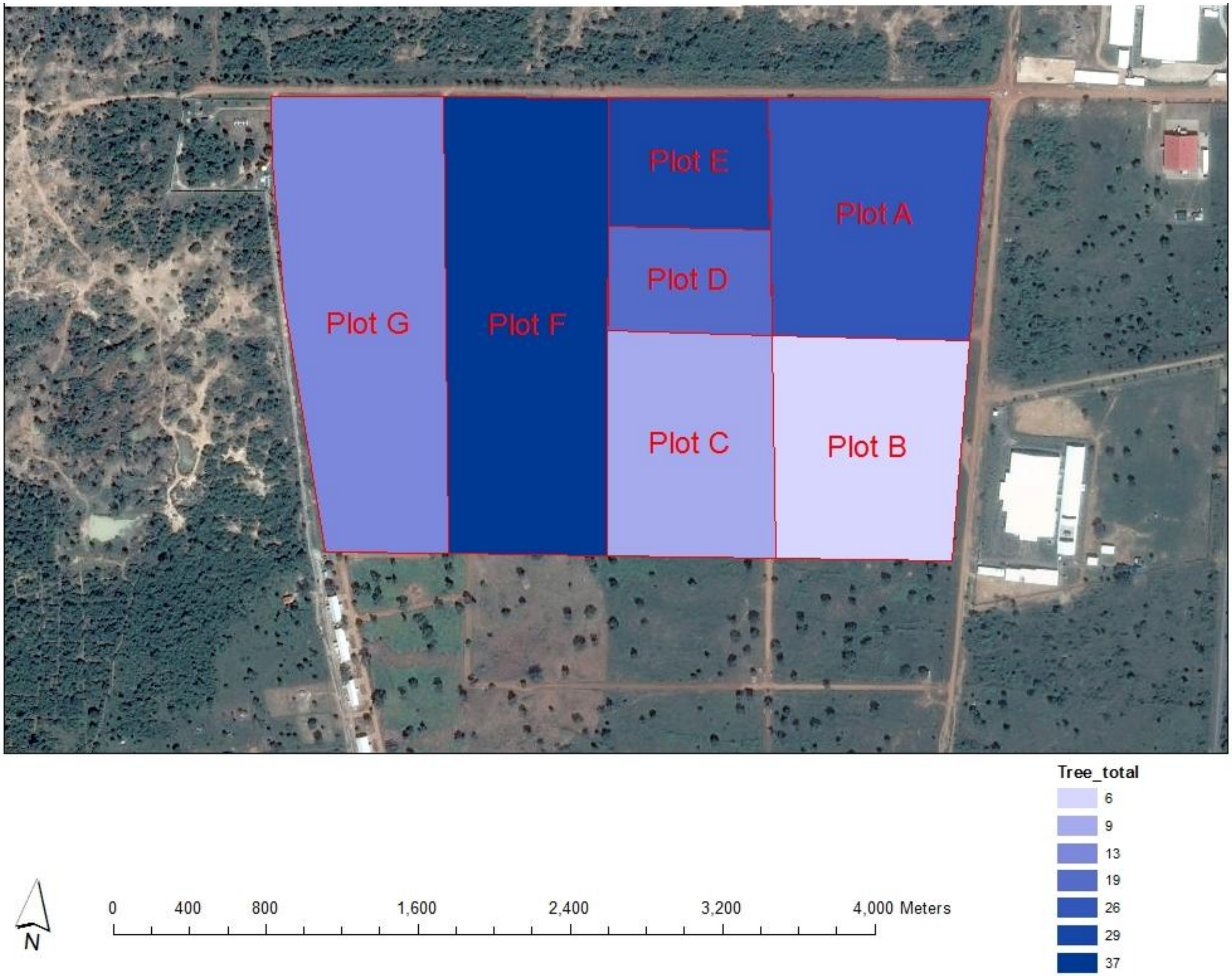


Figure 4.2- Total number of trees species per plot at the research site in Ariviyal Nagar, Kilinochchi, Sri Lanka, 2014

Table 4.3- Inventoried dry zone tree species found in the Ariviyal Nagar research rite rated for their common uses

Tree Species	Fruits	Timber	Medicinal	Fodder	Fuel Wood	N_2 Fixation
Albizia lebbeck	6	1	1	1	1	1
Albizia saman	4	5	4	4	6	2
Azadirachta indica	6	4	2	2	3	1
Bauhinia tomentosa	6	4	5	6	6	6
Chloroxylon swietenia	6	1	2	1	1	6
Ficus benghalensis	6	4	2	6	6	2
Ficus racemosa	1	6	5	2	2	6
Limonia acidissima	1	2	3	4	4	6
Mangifera indica	1	6	3	4	6	6
Manilkara hexandra	4	1	2	3	2	3
Melia dubia	6	5	6	6	6	6
Morinda tinctoria	6	6	1	5	5	6
Polyalthia longifolia	6	6	1	6	6	2
Swietenia mahogany	6	1	6	6	2	6
Syzygium cumini	1	1	2	1	1	6
Tectona grandis	6	1	5	6	6	6
Terminalia arjuna	6	6	2	1	1	6

1 = most relevant; 6 = least relevant

There were 11 commonly planted home garden tree species found in the four villages surrounding the research site (Table 4.4).

Table 4.4 - Common trees cultivated in home gardens in the four villages surrounding the Ariviyal Nagar research site, Kilinochchi

Common Name	Local Name	Botanical Name	Family Name
Areca nut	Paaku maram	*Areca catechu*	Arecaceae
Coconut	Thenna maram	*Cocos nucifera*	Arecaceae
Banana	Vaalai	*Musa spp.*	Musaceae
Papaya	Papa maram	*Carica papapya*	Caricaceae
Mango	Maa maram	*Magnifera indica*	Anacardiaceae
Guava	Koiya maram	*Psidium guajava*	Myrtaceae
Breadfruit	Eera pilakaai	*Atrocarpus altilis*	Moraceae
Jackfruit	Pala maram	*Artocarpus heterlophyllus*	Moraceae
Jambul	Jambul maram	*Syzigium cumini*	Myrtaceae
Date palm	Muthiri maram	*Phoenix dactylifera*	Arecaceae
Drumstick	Murungai maram	*Moringa oleifera*	Moringaceae

Each homestead had at least 0-6 trees planted in their home garden. However, only six crops were planted the most frequently in the home gardens. *Cocos nucifera* (27%) and *Musa spp* (32%) occurred the most frequently in the gardens of the homesteads in the communities surrounding the Kilinochchi research site. All the trees planted in home gardens were predominantly used for their fruits (Table 4.5).

Table 4.5 - Inventoried tree species in home gardens rated for their common uses

Tree Species	Fruits	Timber	Medicinal	Fodder	Fuel Wood	N_2 Fixation
Areca catechu	1	5	4	3	3	6
Atrocarpus altilis	1	5	5	2	4	6
Artocarpus heterlophyllus	1	1	6	1	6	6
Carica papaya	1	6	1	2	6	6
Cocos nucifera	1	5	6	2	6	6
Magnifera indica	1	6	3	4	6	6
Musa spp	1	6	5	2	6	6
Psidium guajava	1	4	2	6	2	6
Syzigium cumini	1	1	2	1	1	6

1 = most relevant 6 = least relevant

4.4 Discussion

The research site was dominated by drought tolerant and hardy dry zone tree species that are native to Sri Lanka, and thrive in a wide range of soil types (refer to appendix 1). Dry zone regions around the world are classified as having harsh climatic conditions that are water scarce (Ministry of Environmental Conservation and Forestry 2009). As a result any tree species existing in dry zone forests are adapted to thrive in those environments. Consequently, the research site in Ariviyal Nagar was expected to be densely populated with a wide variety of dry zone tree species. However, the research findings revealed a dramatic drop in tree density, frequency, and species richness. This is a unique finding because, as a rule, tropical dry forests typically have 30-90 tree species per 1-3 ha of land (Vieira and Scariot 2006). However, the Ariviyal Nagar research site was previously a war combat zone and was subjected to massive deforestation over a long period of time. As a result, there are only 17 tree species and 139 trees remaining on the 168 ha of surveyed land.

The civil war that was fought in northern Sri Lanka caused extreme environmental stress on the dry forests in the region for a period of thirty years. Consequently, the physical characteristics of the land, its biotic community, and soil nutrient status was negatively impacted and nearly eradicated during the conflict time (Brown and Lugo 1994). Human-induced deforestation during the war period resulted in soil degradation, and has created problems for the agrarian communities living in post-war Kilinochchi. The soil survey conducted in Ariviyal Nagar (refer to chapter 3), indicated that soils in the region were chemically and physically degraded. The results showed that the soils had low levels of soil organic carbon, soil organic matter, and total nitrogen, and was also slightly compacted. Chemical degradation of the soil was caused by the loss of natural vegetation on the land, which resulted in the loss of organic matter from the topsoil (Oldeman 1992).

Compaction, associated with the physical degradation of the land, occurred when the soil cover was not adequately protected from the impact of rain (Oldeman 1992). The movement of army tanks and other armored vehicles during the war period in northern Sri Lanka could have contributed to the compaction of the land (Keller and Hakansson 2010). Forests and trees help to prevent land degradation by using their roots to stabilize soil, reduce erosion, and improve the soil's ability to retain water (FAO 1992). Therefore, it is important to increase tree cover within the Kilinochchi region in order to prevent the further degradation of land.

In addition, tree canopies and litterfall can increase ground cover to prevent soil degradation of the land, and facilitate the increase of soil organic matter content (Isichei and Muoghalu 1992; Baldock and Nelson 2000). Therefore, it can be speculated from the conducted soil analysis and interviews with the farmers that the lack of trees in the research site and the surrounding areas has impacted soil fertility and agricultural productivity within Kilinochchi. These impacts include decreased availability of essential soil nutrients and soil organic matter needed for crop growth (Binkley and Fisher 2013). Subsequently, increased presence of trees can add to the existing canopy cover of Kilinochchi. Increased canopy cover can improve soil humus layer, enrich soil nutrient availability, and improve the integrity of degraded land (Reeves 1997). In addition, humus found on the upper most layer of soil, allows roots to penetrate the ground, and access necessary nutrients needed for plant growth (Reeves 1997). Increase in organic matter content within the soil can also increase total nitrogen and carbon availability in the ground, which can greatly improve soil fertility and land productivity (Isichei and Muoghalu 1992; Baker et al. 2003). Moreover, increased presence of certain dry zone tree species can further increase total nitrogen availability in the soil.

Currently, soil nitrogen levels are low in the research area and the lack of readily usable soil nitrogen is detrimental to plant growth, and can influence the composition of tree species in the environment (Handley 1961). A thorough characterization of existing trees in the field site indicated that 35% of the total species are capable fixing atmospheric nitrogen for plant uptake (Table 4.5). However, some trees are more capable of forming symbiotic relationships with nitrogen-fixing Rhizobium than other trees (Zahran 1999; Bekunda 1993). Therefore, even though 35% of the tree species are capable of fixing nitrogen within the Ariviyal Nagar research site, it may be that only a few species actually fix nitrogen within the area, as indicated by the low nitrogen levels stated in the previous chapter. Certain tree species, such as acacia, are capable of fixing nitrogen better than other tree species (Brockwell et al. 2005; Zahran 1999). According to Vitousek and Howarth (1991), the presence of nitrogen-fixing organisms within an environment increases the level of fixed nitrogen in the soil, and supports the elements availability in the ecosystem. Furthermore, soil nitrogen levels affect the amount of organic matter found in the ground, and is associated with the accumulation of soil organic carbon from tree literfall (Binkley 2005; Sayer 2011). More specifically, the presence of soil nitrogen helps to break carbon bonds during the decomposition of organic matter (Post and Mann 1990), and helps to expose essential elements, such as phosphorous, for plant uptake (Chapin III et al. 2011). Therefore, increasing soil nitrogen levels can augment SOM content (Lamb et al. 2014), promote plant growth, and ultimately restore degraded land to its full ecological capacity. The results from the research site in Ariviyal Nagar showed that only six out of seventeen tree species, *Albizia lebbeck*, *Albizia saman*, *Azadirachta indica*, *Ficus benghalensis*, *Manilkara hexandra*, and *Polyathia longifolia*, were capable of fixing nitrogen in the plots. According to Franche et al. (2009), R*hizobia* and *Frankia* are two major nitrogen-fixing bacteria that associate with vascular plants, of which *Rhizobia* associates only with leguminous plants that belong to the Fabaceae angiosperm superfamily. Both *Albizia lebbeck* and *Albizia saman* belong to the Fabaceae family. The nitrogen-fixing bacteria that belong to the *Enterobacteriaceae* family associates with the nodules of trees associated with the Meliaceae family (Uchino et al. 1983). The tree *Azadirachta indica* belongs to the Meliaceae family and fixes nitrogen. In addition, tree species that belong to the non-leguminous family Moraceae, Sapotaceae, and Annonceae can be stimulated to fix bacteria when they are intercropped with leguminous tree species, such as those that belong to the Fabaceae family (Pendraza et al. 2007). This phenomenon is caused by *Azospirillum*, a free-living nitrogen-fixing bacteria that is a commonly found microorganism in soils, which promotes plant growth in tropical soils (Rao 1983; Ghai and Thomas 1989; Pendraza et al. 2007). However, the overall lack of tree species, nitrogen-fixing or otherwise, within the Ariviyal Nagar research site was caused by the deforestation event that occurred during the civil war. However, this is not true for trees cultivated in home gardens. None of the trees found in people's home gardens are nitrogen fixers.

Home gardens are micro-environments that are comprised of cultivated multipurpose trees, deliberately grown by rural household members to meet the nutritional and income needs of their family (World Agroforestry Centre 2011; Nair 1993; Gautam et al. 2006). Therefore, the trees found in the home gardens of agrarian households were selected primarily to meet food needs of the family rather than soil fertility. However, it must be noted that though home gardens provide some form of nutrition security to rural households, it is not sufficient to alleviate all household food insecurity that is prevalent within the Kilinochchi region (Vhrumuku et al. 2012). In addition, home gardens are cultivated with indigenous, native, and endemic tree species, which augments local tree biodiversity (Kumar and Nair 2004). As a result, home gardens that incorporated multi-purpose trees are considered to be micro-environments that have soils that are rich in soil organic matter, carbon, and nitrogen, and are not compacted (Pinho et al. 2012). As a result, soils found in home gardens are considered to be fertile (Pinho et al. 2012; Schroth et al. 2001), and therefore the number of nitrogen-fixing species is expected to be lower than in a dry tropical forest. Agroforestry systems have to include trees that are native and indigenous because they are specifically suited and adapted to the soil and microclimate of Kilinochchi. As such farmers were asked about threes grown in their home gardens so those tree species can be compiled. This compilation could be used to lay the foundation to create a database from which an agroforestry model can be recommended. In this way, these trees inform the agroforestry systems recommended in chapter six. Therefore, the agroforestry designs are community based and community-driven to meet the needs of agrarian communities living in Kilinochchi. Trees found in home gardens are used to add to the food and nutritional security of those households. In addition, these trees add to the overall heterogeneity of the forest canopy of the area, which is important to enhance the ecological capacity of the regional forest ecosystem.

The ecological capacity of a forest ecosystem can only be reached by enhancing tree biodiversity. Ecological capacity is defined as the "overall ability of an ecosystem to maintain its natural, original, or current condition to produce goods and services" (Sustainable Development Indicator Group 1996). Furthermore, biodiverse ecosystems are more stable and resilient to adverse environmental changes (Cleland 2011). Subsequently, increasing tree biodiversity will improve the structure, function, species composition, and productivity of ecosystems, which are all functions that are associated with natural forests (Thompson et al. 2009). It also maintains vital ecological services required to support agricultural systems and other biological communities (Peterson et al. 1998). Amplifying tree biodiversity through restoration can greatly improve soil fertility and health in the Kilinochchi region. Reforesting and restoring the area with more indigenous nitrogen-fixing dry zone tree species that are proven to be capable of fixing nitrogen (ex. Acacia tree species), will return soil nutrient and productivity to the land. The increased productivity of land will ameliorate other climatic stresses, such as drought, that are currently impacting the region today, as well as add to food security for communities in the Kilinochchi district.

4.5 Conclusion

Currently, the Ariviyal Nagar research site is sparsely populated with a few native dry zone tree species. Incorporating more indigenous tree species that are suitable to the regional arid conditions will increase forest diversity, and restore degraded soils in Kilinochchi. There is a strong need to incorporate tree species that are nitrogen fixers, which will positively improve soil organic matter content in the soil, and promote vegetative growth. Furthermore, the chosen tree species should have other value-added benefits, such as the production of fruits to increase food security in the surrounding communities.

CHAPTER 5: Agricultural Livelihoods and Land Management Practices in Kilinochchi

5.1 Introduction

Current agricultural practices are resource intensive and have negative impacts on the environment. Research has revealed that intensifying agriculture through increased use of agrochemicals (pesticides, herbicides, and fertilizers) caused land degradation, deforestation, fresh water contamination, and loss of soil fertility (Tilman et al. 2011). These factors have all contributed to increase food insecurity in subsistent agricultural communities found in developing countries (Rosegrant and Cline 2003). One such developing country is Sri Lanka, which in addition to poor agricultural practices has also been impacted by three decades of civil war; and where 20-40 % of its population continues to be employed in agriculture (FAO 2014).

Agriculture continues to be a vital form of livelihood for 27% of households living in the post-war Northern and Eastern provinces of Sri Lanka (Vhurumuku et al. 2012). However, this data does not accurately portray the number of farming households within just the Kilinochchi district. More specifically, there is a gap in the literature on the percentage of farming-dependent communities living within the Kilinochchi district. Nevertheless, field observations taken in 2014 have shown that many communities within the Kilinochchi district were dependent on farming for household income, survival, and food security. Paddy cultivation was the primary form of agriculture practiced in this region (Achuchtan 2012). Furthermore, small-scale farmers had always produced a surplus of red rice since the 1980s (Matthews et al. 2012; Sarvananathan 2007). During this time, farmers had been able to sustain the food requirement needs of their families along with external market demands for the rice crops (Dharamasena 2014). For the purpose of this study, mixed-farming techniques incorporate both traditional and modern methods of farming. Traditional methods of farming utilize cow manure, compost, green manure, animal waste products, and other organic matter to fertilize the soil and promote crop growth. In addition, traditional methods include home-grown pesticide solutions to prevent pest outbreaks in the crop field. Modern farming methods are defined as techniques that use mineral fertilizers, pesticides, and herbicides to obtain healthy crops and increased seasonal harvests.

In recent years paddy cultivation started to decline in Kilinochchi despite increased use of agrochemicals, and despite the shift to modern agricultural techniques to improve crop yields in the field (Poux 2008). This resource intensive agriculture resulted in farmer dependency on external resources to obtain profitable harvest outputs. According to Dharmasena (2010) and Jeyawardene (2003), paddy cultivation declined due to these same modern agricultural systems that encouraged monocropping of a limited number of rice grains, which promoted severe pest outbreaks, resulted in soil degradation, and decreased crop yields. Additionally, declining land productivity further increased farmer dependency on expensive and highly unaffordable agrochemicals, making it difficult for farmers to continue practicing agriculture in a sustainable manner. The excessive use of agrochemicals in farm fields have degraded the land and depleted soil nutrients, which has resulted in soil salination and erosion (Erkan 1995), and contributed to the loss of agricultural crop yields (Bhandari 2014). Therefore, this degradation of farm fields caused by the unsustainable use of agrochemicals has impacted household food security within the Kilinochchi region. Yet, agricultural families continued to maintain home gardens within their homesteads, which provided some form of food and nutritional security in these communities (Galhena et al. 2013).

Nonetheless the future of home garden cultivation is questioned as increased numbers of farmers have left agriculture production due to it not meeting their needs and instead joined a growing population of wage laborers in the Northern Province (Department of Census and Statistics Sri Lanka 2011; FAO 2011; Kumar and Nair 2006). It was speculated that the sudden shift of farmer employment into the service sector was caused by high levels of indebtedness and low levels of crop productivity, similar to cases found in rural India (Sajjad and Chauhan 2012). According to Petersson et al. (2011), the three decades of civil war within the Northern Provinces was the root cause of food insecurity in Kilinochchi due to increased inaccessibility of land on which to farm, displacement of farmers and crops destroyed in warfare. The civil war resulted in the displacement of hundreds and thousands of people. However, now in spite of post-war resettlement, farmers have found themselves without property, assets, and monetary resources to restart their livelihoods (Petersson et al. 211). In addition, they are restricted to access arable land due to mines and sanctioned high security zones (Petersson et al. 2011; Vhurumuku et al. 2012; Fonseka and Raheem 2011).These factors were and continue to be major forces that impact food security and farmer lack of livelihoods in Kilinochchi. In addition, recent studies and articles indicated several other factors, such as droughts (Srinivasan 2014), lack of proper irrigations systems (Dharmasena 2011), and lack of cohesive market mechanisms (Srinivasan 2014) that has further fueled food insecurity and farming livelihoods in the region.

However, the research does not specify the processes and mechanisms of how land, water and market inaccessibility impact farmer livelihood and food security in Kilinochchi. In addition, there is very little qualitative evidence of how these factors affect agricultural practices and contribute to farmers' struggles in maintaining or regaining subsistent livelihoods and food security. Moreover, there is very little knowledge on how farmers' conditions and agricultural practices have changed to adapt to farm on land impacted by war. It is essential to bridge these gaps to understand and implement a suitable agroforestry system that will positively augment farmers' agricultural practices in post-war Kilinochchi. This paper has aimed to bridge these gaps in literature through extensive farmer interviews detailing the day-to-day struggles affecting agricultural practices and the associated food security in Kilinochchi.

The purpose of this study was to understand the exact mechanisms of crop production used by practicing farmers to determine how they have adapted their agricultural techniques to cultivate degraded land in post-war Kilinochchi.

5.1.1 Research Questions and Objectives

5.1.1.2 Research Question

Two sub-questions for this research were:

1) How was farming different before and after war, and how does this impact farmers' livelihoods and access to food.
2) What were the land management practices put into place in post-war Kilinochchi, and what sort of practical knowledge informs these changes, if any.

5.1.1.1 Research Objectives

The primary research objective for this study was to understand the current state of farming in agrarian communities living in post-war Kilinochchi to determine how it impacts livelihoods and food security in that region

The specific objectives for this study were:

1) To determine current farming practices and its potential impact on soil degradation in agrarian communities living in post-war Kilinochchi
2) To understand the struggles faced by farmers to continue farming in Kilinochchi
3) To chronicle the Traditional Ecological Knowledge of farmers with regards to the natural surroundings, traditional farming practices, and local trees, which were all used to inform agroforestry recommendation outputted by this study in chapter 6.

5.2 Materials and Methods

After ethics clearance was obtained from the Office of Ethics Research at the University of Waterloo, thirty semi-structured interviews were conducted to evaluate land management practices in Kilinochchi, Sri Lanka. The interviews took place during the 2013-2014 growing season through October to February 2013-2014. The communities chosen for interviews were selected based on their proximity to the project site. Interviews were conducted in four communities (Bharathipuram, Kanakambikaikulam, Thiruvaiyaar, Malaiyaalapuram) adjacent to the Kilinochchi project site. For the purposes of this research, the questions for the semi-structured interviews started with general questions (see Appendix 2), which were tailored throughout the interview process to include new questions and clarifications. All questions including any clarifications in the interviews were focused on the themes surrounding 1) practice of traditional ecological knowledge (TEK); 2) Current knowledge about sustainable land management practices; 3) Existing traditional knowledge about agroforestry systems and practices, such as home gardens; 4) Community ability to access means of production (MoP) (tractors, seeds, fertilizers) and current cropping practices. Farms in the four villages were approached in a linear fashion off the main road.

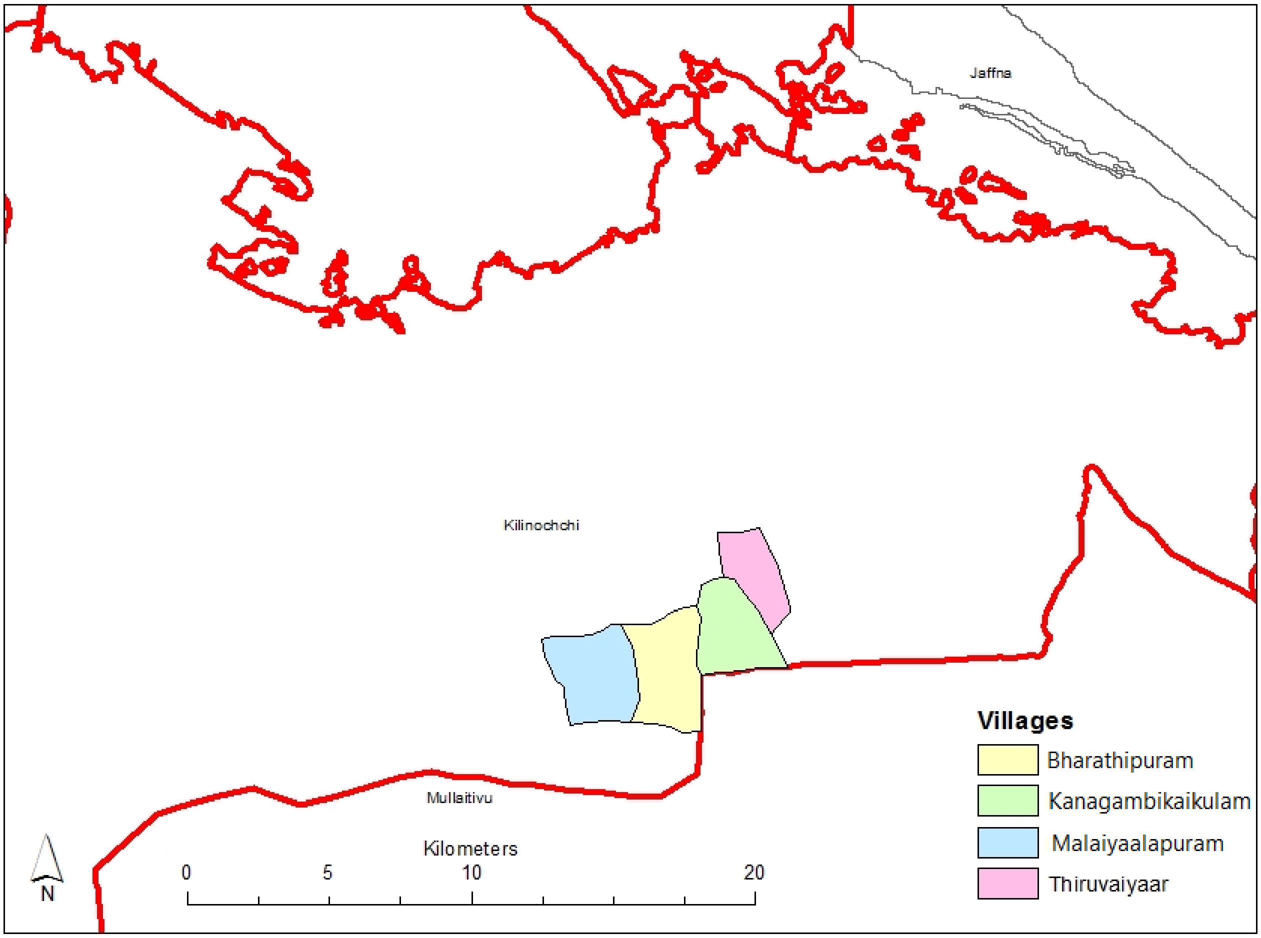


Figure 5.1 – The four communities of Bharathipuram, Kanakambikaikulam, Thiruvaiyaar, Malaiyaalapuram chosen for qualitative interviews, and adjacent to the Ariviyal Nagar research site

Only farms that had visible farming fields or home gardens attached to their property were approached. Self-identified farmers were asked for permission to conduct an interview. In instances where the farmer was not present or available their spouses were asked permission. Those farmers who refused to participate in the interviews were respected, and marked as refusals. In total, eight families were interviewed in Kanakambikaikulam, one in Bharathipuram, twelve in Thiruvaiyaar, and nine in Malaiyaalapuram. The interviews were conducted in the local dialect of Tamil.

The data collected from the interviewees was recorded, transcribed, and organized as accurately as possible after the interview collection period in the field. The data was coded using NVIVO 10 to identify and track the frequency of overarching themes in all interviews. Participant names were not revealed in order to maintain anonymity.

5.3 Results

Many of the farmers practiced agriculture prior to the start of war in 1983, and have provided insight to dramatic changes within the agricultural sector that contributed to the decline in agrarian livelihoods today. The results indicated that many of the participants in this study were middle-aged or older. Only two participants categorized themselves as being between the ages of 25-30. These individuals belonged to young families that were part of the Sustainable Agricultural Development Programme (SADP) scheme. Both men and women participated in this study. However, those who identified themselves as being enrolled in SADP were dominantly women.

5.3.1 General Trends and Struggles of Practicing Agriculture in Post-War Kilinochchi

In general, all the farmers indicated that there was a decline in rice crop production, which they noted in their farming experience, was caused by their excessive use of agrochemicals. Almost all the farmers indicated that marketing their products had become harder due to external competition and inaccessibility to markets. They also mentioned that Kilinochchi farmers used to sell their products through an auctioning system. This auctioning system allowed them to sell their goods to the highest bidder, and as a result they were always able to profit at the end of the harvest season. This auctioning system no longer exists in present day Kilinochchi.

In addition, they also stated that the cost of planting, maintaining, and harvesting rice and other crops far exceeded any revenue derived from selling the produce in the market. The other crops, such as eggplants (*Solanum melongena*), tomatoes (*Solanum lycopersicum*), peppers (*Caspicum annuum*), cowpeas (*Vigna unguiculata*), long beans (*Vigna unguiculata sesquipedalis*), and peanuts (*Arachis hypogaea*), were planted primarily for household consumption with the surplus sold in the market. The farmers stated the lack of capital return on these products made it harder for these farmers to invest more money into agriculture. As a result, farmers indicated that they expected and foresaw their children and the future generation seeking livelihood and employment outside of agriculture. Farmers indicated that they used some form of Traditional Ecological Knowledge (TEK) to cultivate their paddy fields but admitted that this knowledge was used in conjunction to modern agriculture techniques practiced in the region, known as mixed-farming techniques. Furthermore, they indicated that water scarcity has forced them to reduce rice cultivation, and attributed crop success to traditional strategies implemented in their field. All experienced farmers used mixed-farming techniques to maintain their crops rather than pure modern or traditional techniques (Figure 5.1).

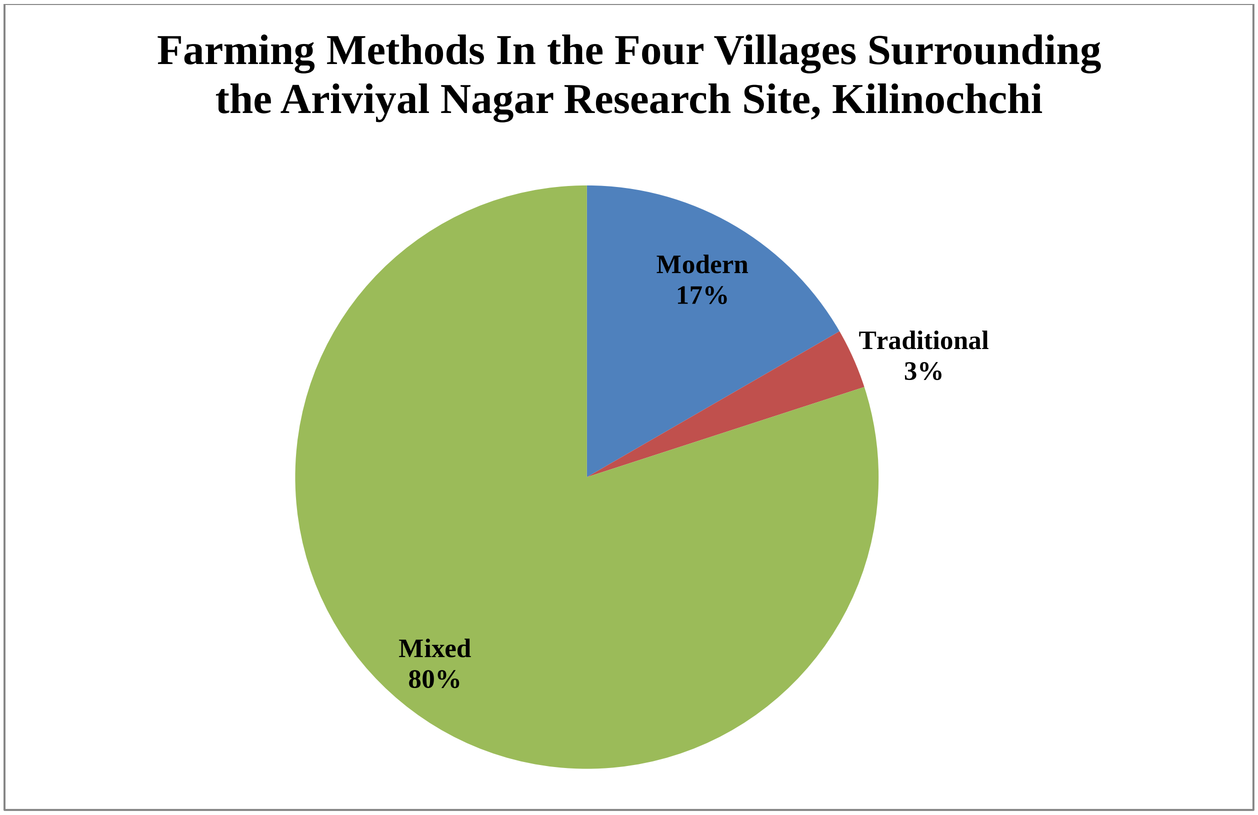


Figure 5.2- The percentage of farmers who utilized mixed-farming in all four villages surrounding the Ariviyal Nagar research site

All farmers also indicated that pre-war traditional forms of cultivation was best suited for the land and produced the greatest profit for them, but admitted that this practice was no longer used due soil infertility, unprofitable markets, lack of time to derive a profit, and precarious post-war land tenure conditions. Lastly, many of the farmers indicated that prior to 1995 bulls were used to plough the field. Farmers had now purchased or leased tractors to till the land because cattle were extant from the region, and they had no time, energy and money needed to raise and train the animals (Figure 5.2).

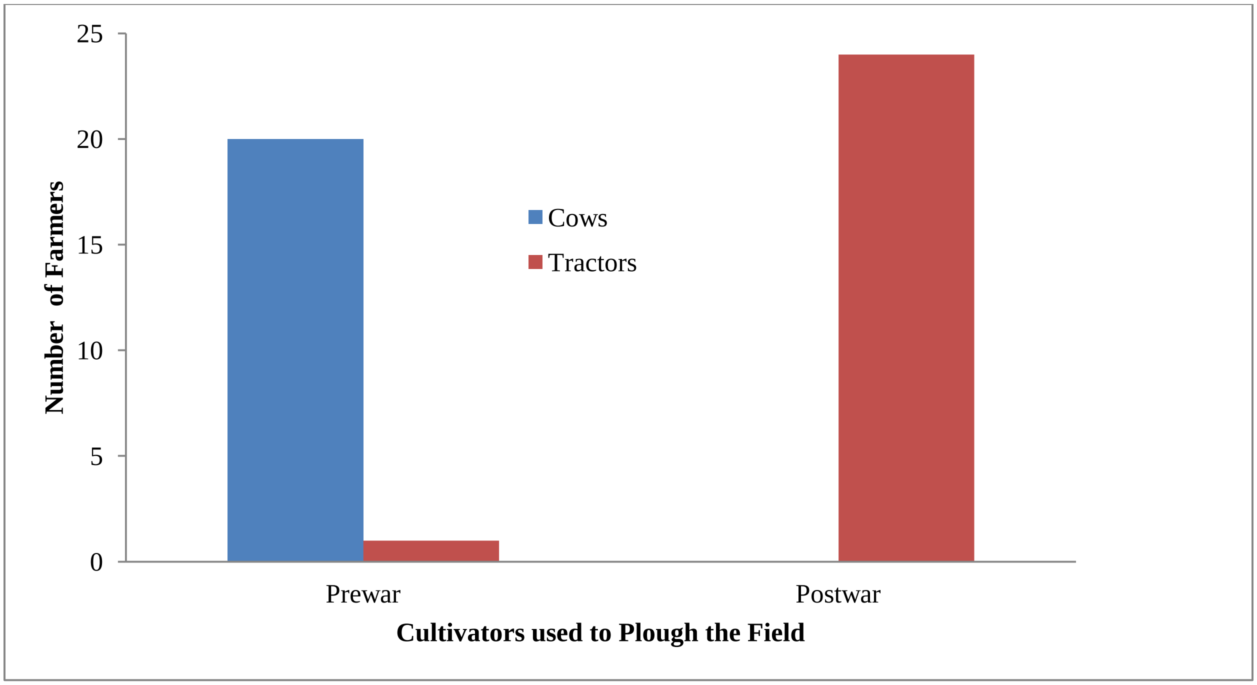


Figure 5.3- Post and pre-war cultivators used the most to plough the field before each growing season in the four villages surrounding the Ariviyal Nagar research site

However, they stated that using a bull to plough the field was ultimately better for the field because bulls in the fields turned the soil deeper, managed the weeds and mixed organic matter into the soil better than the machines. In addition, all famers practiced paddy cultivation, and used seasonal cropping regimes in their farm fields and home gardens. These crops were used for both household needs and income for farmers in Kilinochchi (Figure 2). However, the seasonal varieties chosen to be cultivated were monocropped throughout the region, and contributed to further decline in land integrity. All crops were rain fed based on interviews.

Out of thirty farmers, twenty-seven expressed that their households cultivated an agroforestry system of home gardens that integrated tree and vegetable crops to meet household food security needs. The women and children of the household mostly maintained the home gardens. There were eight commonly planted home garden tree species found in the four villages surrounding the research site (Table 5.1). The trees in the home gardens provided some form nutritional security to agrarian households. However, it is not sufficient to alleviate household food insecurity in the region. The increased problem of water scarcity in Kilinochchi has forced many farmers to reduce or completely abandon paddy cultivation. Those who continued to cultivate their fields achieved sub-standard harvests or lost their harvests altogether. These farmers have been forced to sell their land to pay off debts from the previous growing season or seek work as farm laborers elsewhere. Both conditions have placed farming families to live in poverty. Based on these results agriculture is no longer a form of sustainable livelihood for people living in post-war Kilinochchi because of poor soil fertility, harvests, and insecure access to land. These negative impacts on livelihood have contributed to food insecurity in the district of Kilinochchi.

Table 5.1 - Eight commonly planted home garden tree species found in the four villages surrounding the Ariviyal Nagar research site, Kilinochchi

Common Name	Local Name	Botanical Name	Family Name
Coconut	Thenna maram	*Cocos nucifera*	Arecaceae
Banana	Vaalai	*Musa spp*	Musaceae
Papaya	Papa maram	*Carica papapya*	Caricaceae
Mango	Maa maram	*Magnifera indica*	Anacardiaceae
Guava	Koiya maram	*Psidium guajava*	Myrtaceae
Breadfruit	Eera pilakaai	*Atrocarpus altilis*	Moraceae
Jackfruit	Pala maram	*Artocarpus heterlophyllus*	Moraceae
Jambul	Jambul maram	*Syzigium cumini*	Myrtaceae

5.4 Discussion

5.4.1 Impacts of War on Land degradation and Soil Infertility

The excessive use of agrochemicals during the Green Revolution in the 1960s contributed to land degradation in Northern Sri Lanka (Ambihai and Gnanavelrajah 2013), and is further exacerbated by three decades of civil war in the Northern Province of Sri Lanka.

The three decades of war has been the cause of large-scale bombings on people's homes and agricultural fields, which led to land degradation in Kilinochchi and many other districts in Northern Sri Lanka. During these times, farmers are forced to flee from their homes sometimes in the midst of planting their rice paddies. McNeely (2003) stated that long periods of war indirectly lead to soil erosion and chemical contamination of land through aerial bombardments, which impacted a farmer's ability to cultivate the land after conflict. One woman in Kanakambikaikulam describes this event as one of disorientation and disenfranchisement:

> *"In 1995, a period when people were being internally displaced, we would start farming where ever we were [displaced], then were quickly forced to abandon it when they started shelling that area or shelling the farm land. Those were the days of war"* (Kanakambikaikulam 1)

Furthermore, the ongoing war prevented farmers from having the necessary time to cultivate their farm fields in a sustainable manner, because it placed them in a precarious position where they were unsure when they would be forced to abandon their fields yet again (Tait 2014; Salah 2014). As a result, these conditions created a situation where farmers in Kilinochchi stated that they were forced to become reliant and dependent upon available agrochemicals to quickly obtain harvests to at least meet their own household food requirements. However, when the LTTE took control of the Jaffna Peninsula, the Government of Sri Lanka (GoSL) reacted by enforcing an economic embargo on the Northern Province (Sarvananathan 2007). This embargo restricted, amongst many items, the amount of agrochemicals and fuel that were allowed into the region (Sarvananthan 2007). The lack of fuel greatly hampered farmers from successfully irrigating their fields, and achieving food security in their households. Despite the economic embargo, the region became a protected area for the farmers in the region, who were to some extent able to continue with their livelihoods (Pathmanathan 2013 pers. comm). Consequently, farmers were able to revert back to traditional and sustainable forms of agriculture. Nonetheless, since war was still ongoing farmers have indicated that they learned to cultivate their land using a mixed form of agriculture that utilizes both traditional and modern forms of agriculture to obtain harvests and meet their household needs. In addition, the economic embargo that was imposed in the 1990s was upheld in the Kilinochchi region till 2002 (Sarvananthan 2007). However, despite these innovations, the influence of war still continued to affect farmers' ability to sow crops, obtain a harvest, and achieve food security within their households. These issues are compounded by restricted access that is military-enforced to arable land.

The results of this survey indicated that 38% of households who mentioned land ownership during their interviews leased the land they cultivated, and as a result they were unable to independently develop the land without breaking their lease agreements. Hence, many of these farmers are landless. The literature stated that this is caused by inadequate land development ordinance (LDO) and land policies in Sri Lanka (Raheem and Fonseka 2011). Furthermore, Kilinochchi is a region that is becoming highly militarized, which has resulted in the active appropriation of arable lands by high-ranking officials for military purposes, such as creating military bases, high security zones (HSZ), and other cultural Sinhalese monuments and structures (Raheem and Fonseka 2011; Senathirajah 2014; Klopp 2002; Lindberg and Herath 2014). Consequently, lack of access to land and thereby the inability to practice their traditional livelihoods was making famers and their families' food insecure.

The World Food Programme (2014) defined food security as the ability of households to have unlimited access to sufficient, safe, and nutritious foods in order to have a healthy, active, and happy life. Food security in farming communities in Kilinochchi is affected by many socio-economic factors, such as the ability of farmers to maintain their traditional livelihoods and farm productivity (Tiwari and Joshi 2012). In addition, farmers interviewed in the Kilinochchi area were facing many constraints trying to sustain their livelihoods, which comprised of: 1) limited access to fertilizers and natural amendments, 2) inability to optimize agricultural potential of land, 3) inadequate management of soil and water scarcity, 4) inability to market their produce.

5.4.2 Limited Access to Fertilizers and Natural Amendments

Farmers in post-war Kilinochchi are impoverished. According to the World Food Programme report on *Food Security in the North and North Eastern Provinces* of Sri Lanka (2011), Kilinochchi has the lowest median monthly income of 2 189 rupees ($19.10 CAD) per person, which is below the country's own national poverty line of 3 318 rupees ($28.95 CAD). Consequently, farmers in Kilinochchi struggle to purchase fertilizers for their paddy fields, but continued to do so because they are too financially insecure to wait for harvests that can be cultivated without agrochemical inputs. Many farmers echoed this farmer's statement:

> "*It is expensive [to purchase fertilizers], but it is easier to use because you just have to mix it with water and spray it on the banana plantations. You can't get good harvests with traditional methods of farming nowadays. What you put in today, you can only profit from the next year. But if you want profit immediately, you need to use some mineral fertilizers, such as urea, which will give you immediate results*" (Kanakambikaikulam 6)

However, in spite of agrochemical inputs, farmers stated that they still obtained poor harvests because of soil infertility in their fields, which they directly connected to their current fertilizer-intensive farming methods. The use of agrochemicals annihilates beneficial soil organisms, soil nutrients, insects, and fungi that play a key role in crop production (Thrupp 2000). After prolonged exposure, the use of agrochemicals degrades the land and reduces crop outputs (Thrupp 2000) forcing farmers to increase more of these inputs to maintain their means of income. Subsequently, farmers were unable to return to traditional forms of farming because soils that have been subjected to agrochemical regimes required five years to fully recover the lost soil organisms and minerals that define fertile soils (Speir and Ross 2002). This long process of soil recovery deterred farmers from switching back to traditional farming styles as they are dependent upon agriculture to fulfill their immediate economic needs. As a result, farmers in Kilinochchi continued to struggle to maintain their livelihood and obtain adequate harvests, which make them financially insecure. Yet, despite their financial insecurity farmers in Kilinochchi stated that they renewed purchase of fertilizers for their fields in hopes of better harvest the following year. Furthermore, poor harvests indicate that farmers were unable to provide food for their families, and therefore must purchase their food. Vhurumuku et al. (2012) stated that the average household in Kilinochchi spends 51% of their income on food purchases, which is the largest expenditure for the region. Farmer's ability to purchase food and sustain their families has become dependent on expensive and highly unaffordable food (World Food Programme 2014). Moreover, farmers in Kilinochchi are dependent on agrochemicals due to the lack of manure production caused by limited livestock in the region and decline of silvopastoral methods.

Prior to war, farmers were dependent on cows and bulls to fertilize and plough their fields. They relied primarily on bovine manure, tree prunings, and crop residues to replenish soil nutrient and organic matter stocks before the next growing season. Furthermore, all farmers in Kilinochchi strongly believed that cattle manure helped to keep their soils soft and pliable for root growth. Studies indicate that cattle manure is form of organic amendment that helped restock organic matter, improve fertility, and increase moisture content in soils (Feng et al. 2013), making water and other nutrient easily accessible during plant growth. Unfortunately, farmers lost their livestock during the multiple displacement events throughout war period, and with it the ability to fertilize their fields in a sustainable manner.

"*Cows were eliminated during the displacement events. Only one person in the entire village will have a cow but they won't give us the manure because they'll need it for themselves. In order to get a good amount of manure we need to spend a whole day collecting [it]*" (Malaiyaalapuram 5)

It is estimated that 50 000 cattle were abandoned during the conflict period, and the GoSL is only now repatriating them back to families in the North (FAO 2014b). However, returning the cows back to farmers will take multiple years, and in the meantime farmers rely on tractors and land-masters to plough their land. However, many farmers have expressed their distaste in using tractors and stated:

"*During those times, we used to plough the field with cows. We would plant rice and spray herbicides on the land, after 3 days we would use a wooden plough to till and then level the land, which would control all the weeds in the field. Now it isn't like that. When you use the tractor to plough the land, the weed and rice grains will come out all at the same time*" (Malaiyaalapuram 4)

In general, ploughs drawn by oxen are easier to handle than their mechanized counterparts because they are lightweight and are able to move well in paddy fields (Gebresenbet and Kaumbutho 1997). In addition, ploughs were more efficient turning soil over, which helped to bury weeds and bring new nutrients to the surface for the crops to access, as well as aerating the soil, and allowing for better moisture retention in the soil (Agroproducts 2008). One farmer expressed the benefits of oxen drawn ploughs by saying:

"*Even though we use machines now, it only ploughs 2 ½ to 3 inches into the soil. The iron ploughs that are attached to the bulls dig at least ½ feet into the ground. As a result, the soil is turned quite well, that is, the soil from the bottom is brought up to the top. So that is the best for agriculture*" (Kanakambikaikulam 6)

Since farmers in the region are impoverished, they have stated that purchasing new oxen are too expensive, and can cost up to 60-70 000 rupees ($532-621 CAD), which is the equivalent of purchasing a tractor. In summary, farmers' inability to access natural fertilizers and dependency on expensive agrochemicals have impacted their ability to maintain their agrarian livelihoods, and therefore affected their ability to achieve food security for themselves and their families. In addition, these limitations have also affected their ability to optimize the agricultural potential of their land.

5.4.2 Inability to Optimize Agricultural Potential of Land

The farmers in Kilinochchi have rich traditional ecological knowledge (TEK) (Figure 5.3). Broadly described, TEK is a “body of information about the interconnected elements of the natural environment, which traditional indigenous people have been taught, from generation to generation, to respect and give thanks for” (Menzies and Butler 2001). Traditional ecological knowledge is locally developed, land-based, provides important knowledge of biological species, and is of the belief that humans are part of the landscape instead of being separate from it (Mulder and Coppollilo 2005; Shiva 1997). This knowledge is unique in that it is fluid and can easily be revised to suit local conditions.

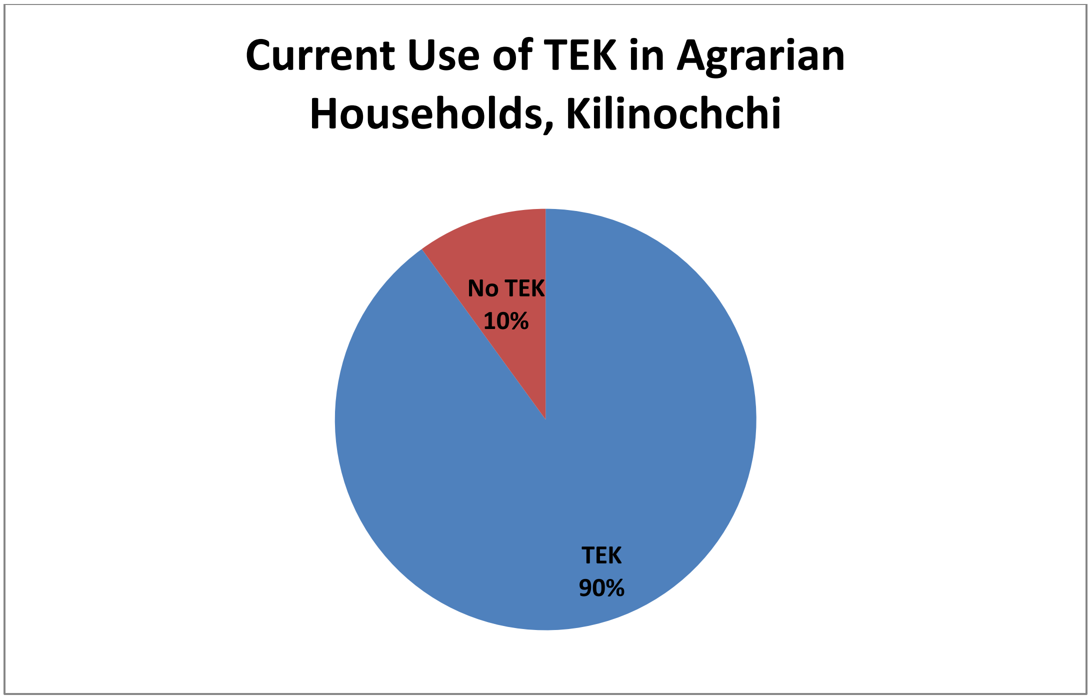


Figure 5.4- The percentage of households that use traditional ecological knowledge to cultivate their farm fields in the four villages surrounding the Ariviyal Nagar research site

However, current insecurity in agrarian livelihoods prevented many farming households from completely using this knowledge on their farm fields though they stated that it was practiced during the cultivation of their home gardens. Nevertheless, some farmers still tried to use attributes of their traditional knowledge to prepare the land for cropping, but often lacked access to tree species, such as *Thespia populnea*, that are beneficial for replenishing soil organic matter and nutrients. The inaccessibility of these trees was due to the large-scale deforestation events that occurred during the conflict period. During interviews with residents working in Kilinochchi, they mentioned that in the 1980s and early 1900s government soldiers cleared large tracts of dry forests in the North to prevent LTTE soldiers from using it as camouflage. Presently, only 24% of land in Sri Lanka remains covered by forests (MEPA 1991). Furthermore, many traditional fertilizers that were prepared by farmers in Kilinochchi to be used in the field required large amount of cow manure and urine, which have now become inaccessible as well. In addition, farmers in

Kilinochchi say that preparing traditional fertilizers takes time, energy, and resources that they no longer have. For example, one farmer explained the mechanisms of creating traditional pesticides for his home garden crops said:

> "*I use cow urine, neem seeds, Gliricidia, and cow manure, and place them all in the container for about 15 days. Afterwards, I separate it into 3 parts, and take those parts to mix with water and spray [it on the crops]. I have to drain the mixture first before I can mix it with the water before spraying*" (Malaiyaalapuram 7)

However, the farmer admitted that this would be impossible to replicate on his 1 hectare or 2.5 acre farm field. Consequently, farmers in the region were dependent on agrochemicals to fertilize their fields even though they realized it is not as profitable as using traditional fertilizers:

> "*When I used to sow salad green using their [chemicals] I found that I wasn't even able to harvest about 150 g. However, making my own fertilizers using traditional methods, I found that I was able to harvest about ½ kilogram. It's very profitable*." (Malaiyaalapuram 7)

Furthermore, their continued dependency on agrochemicals made it difficult for them to become self-sufficient in their farming practices (Altieri 2002). As a result, their land continued to degrade, they continued to struggle to obtain some form of profit from their harvests, while still expending large portions of their income on unaffordable food, which makes them poorer and more food insecure. According to a joint survey conducted in 2009 by the World Food Programme, UNICEF, and the GoSL, about 20% of Sri Lankans living in the Northern Province are food insecure. Improper management of soil and the persistent water scarcity issue prevalent in the region further aggravated this food insecurity.

5.4.3 Inadequate Management of Soil and Water Scarcity

Farmers in Kilinochchi do not have the proper resources, time, or energy to properly cultivate their land before each growing season due to the lack of natural amendments and lack of access to ploughs and cows. Most farmers in the region state that they lease a tractor on a needed basis to till their land because they are too expensive to purchase. According to Snapp and Pound (2008), tilling the land properly was essential for eliminating weeds in the field and enhancing nutrient availability in the soils for crop production. In small-holder farms, such as those found in Kilinochchi, this was usually done with oxen-drawn ploughs and other farm implements. However, with the onset and continuation of war, many of these customary implements and animals were lost. Subsequently, farmers in Kilinochchi were also too impoverished to employ farm laborers, who are expensive to hire, to help them till the land (Karunagoda 2004). As a result, farmers in Kilinochchi were dependent upon themselves and their families to sow and harvest the land. However, many of the farmers stated that their children do not help them farm as they are too busy getting an education and going to work elsewhere, as these women said:

> "*They were studying then got jobs in the government, and as a result were never interested in farming even though we ourselves farmed*" (Kanakambikaikulam 5)

> "*I doubt the future generation will continue to practice farming, because my children won't even help me while I'm farming. If they won't help in the field while I'm doing it, I doubt they will do it by themselves.*" (Thiruvaiyaar 10)

Studies in Sri Lanka have indicated that small-scale farming is becoming unprofitable, and is no longer a feasible form of income (Institute of Policy Studies of Sri Lanka 2014). As a result, employment in the agricultural sector has decreased as more and more farmers and their families seek work within the rising service sector of Sri Lanka (Department of Census and Statistics Sri Lanka 2011). Despite the increasing trend of employment within the service sector, unemployment rates, between 7.3-9.3% within the Kilinochchi district remains the highest in the country (Department of Census and Statistics Sri Lanka 2011). It is representative to rural families being forced out of their traditional livelihoods due to lack of profit. Additionally, poor profits were also attributed to water scarcity in the region.

The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) (2014) report that over 1.8 million Sri Lankans have been severely affected by drought since 2013. According to OCHA (2014), people living within the Kilinochchi regions are the most vulnerable to these drought events as people living there are poor, and are unable to protect themselves from climatic crisis. One farmer in Kilinochchi notes the changes in rain patterns and states how he lost his rice grains due to the drought:

"*In the past, by September 15th we see rain, but today we can only see rain after the 5th of December. In the past, by the 15th of September we had to have sowed our beans. Now, the rains are coming later and later. This year I lost two paddy fields worth of rice grain twice*." (Malaiyaalapuram 7)

In addition, when farmers in Kilinochchi lose their crops to drought the first year it becomes harder for them to sow crops the next year as they have no capital to seed their fields.

"*...because of the lack of water, we lost 30-40 000 rupees in the field. Then we lost another 15 000 rupees in the garden*" (Malaiyaalapuram 4)

Almost all of Sri Lanka's agricultural activities depend on major reservoirs for irrigation. However, due to droughts almost all the reservoirs are completely depleted of water (OCHA 2014). Subsequently, all the irrigation systems in Kilinochchi are damaged due to the civil war (IDA 2013). As a result, farmers are unable to harvest enough rice for the market and for their own needs. Moreover, the ongoing drought within Kilinochchi caused anxiety for farmers and added to food insecurity in the region (OCHA 2014; IRIN 2012). In fact, the World Food Programme Food

Security Analysis (2014) reported that due to erratic rainfall, “agricultural livelihoods in the Dry Zone will become unfeasible and unsustainable,” and estimates that 768 000 people are currently food insecure in Kilinochchi and the Northern Province. Moreover, to make matters worse, the Northern Provincial Council is planning to divert water from the Iranamadu tank, a major reservoir, in Kilinochchi to areas in Jaffna (Srinivisan 2014). Many farmers in Kilinochchi condemned this move by the Council as it only added to the water crisis presently affecting the region.

> “*We had members from the water management group in Kilinochchi who came here to ask for signatures to take water to Jaffna. We didn’t sign it. I told them we didn’t have enough water to irrigate our own fields. Then I also asked them to give us the water to cultivate our land, and whatever water is left over from us, they could take that to Jaffna. They told me that I shouldn’t talk like this when I am living alone*” (Thiruvaiyaar 10)

Both inadequate management of soil and lack of water added to eliminate or decrease harvests in Kilinochchi. Those farmers who managed to obtain some harvests after the growing season are faced with many difficulties trying to sell their products in the market.

5.4.4 Inability to Market Farm Produce

Farmers in Kilinochchi faced serious setbacks trying to sell their products in the market, including the inability to access markets and reduced sales prices for their produces caused by competition with external producers. Market access is related to the distance the farmer has to travel to get to the market (Buckmaster 2012). Interviewed farmers in Kilinochchi stated that produce markets that are far from their homes affect their abilities to sell the products, and earn an income. Accordingly, Immink and Alarcon (1993) assert that lack of access to market, changes in farmer harvest and agrochemical prices, market failures as well as poor and inefficient marketing institution, reduce a farmers annual profits and lead to income loss.

“*Look at those cowpeas. It took us a lot of time and energy to plant them but we are unable to market them because we have no way of taking it to the market. The government is supposed to help us with marketing the product, but they don’t and as a result we are suffering from it*” (Malaiyaalapuram 1)

All these factors contributed to increase farmer vulnerability to food insecurity in the district. Additionally, Kilinochchi farmers declared that they are under market pressure to sell their produce at a low price, stemming from the economic liberalization program advocated by the government (WaronWant 2014).

Economic liberalization is defined by the United Nations (2010) as the “processes, including government policies that promote free trade, deregulation, elimination of subsidies, price controls, and rationing systems.” It is believed that economic liberalization policies would increase market growth and reduces poverty within a country (UN 2010). However, the current agricultural policies that were produced through this movement have the opposite effect on small scale farmers in Sri Lanka (WaronWant 2014). Instead of procuring an income, farmers in Kilinochchi say that they have to sell their produces at reduced prices that force them to lose profit. Furthermore, most farmers say they are actively competing with government imported goods that were produced with less resource input, and therefore artificially depresses their own produce price.

“*The marketability of our own organic produce is affected by the government importing produce that have been grown chemically [from other regions]. As a result, our own produce, which are smaller in comparison to theirs, don’t sell as well*” (Malaiyaalapuram 7)

Additionally, due to the economic liberalization policies, the GoSL provided no social infrastructure support, in the form of energy, seeds, tools, inputs, and monetary subsidizations to sustain struggling farmers in Kilinochchi during the war or in the post-war period. Recently, the

Northern Provincial Council guaranteed farmers that it would purchase rice harvest from farmers, but have yet to follow through with their promises (Srinivasan 2014).

"*The government tells us they will purchase all our rice but that isn't true, it doesn't look like they are going to purchase everything. If we take it to them, they tell us that our rice has fungus or something else…They are making up excuses*" (Malaiyaalapuram 4)

Accordingly, the inability of agrarian households to generate enough profit to cover their own living, food, and farming expenses have resulted in high levels of debt and food insecurity within the Kilinochchi district (Vhurumuku 2012). As a result, it is believed that developing agroforestry farming systems that incorporate trees and are independent of commercial inputs can help to improve household food security in the region.

5.5 Conclusion

In short, the results from the farming interviews indicated a wide variety of factors and constraints impacting land management practices and food security in the region. These constraints include limited or no access to agricultural inputs (seeds and capital), lack of land tenure, water scarcity and poor environmental conditions, inability to hire laborers due to monetary limitations, inaccessible markets, external exports competing with local markets, and poor soil fertility.

The success of agroforestry systems to remediate soils in that region, improve harvests, and therefore alleviate the food crisis in Kilinochchi is dependent upon the national government providing social infrastructure, land documents, proper irrigation systems, market subsidization equal market opportunities, and farmer autonomy to dictate agricultural markets in the region. In essence, developing agroforestry systems in Kilinochchi can only be successful if proper socio-economic infrastructures are also present in the region.

Implementing agroforestry systems that incorporates farmer recommendations and endemic dry zone trees to remediate soils found in Kilinochchi will alleviate issues of soil infertility and improve food security in the region.

CHAPTER 6: Proposed Agroforestry Systems the Ariviyal Nagar Research Site and Dry Zone Kilinochchi

6.1 Agroforestry for Soil Remediation and Food Security in Dry Zone Kilinochchi

Agroforestry is a form of sustainable land use management system that has many benefits for rural farmers cultivating crops in highly degraded tropical biomes around the world. Based on the recent definition by the World Agroforestry Centre, Schroth et al. (2004) stated that "agroforestry is characterized as a dynamic, ecologically based natural resource management practice that through the integration of trees and other tall woody plants on farms and in the agricultural landscape, diversifies production for increased social, economic, and environmental benefits." It is considered to be better than conventional cropping methods because of the multi-faceted benefits derived from incorporating trees and other woody perennials into the landscape (Schroth et al. 2004). These benefits include (Singh 1994):

1. Improved soil quality through erosion control, nutrient cycling, increased soil organic matter, and nitrogen fixation
2. Improved crop yield due to improved soil fertility
3. Increased food security derived from food products such as fruits
4. Potential economic benefit obtained through timber harvest, and reduced dependency on external farm inputs

Furthermore, agroforestry practices help to naturally remediate soil infertility by reintroducing indigenous tree species into degraded agricultural landscapes (World Agroforestry Centre 2014). Trees play an integral role in returning organic matter to the soil through litterfall, retaining soil moisture, increasing essential soil nutrients, and enriching agrobiodiversity (Halberg and Muller 2013; Schroth et al. 2004). These factors contribute to improving soil fertility that helps to increase crop yields and food security in agrarian communities (Pinho et al. 2012). In addition, agroforestry systems are designed to restore specific land-related problems, such as soil infertility, in the regions and communities where they are implemented (Nair 1993).

The primary form of agriculture in the Northern Province of Sri Lanka is rice paddy cultivation. Paddy cultivation in this region, and within the Kilinochchi district, is rain fed and dependent on the monsoons for irrigation (Department of Agriculture of Sri Lanka 2006). Unfortunately, northern Sri Lanka is also the most vulnerable to drought (Withananchchi et al. 2014). The onset of droughts in the north poses a threat to the survival of rice crops during all periods of paddy cultivation (Moldenhauer and Slaton 2004). According to Withanachchi et al. (2014), there are three growing phases in rice cultivation that are heavily dependent on proper monsoonal rains, and any fluctuations in these patterns can impact the production and harvest of rice crops. In essence, rice is consistently submerged in water throughout its lifespan, and yet not many dry zone trees are able to tolerate or thrive in perpetual waterlogged conditions (Halcomb 2013). In fact, very little information exists on rice-based agroforestry systems in Sri Lanka and globally (Hocking and Islam 1995).

Based on the literature, the agroforestry designs that are recommended for post-war dry zone region of Kilinochchi took into consideration the unique microclimate of paddy systems (i.e. waterlogged plots). As a result, the proposed trees and crop systems recommended for this region are suited for the highly wet environments of the paddy fields. In addition, recommendations by local farmers, which were informed from their TEK and farming experience, were also taken into consideration for the proposed agroforestry design. All designs incorporate tree and crop species that can improve soil fertility in the region, and also increase food security for agrarian households.

6.1.1 Research Questions and Objective

6.1.1.1 Research Questions

Would the recommended agroforestry system remediate land degradation and alleviate food insecurity for community members living in Kilinochchi?

6.1.1.2 Research Objective

The two main objectives of this chapter is to recommend three agroforestry designs suited to meet the needs of local farmers in Kilinochchi, and to provide overall conclusions for the entire thesis. The specific objectives for this study are:

1) To recommend agroforestry systems suitable for the microclimate of paddy lands based on data from chapters 3,4, and 5
2) To determine the best tree-crop systems suitable for the current land use practices existing in dry zone Kilinochchi.

6.2 Materials and Methods

The recommendations are based on the data results from the baseline soil survey (chapter 3), the vegetation inventory (chapter 4), and the interviews taken from farmers living in the villages of Kanakambikaikulam, Bharathipuram, Malaiyaalapuram, and Thiruvaiyaar (chapter 5).

6.3 Results

The results from the soil survey indicated that the soils in the Kilinochchi region are degraded, have low soil organic carbon, total nitrogen, and pH that is alkaline. However, it must be noted that the plots from the research site are not fully representative of the surrounding regions (i.e. in the interviewed villages) because they were never intensively managed for crop production using agrochemicals. As a result, the results from the research site only indicate land degradation caused by warfare. The tree inventory for the research site and the home gardens signified that the Kilinochchi region has low tree species richness and forest covers. Furthermore, farmers interviewed in the villages surrounding the Ariviyal Nagar study area, stated that they were predominantly paddy cultivators. They said that once the paddy was harvested, they planted other crops, such as peanuts (*Arachis hypogaea*) and cowpeas (*Vigna unguiculata*) on the same plot of land to replenish lost soil nutrients. This practice revealed the versatility of land use for plots set aside for paddy. As a result, agroforestry designs that are ideal for post-harvest planting will be recommended.

6. 4 Recommendations for Agroforestry Systems in Kilinochchi

The agroforestry design recommendations for dry zone Kilinochchi is based on the soil and vegetative data compiled on plots A, C, F on the Ariviyal Nagar research site and the existing land use systems within the Kilinochchi district. These particular plots were chosen based on the Kilinochchi Master Plan Document (Appendix 3) proposed by the University of Jaffna. According to the University of Jaffna's Master plan, plots A, C, F were allocated for the development of the Green Spine, where students from the environmental department can set up their agricultural experiments, and all areas outside of this space were allocated for the development of building infrastructure. All of the proposed agroforestry designs take into consideration the paddy microclimate during the paddy-cultivating season, but can also be maintained after the harvest of the paddy field. The following Table 1 provides a comprehensive summary of the chosen plots. The last section in table 6.1 provides an informed summary of paddy land soils. The second table (Table 6.2), based on the *Design and Evaluation of Agroforestr*y developed by the World Agroforestry Centre and Food and Agriculture Organization, looks at land-use system constraints in Kilinochchi and provides potential agroforestry solutions to these limitations.

Table 6.1- Summary of soil physical and chemical characteristics and vegetative characteristics in plots A, C, F at the research site and paddy land in Kilinochchi

Soil Texture	Soil Aeration[2]	TN	SOC	Soil compaction[1]	pH	Vegetation	Sites
Sandy loam	Low	Low	Low	High	6.8	*Albizia saman* *Bauhinia tomentosa* *Manilkara hexandra* *Swientenia mahogany* *Terminalis arjuna*	**A**
Clay	High	Low	Low	High	8.3	*Azadirachta indica* *Ficus racemosa* *Morinda tinctoria*	**C**
Clay loam	High	Low	Low	High	6.9	*Albizia saman* *Manilkara hexandra* *Morinda tinctoria* *Syzgium cumini* *Tectona grandis*	**F**
All soil types	N/A	Low	Low	N/A	4-8*	*Oryza sativa*	**Paddy***

Note: SOC = soil organic carbon; TN= total nitrogen
1 Soil compaction results was based on bulk density values
2 Soil aeration results were based on soil porosity values
* From (Dhanpala 2000; Department of Agriculture Government of Sikkim 2014)

According to the baseline soil and vegetation data collected for this region (Chapters 3 and 4), Kilinochchi is comprised of mostly Lixisols (FAO 2014). The research indicated low levels of nitrogen, carbon, and therefore organic matter, and slight compaction in some plots, making the soil unsuitable for crop production. The vegetation in Kilinochchi is typical of dry zone tree species, and tree species are able to adapt to the poor soil conditions found in the region. The trees are drought-tolerant evergreen species that are able to thrive in harsh arid and low nutrient conditions. In addition, seven of the tree species are able to fix nitrogen, and provide multiple socio-economic benefits, such as fruits, medicine, and fodder to community members who utilize the trees. Recommendations for the agroforestry design incorporate these tree species in combination with other potential tree species and crops.

There are three major constraints identified by Kilinochchi farmers (chapter 5) that are impacting farm production and food security in their agrarian communities surrounding the research site (Table 2). These constraints include: 1) limited access to fertilizers and natural amendments, 2) inability to optimize agricultural potential of land, and 3) inadequate management of soil and water scarcity. All of the causes associated with these constraints have also been self-identified by the farmers in Kilinochchi. The plight of these farmers is similar to those faced by farmers in a coffee-based farming system in the highland ecozone of Kenya (Avila and Minae 1992). As a result, the role of agroforestry to help alleviate these issues is similar to those recommended by Avila and Minae (1992), but has been modified to meet the local needs of farmers living in Kilinochchi.

Table 6.2- Summary of constraints, causes, and potential of agroforestry to alleviate land-use related issues in Kilinochchi, Sri Lanka (adapted from Avila and Minae 1992)

Identified Constraints for Crop Production	Causes	Role of Agroforestry
Limited access to fertilizer and natural amendments	Lack of monetary resources to purchase farming inputs	
	Lack of manure production due to limited or no livestock in the region	Increase biomass availability on land through MPTs* to convert to green manure can also be used for fodder
Inability to optimize agricultural potential of land	Lack of ability to utilize traditional ecological knowledge to cultivate land	Expand indigenous fruit trees on farm fields (additional benefit of increased food security)
Inadequate management of soil and water scarcity	Lack of resources, time, energy to appropriately manage soils	Include MPTs in soil conservation practices
	Lack of labor on farm fields	
	Lack of social infrastructure and irrigation systems	Incorporate trees and crops that are drought-tolerant

*MPTs = multi-purpose trees

The suggestions for agroforestry designs (Table 6.3) are based on the soil results from chapter three (Table 6.1) and the farmer interviews from chapter five (Table 6.2). The role of trees in alleviating land-related infertility is similar to those offered by Avila and Minae (1992). However, the suggested tree species were modified from those suggested by the authors due to climatic changes between the two regions of Kilinochchi and Kenya. The newly recommended tree species (found in bold) are native to Sri Lanka and are naturally found in the dry zone region. *Thespesia populnea* or Indian tulip tree was recommended by local Kilinochchi farmers as a good source of mulch for farm fields. The remaining trees, *Diospyros malabarica* (Kumara et al. 2002), *Gliricidia sepium* (Garrity 2004), *Flemingia macrophylla* (Natural Resources Knowledge 2014) and *Tamarindus indica* were chosen because of their adaptability to the dry zone climate of Kilinochchi, and provide multiple services to the area where they are planted. Only two of the recommended trees, *Ficus racemosa* (Nautiyal et al. 1998) and *Tamarindus indica* (Murthy 2014), are fruit-bearing and directly add to food security for farming communities. Nevertheless, trees indirectly help to increase food security by increasing soil fertility through litterfall and providing essential ecosystem services (Lal and Stewart 2013) needed to remediate degraded/marginal land for crop production. Furthermore, all the listed tree species can be used as fodder for livestock.

Fodder trees are used by small-scale farmers to indirectly derive short-term revenue for their households. Subsequently, fodder is used by many farmers living in arid and semi-arid lands to feed livestock (Franzel et al. 2014), whose products can be sold at the market to generate income. According to Conroy and Litvinoff (2013), Ipil ipil (*Leucaena leucocephala*) is a highly recommended fodder tree due to its coppicing nature and ability to provide fodder year round. However, Ipil ipil cannot be recommended for cultivation in northern Sri Lanka because it is highly invasive within that region (Weerawardene 2005; Baguinon et al. 2003). Nonetheless, all the trees recommended for the agroforestry designs are excellent fodder trees, especially *Gliricidia sepium*. *Gliricidia sepium* is capable of growing 3 m in 6-8 months, which makes it a fast-growing, protein rich fodder tree species for animal consumption (Nurulhayati et al. 2014). Well-fed animals provide multiple purposes for subsistent farmers, such as those found in the Kilinochchi district.

A study by Staal et al. (2009) looked at the contribution of livestock, such as dairy cattle, small ruminants, poultry to household income in Sub-Saharan Africa and South Asia, indicated that on average livestock production accounted for almost 40 % of total household income. Furthermore, livestock offer animal-source food, such as milk, eggs, and meat, that provide essential vitamins and minerals, which add to the nutritional security of rural communities (Stall et al. 2009; FAO 2011), such as those living in the Kilinochchi district. Furthermore, milk, eggs, and meat can also be sold in the market, and provide families with another form of income (Kristjanson et al. 2004). According to the FAO (2011), the loss or disappearance of livestock can cause households to descend into poverty, and therefore impact their ability to secure food. In addition, animal excretion is often used by small-scale farmers to fertilize their lands (Dharmasena 2010). Therefore, fodder trees play an essential role in providing small-scale farmers within Kilinochchi the opportunity to obtain short-term income as the recommended agroforestry systems establish themselves. As a result, using fodder trees as short-term strategy can help agrarian communities to decrease food insecurity within their communities. However, it must be noted that these agroforestry design recommendations should not be taken as the only solution to current land-related infertility and food insecurity prevalent throughout Kilinochchi.

Table 6.3- Potential agroforestry designs based on land-use systems with suggested tree and their function in the Kilinochchi Dry Zone landscape (adapted from Avila and Minae 1992)

Land-use System	Potential Agroforestry Designs	Role of Trees	Suggested Trees Species
	Mixed cropping "Rice bund planting"	Fruits Soil moisture retention Nitrogen fixation/mulch Fodder	***Diospyros malabarica*** *Terminalia arjuna* ***Gliricidia sepium***
Food Crops	Living fence	Soil conservation/fodder Soil fertility/fodder Nitrogen fixation/fodder	***Flemingia macrophylla*** ***Thespesia populnea*** *Gliricidia sepium*
	Boundary planting	Soil conservation Tree product Biomass/ mulch	*Azardirachta indica* ***Tamarindus indica*** *Ficus racemosa*

Note: bolded tree species are suggested and currently not found in the region but are native to the region

6.4.1 Mixed Cropping Agroforestry System (Rice bund planting)

Mixed cropping or multiple cropping is an old form of agriculture usually implemented in the tropics to optimize land productivity in an area during one growing season (Gliessman 1980). Mixed cropping systems have some disadvantages and many advantages when incorporating them in agricultural fields. The disadvantage of using mixed cropping systems is due to the potential competition between crops for sunlight, nutrients, and water (Gliessman 1980). However, according to Huxley (1980), in mixed cropping agroforestry systems the growth of the tree and crop species are separated in time, and therefore they exploit different nutrients and environmental resources at different times of the year. Accordingly, these disadvantages are negligible when trees are incorporated with crops. Furthermore, due to the lack of competition mixed cropping agroforestry systems are ideally suited for the light- intensive paddy dominant Kilinochchi landscape. Paddy cultivation only occurs twice a year in Kilinochchi, and usually limited to the *Perumpoham*, or Second-Inter-Monsoon season, when the heaviest rains occurs. Kumara et al. (2002), who conducted a case study in the Kalegama Wasama dry zone region of Sri Lanka, found that large trees are usually conserved in paddy fields found on the study site, but suggested the number of trees to be limited so that the rice crops are able to still receive appropriate light for proper growth. In addition Kumara et al. (2002) state that paddy cultivation is a sequential agroforestry system that becomes converted into another crop system once paddy is harvested. The advantages of using mixed cropping agroforestry system in paddy fields includes: 1) higher degree of biomass return to the system, 2) more efficient circulation of soil nutrient in the system through incorporating trees, 3) reduction of water evaporation, 4) improved soil aeration and filtration due to trees, 5) better nitrogen fixation, and 6) more resilient to climatic variability (Gliessman 1980; Francis 1986). Hence, multiple cropping systems are an effective strategy that can be used by farmers in Kilinochchi to secure paddy harvests, replenish soil nutrients, remediate degraded land, and improve food security within their communities (Waha et al. 2013).

The suggested mixed cropping agroforestry system takes into consideration the paddy microclimate during its growing season (Figure 6.1). The recommended trees are not limited to those suggested in Table 6.3. There are also many other suitable trees (see Chapter 4, Table 6.4). However, for the purpose of creating a definite and complete agroforestry system, this design aims to incorporate *Disospyros malabarca, Terminalia arjuna, and Gliricidia sepium* (Appendix3). All three tree species are native to the dry zone region of Sri Lanka (Kumara et al. 2002). *Disospyros malabarca and Terminalia arjuna* are suggested for planting near and around the edges of the paddy field due to their medium crown size (Krishen 2006) that may provide shade for the paddy crops. Whereas, *Gliricidia sepium* is suggested for planting in the middle of the paddy fields, as they are smaller trees with smaller canopy cover (Krishen 2006). The trees associated functions in the paddy field are presented in Table 6.3, and are chosen to improve food security in the community, provide nitrogen, and increase soil integrity in the paddy lands. This design can also be modeled in plot A of the Kilinochchi research site.

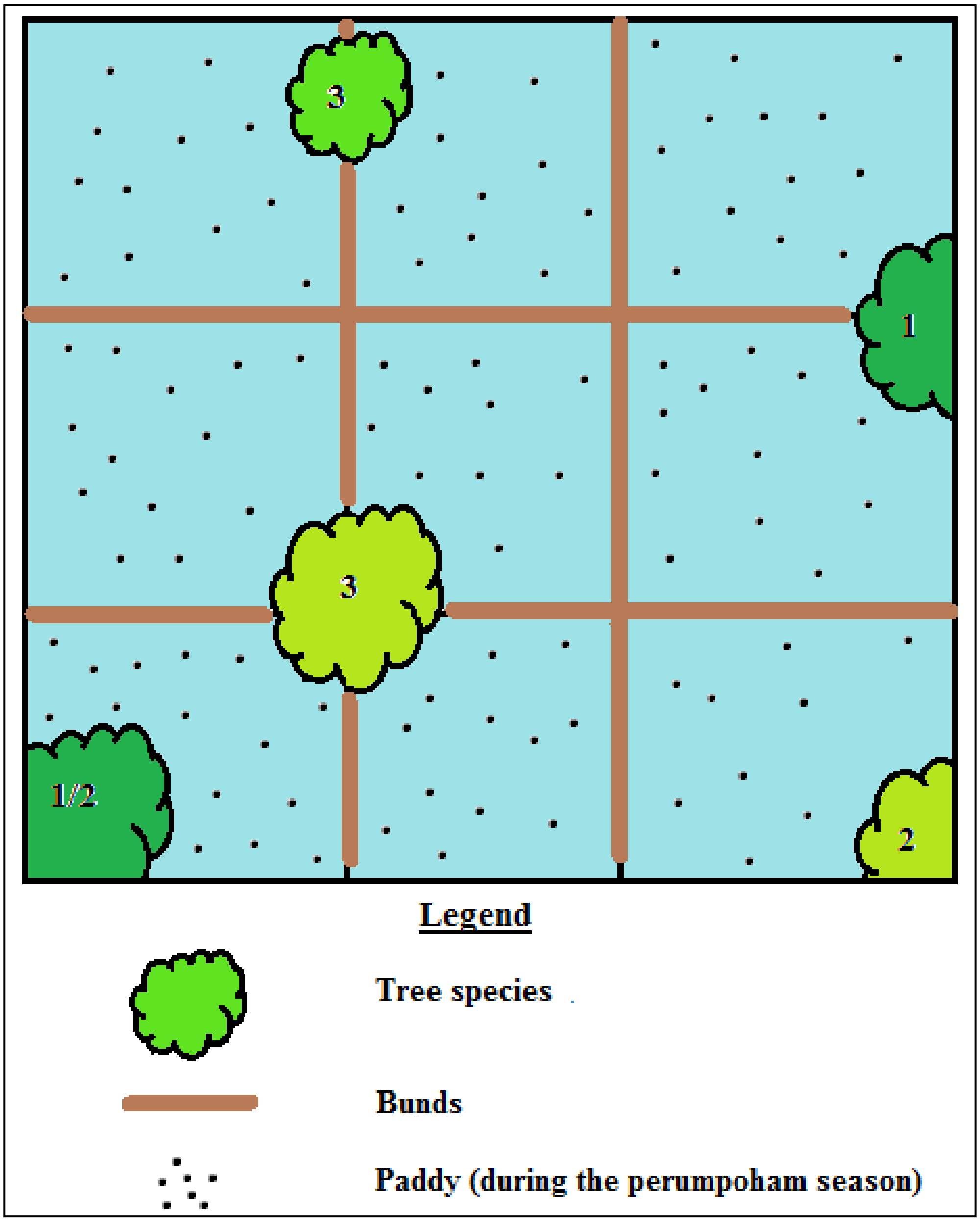


Figure 6.1- Mixed cropping agroforestry system interspersing *Diospyros malabarica* (1), *Terminalia arjuna* (2), and *Gliricidia sepium* (3) tree species on paddy fields (modified from Huxley 1985)

6.4.2 Living Fences

The living fence agroforestry system (Figure 6.2) is similar to hedgerow cropping and is a popular agroforestry technique used in many parts of the tropics (Gabriel 2004). This system involves growing multiple leguminous trees around the perimeter of the farming field (Nair 1993). The trees are periodically pruned to add mulch to the farming field (Nair 1993). This design can also be used by farmers during paddy season because the trees are planted at a distance and do not interfere with the growth of the field crops (Gabriel 2004). There are multiple benefits for incorporating living fences into the farm field, and include: 1) they act as natural boundary markers, 2) improve soil through nitrogen fixation, 3) pruned materials helps to increase soil fertility 4) can be used as animal fodder and fuelwood (HDRA 2001). In addition, living fences can act as windbreaks to reduce wind speeds and prevent soil erosion (HDRA 2001). However, Nair (1993) states that living fences that are designed to be windbreaks must be oriented in a particular direction to be effective. Hence, in this particular system the living fence would be used only as a boundary plant because dry zone Sri Lanka is not affected by high damaging winds (Department of Agriculture Sri Lanka 2006). The suggested living fence comprised of three native tree species *Flemingia macrophylla* and *Thespesia populnea*, and *Gliricidia sepium* are documented to be fast growing excellent nitrogen fixers (Schultze-Kraft and Peters 2014). In addition, all three tree species help to improve soil fertility by increasing soil organic matter, soil aeration through root activity, and moisture content, which enhances harvest yields (Schultze-Kraft and Peters 2014).

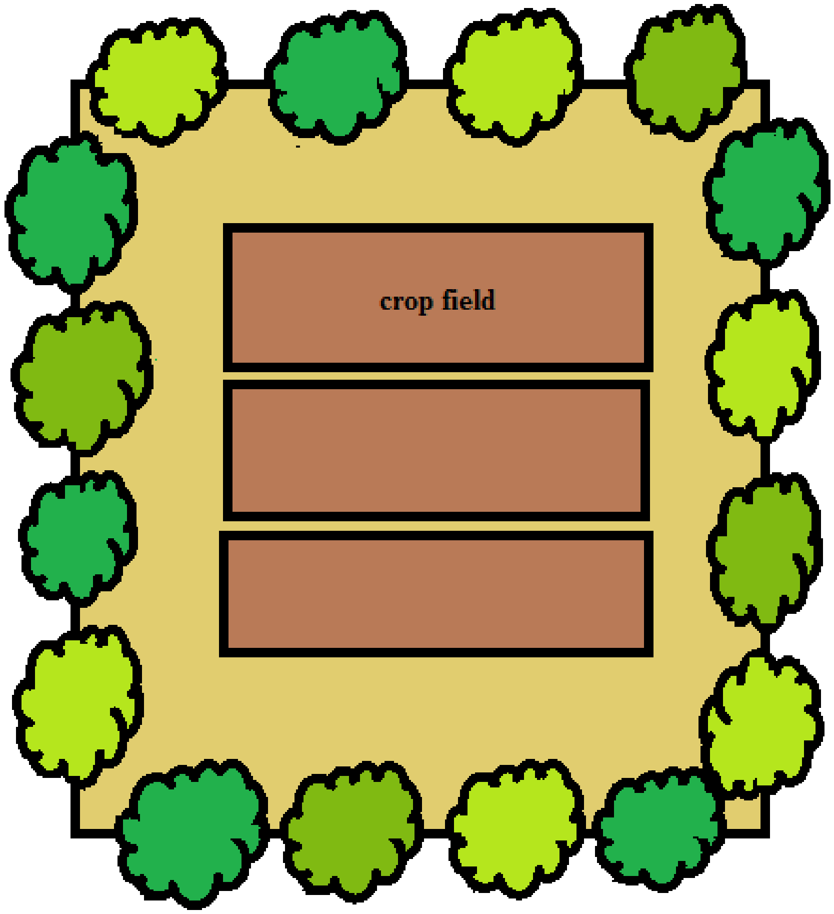
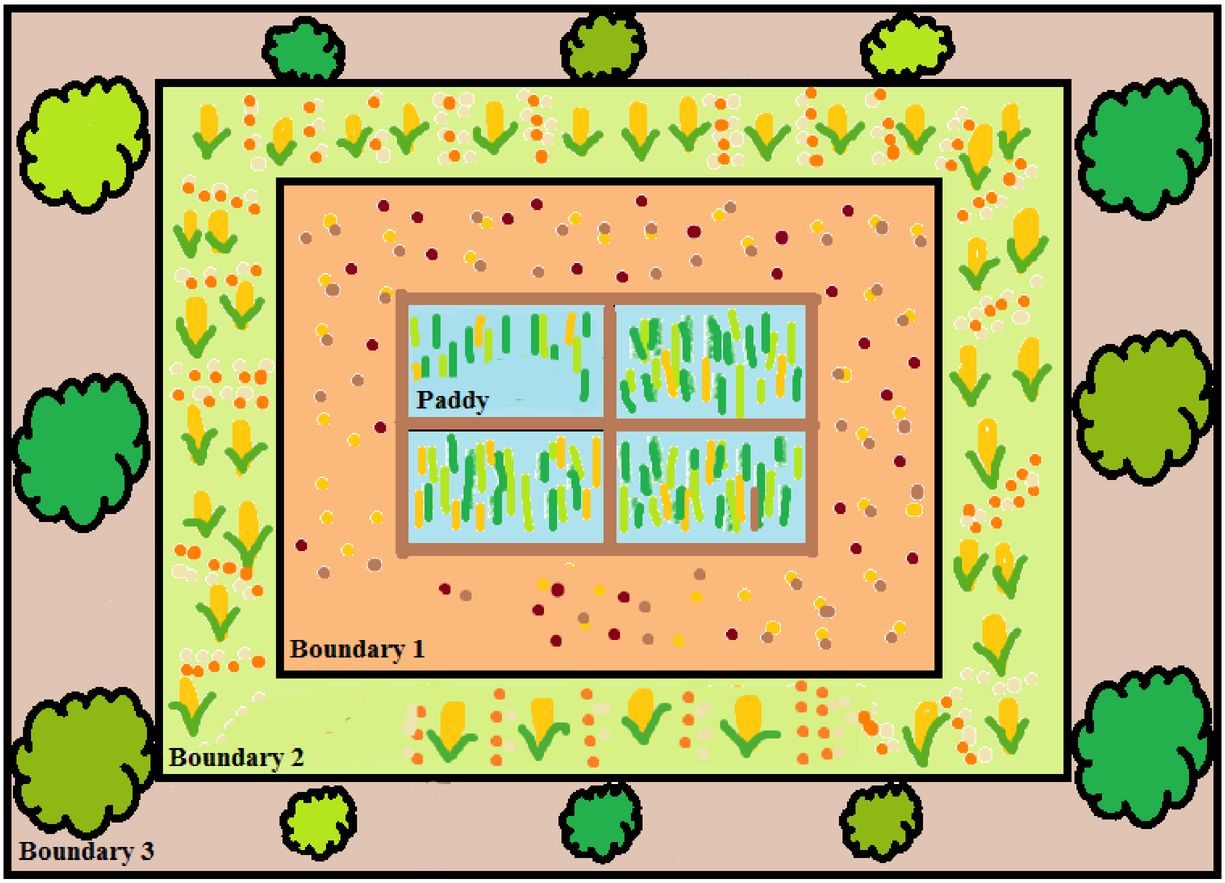


Figure 6.2- Living fence of three nitrogen-fixing tree species *Flemingia* macrophylla and *Thespesia populnea,* and *Gliricidia sepium*

6.5. Boundary Planting Agroforestry System

The recommended boundary planting agroforestry system is a paddy-sorghum-corn/pigeon pea-fruit tree quinto-culture (Figure 6.3). This design incorporates five different crops within the same agroforestry system, referred to as quinto-culture, and is suitable for both paddy fields planted at lower elevations, and those cultivated on flat land, because farmers in the region are seen to build bunds around their rice crops.

The recommended tree and crops reduces nutrient loss in paddy fields planted in valleys, returns nitrogen to soils, and creates potential biomass that can be used to ameliorate the degraded soils of Kilinochchi. Furthermore, the recommended trees are predominantly fruit-bearing and can be used to improve nutritional security for local households. As a result design focuses on maintaining the paddy culture prominent on the Kilinochchi landscape during the *Perumpoham*. Due to the nature of the quinto-culture, the design can also be used after paddy harvests. The design incorporates sorghum (*Sorghum bicolor*) in the first boundary layer around the paddy field because of its ability to survive temporary waterlogged environments and control soil erosion (FAO 2014). Furthermore, Pedersen et al. (1977) indicated in their study that sorghum is capable of fixing more nitrogen when it is planted as a sole crop. In another study, Gyamfi et al. (1997), revealed that on an annual basis sorghum is able to fix 50 kg N ha^{-1} when it is planted as a sole crop than when it is planted in an intercrop with pigeon pea (*Cajanus cajun*), where it was only able to fix 25 kg N ha^{-1}. In this design sorghum is planted as a sole crop in the first boundary. The second boundary includes an intercrop of pigeon pea and maize (*Zea mays*). Maize and pigeon pea are intercropped in the second boundary because of their different growth rates and maturity period (Singh and Singh 1980). Pigeon pea is deep-rooted and grows at a slower rate during the early stages of its growth period in comparison to the fast-growing maize, and hence both crops are able grow well without competing for natural resources (Marer et al. 2007). Furthermore, pigeon pea increases the biomass and harvest potential of maize due to its ability to fix nitrogen (Gyamfi et al. 997). It is recommended that the maize to pigeon pea row ratio to be 4:2 in order to obtain the higher yields (Marer et al. 2007). High and successful yields of maize will greatly improve food security in Kilinochchi. Moreover, crop residue from maize and pigeon pea harvest could also be used as fodder and mulch in farming fields to increase and replenish organic matter and nutrients in the soil. The last boundary of the agroforestry design incorporates indigenous fruit trees. The type and nature of the fruit trees can be chosen by the farmer based on their specific traditional knowledge in order to meet their household needs. Some suggestions and their uses are included in Table 3. This design can be modeled in plot C of the research site.



Legend

Boundary 1 = Sorghum
Boundary 2 = Corn/ Pigeonpea
Boundary 3 = Fruit trees
Bunds

Figure 6.3- Boundary planting agroforestry design that incorporates paddy-sorghum-corn/pigeon pea-fruit trees quinto-culture for soil regeneration and food security (modified from Snapp and Pound 2008)

Integrating one or all of the proposed agroforestry design within the farm fields of agrarian communities in Kilinochchi, Sri Lanka can greatly improve soil fertility and food security within that region. However, the suggested agroforestry systems are fluid designs that can be further modified to meet any additional needs identified by the community for whom it is designed. As a result, these designs must be implemented with the full approval of community members to be ethical and useful to them. Furthermore, it is strongly recommended that these designs are modeled in the suggested plots A, C, and F so that communities have the opportunity to familiarize themselves with the design before implementing it themselves within their own farm fields. Conveniently, modeling these systems in the Ariviyal Nagar research site provides future researchers, communities, governments, universities, and non-governmental organizations an opportunity to study the effectiveness of the agroforestry systems on soil fertility, crop yield, and food security.

6.6 Conclusion

Kilinochchi, Sri Lanka is a region that has recently emerged from three decades of civil war, which has caused massive environmental degradation. The prolonged period of war and its associated activities has resulted in massive disruption of farmer livelihoods and land degradation within the Kilinochchi region, and has resulted in food insecurity within communities living in this district. Furthermore, unsustainable management of agro-ecosystems by farmers that are heavily dependent on agrochemicals has eroded the land, making it unsuitable for agriculture. In addition, Kilinochchi is one of the poorest districts found in Northern Province of Sri Lanka, of which a bulk of the population is employed in the agricultural sector (Department of Census and Statistics Sri Lanka 2011). Based on this premise, it is believed that implementing agroforestry systems, and sustainable land-use practice, tailored to meet the needs of the community can help to remediate soil infertility and improve food security within agrarian households living in the area.

Consequently, focusing only on land-related constraints to agriculture, it is recommended that mixed cropping (rice bund planting), living fence, boundary planting agroforestry systems be utilized in the region to improve soil fertility and increase food security in the communities. However, the farmers would also need social support to combat the constraints placed by historic disadvantages and the recently ended war. The constraints include farmers' difficulty in selling their produce due to external competition and they cannot access markets because of restriction of movement by the military presence. However, note that without the proper social infrastructure, and support from the local and national governments, implementing agroforestry systems within dry zone Kilinochchi would not be beneficial for the farming communities.

This research is significant in that it is the first of its kind quantifying soil physical and chemical properties in post-war Kilinochchi. Furthermore, this project also determines the root causes of soil degradation in the area and its impact on local farmer livelihoods, and the means to alleviate these livelihood issues to improve food security in the region. The quantitative data from this project can be used to make recommendations by national and international policy makers to create sustainable land management practices to conserve the environment, and address burgeoning issues of climate change. Some of these recommendations include:

1) Involve local farmers in developing agroforestry designs. From the interviews with farmers, it is clear that their experience and traditional ecological knowledge needs to be included to determine suitable tree species for their communities and local environments
2) Create awareness and implement workshops to educate, encourage, and support farmers on proper use of agrochemicals and their impacts on the land and environment. Both research

and interviews with farmers have shown improper use of agrochemicals is one of the causes for land degradation in the region.

3) Implement demonstration agroforestry models and monitoring protocols to determine effectiveness and suitability of the systems in the local region
4) Create databases that can be utilized to expand current knowledge on tropical soil management and conservation.

It is important to monitor and have an archive of the changes in soil fertility before and after the implementation of agroforestry systems to provide researchers and other interested parties with concrete quantitative data for analysis and evaluation. In addition, the collected quantitative evidence could be further used to bring any land-use policy reforms for regions in the north, and within Sri Lanka itself. Moreover, further research can be conducted on the implemented agroforestry systems to determine the possibility of using the recommended trees, specifically *Gliricidia sepium*, to derive sustainable and clean bioenergy to support energy requirements needs of household, in combination with improving food security in rural communities living throughout Sri Lanka and around the world.

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APPENDIX 1

Detailed Description of Tree Species Inventoried at the Research Site

Morinda Tree (*Morinda tinctoria)*
Morinda tinctoria reaches a height of 5-10 m and is perceived to be a small tree (Shanthi et al. 2012). All parts of the Morinda tree have medicinal properties. The leaves are used to cure intestinal problems, such as diarrhea, ulcerations, and issues related to digestion (Shanthi et al. 2012).The fruit of the Morinda tree is believed to prevent and cure many diseases by stimulating the immune system to fight the bacterial, viral, parasitic, and fungal infections (Anuradha et al. 2013).The Morinda tree grows well in soils that are flat, deep, fertile, well-drained, varying from clayey loam to loam, and porous (Datta 2002). It also does well in slightly acidic soils that have a pH range of 6.2 to 6.8 (Government of Karnataka 2014; Datta 2002). Morinda tinctoria requires full sunshine for at least nine to thirteen hours a day for full growth (Datta 2002). The wood of the Morinda tree is brittle and is known to split while drying, and as a result its uses are restricted to fuel, fodder, and poles (World Agroforestry Centre 2014)

Ceylon Ironwood (*Manilkara hexandra*)
The Ceylon ironwood is a medium-sized tree that reaches a height of 36 m, and requires fairly rich and well-drained soil (Orwa et al. 2009). This tree is shade tolerant, and is considered an evergreen climax tree species (Arunachalam et al. 2003). Furthermore, the Ceylon Ironwood is drought tolerant (Santiapillai and Wijeyamohan 2014). It thrives well on sandy soils (Santiapillai and Wijeyamohan 2014) that have high soil moisture and low soil temperatures (Gunarathne and Perera 2014). It is known for its strong timber and is usually harvested to make furniture, doors, and windows (Santiapillai and Wijeyamohan 2014). The bark of the Ceylon ironwood tree has many medicinal properties (Santiapillai and Wijeyamohan 2014) and is used to treat ulcers, dyspepsia, bronchitis, and leprosy (Malik et al. 2012). It fruits has great nutritional value and is a good source of vitamin A (Malik et al. 2012). The Ceylon Ironwood is a good source of fuel wood, and provides nitrogen fixation (Orwa et al. 2009)

Ceylon satinwood (*Chloroxylon swietenia)*
The Ceylon satinwood is a slow growing tree that occurs in dry mixed evergreen forests in various dry zone regions around the world (IUCN 2014). It reaches a height of 18-25 m, and grows well in well drained sandy or rocky soils (Schmelzer 2008; Fern 2014). The tree prefers soils that have a pH range between6-7 but is able to tolerate 5-7.8 (Fern 2014). They are shade intolerant, and when mature are drought tolerant (Fern 2014). This tree is known for is strong timber, and is mainly used for furniture, cabinet work, musical instruments, luxury goods, and heavy construction (Schmelzer 2008). Furthermore, tree parts are used medicinally to treat wounds, snake bites, fever, headache, and bruises (Schmelzer 2008; Deb and Dash 2013). The Ceylon satinwood is not a nitrogen-fixing tree (Chimera 2011)

Jambul (*Syzygium cumini*)
Syzgiumcumini is a medium-sized evergreen tree that can grow up to 30 m in height (Orwa et al. 2009). It grows best in well drained loam or sandy soils, and can be tolerant to saline soils (Orwa

et al. 2009). *Syzgium cumini* also grows best in soils that have a pH of 5.6-6.0 or is slightly acidic (Dave 2014). Mature trees are drought tolerant compared to seedlings (TropilabInc 2014). The fruit of the Jambul usually eaten fresh (Orwa et al. 2009), and is known to have many medicinal properties that is antidiabetic (Ayyanar and Subash-Babu 2012; Teixeira et al. 2014). Furthermore, the trunk of the Jambul tree is used for timber and fuel while the leaves of the tree can be used for fodder in the various introduced regions (Ayyanar and Subash-Babu 2012; Orwa et al. 2009).

Neem tree (*Azadirachta indica*)
Neem is a tropical multipurpose tree that grows to a height of 30 m (Orwa et al. 2009), and is able to thrive in infertile soils but best adapted to growing in deep, permeable, and sandy soils (Mathews et al. 1997; Csurhes 2008). Furthermore, Neem does well in soils that have pH from 6.2-7.0 but can also grow in soils that range between 5.0-8.0 pH (Csurhes 2008). A. indica requires full sunlight but is able to tolerate shade during the first few years of germination (Orwa et al. 2009).Neem has many medicinal uses, and compounds extracted from different parts of the tree are used to treat fevers, thirst, nausea, vomiting, and some skin diseases (Csurhes 2008; Mathews et al. 1997; Neem.fr 2014). It can also be used to fertilize soils for agriculture, and is known to have high nitrogen content (Csurhes 2008; Orwa et al. 2009). Neem can also be used as fuel, fodder, and timber for construction (Orwa et al. 2009).

Yellow Bauhinia (*Bauhinia tomentosa*)
The Yellow Bauhinia is a small tree that grows up to 4 m in height (National Tropical Botanical Garden 2014). It grows well in well drained loamy and sandy soils that are neutral or acidic (Learn2Grow 2014) ranging from pH of 5.6 to 6.5 (Dave 2014). It is shade tolerant (Learn2Grow 2014). *B. tomentosa* is a well know medicinal plant that is known to treat all forms of gastrointestinal infections (Rhama and Madhavan 2012). The tree does not produce any significant source of fodder or fuel (Orwa et al. 2009).

Buddha tree (*Polyalthia longifolia)*
The Buddha tree can grow up to a height of 20 m (IFAS 2012).It requires full sunlight for optimal growth, and is drought tolerant (Dave 2001). It grows well in non-saline basic soils (Wahat Al Sahraa Nurseries 2014). The Buddha tree has many medicinal properties, and is known to treat fever, skin diseases, diabetes, and hypertension (Katkar et al. 2010; Shilpkar 2009; Mundhe 2010).The Buddha tree can be used for its timber but is usually cultivated as an ornamental home garden species (Horticultural Impex 2009).Furthermore, the Buddha tree depends on mycorrhizal to fix nitrogen (Atangana et al. 2014).

Beed Tree (*Melia dubia)*
According to Chander (2014), the Beed tree is a deciduous tree species that can grow up to 25 m in height. It grows well in deep fertile sandy loam soil, and is shade intolerant (Tamil Nadu University 2014).The tree grows well in soils where the pH is below 7.5 (Sankar 2013). It is usually cultivated as an ornamental tree. Timber from the tree is not very durable (Tamil Nadu University 2014) but is harvested and made into furniture and agricultural tools. It is not a good source of fuelwood (Chander 2014).

Rain Tree (*Albizia saman*)
In their article Elevitch and Staples (2006) state that the Rain tree is a large tropical tree that can grow up to 60 m in height, and has edible fruits. The Rain tree adapts to soils that are freely draining but can tolerate waterlogged soils as well. It is able to grow well in a wide range of soil types that include light, medium, and heavy soils. The Rain tree typically grows well in neutral pH of 6.0-7.4, but can also grow in more alkaline soils of 8.5.This tree is not drought tolerant, requires full sunlight for propagation, and is shade intolerant. The Rain tree is able to fix nitrogen through an association of rhizobia bacteria (*Brady rhizobium*). The tree leave, which provides 13-18% of protein, is a great source of fodder for animals. The Rain tree is used as a traditional remedy for colds, diarrhea, headache, intestinal ailments, and stomach aches (National Tropical Botanical Garden 2014).

Banyan tree (*Ficus benghalensis*)
The Banyan tree can grow up to a height of 21 m (Eco India 2008), and require full to partial sunlight to thrive (Floridata 2012). Mature and well-established banyan trees are drought-tolerant (Floridata 2012). Furthermore, they require well drained but moist soils to take root and grow (Floridata 2012). The Banyan tree is an important medicinal plant in many traditional communities residing in South and South East Asia. It is used to treat bowel maladies as well as ulcers, vomiting, fever, inflammations and other physiological issues (National Tropical Botanical Garden 2014). The Banyan tree is no significant source of fodder or fuel, but its timber is used to make furniture and other house wares (Eco India 2008). The Banyan tree is often grown to help remediate degraded soils (Eco India 2008). The Banyan tree is able to fix nitrogen through its aerial roots, which was found to have *Azotobacter chroococcum* that is capable of fixing atmospheric nitrogen *(*Iswaran and Subba-Roa *1967).*

Wood Apple (*Limonia acidissima)*
Wood apple can grow up to 20 m in height (Sasidharan 2014), and is adapted to thrive in light soils, which can be sandy, chalky, or peaty (Anonymous; Morton 1987). However, it grows best in well drained sandy loam soils (Orwa et al. 2009). In general, wood apple is not grown in fertile soils (Anonymous). It is able to grow well in soils that range from a pH of 5 to pH of 10 (Anonymous). According to Orwa et al. (2009), wood apple fruits are predominantly used as a source of food and nutrition to improve household food security. Furthermore, the fruit and leaves of the trees is used as ayurvedic medicine to treat dysentery, diarrhea, and other intestinal issues. Furthermore, Wood apple trees can also be used for fodder for animals and fuel for cooking. Wood apple trees have heavy, hard, durable timber that is invaluable for construction and agricultural tools.

Mahogany (*Swietenia mahogani*)
The Mahogany can grow up to 23 m in height (Gilman and Watson 1994). According to the International Union for Conservation of Nature (1998), the Mahogany tree is considered an endangered tree species. According to Gilman and Watson (1994), Mahogany grows well under shade and partial sunlight, and is drought tolerant. Furthermore, it grows well in clayey, loamy, and sandy soils, as well as soils that are acidic, well drained, alkaline and occasionally wet. Mahogany is a great source of timber, which is usually hard and reddish brown in color, and used mostly for cabinet work.

Arjun Tree ***(****Terminalia arjuna)*

The Arjun Tree is a large evergreen tree that grows to 30 m in height (Orwa et al. 2009; Grow-Trees 2014). The tree grows well on well drained soils that have a neutral pH (6.5-7.0), fertile, loamy, red lateritic, and adequately drained (Orwa et al. 2009). The Arjun tree is able to grow well in partial shade, and when mature is able to tolerate drought conditions (Anonymous). According to Orwa et al. (2009), the Arjun tree is a good source of fuel wood for communities, and produces excellent charcoal and firewood. In addition, the leaves of the Arjun tree is rich in micronutrients such as, nitrogen, phosphorous, potassium, calcium, and sodium, and make good sources of fodder for cattle and other farm animals (Sharma et al. 2011). The Arjuna tree is known in Ayurvedic medicine as an effective treatment for various heart diseases (Grow-Trees 2014). Furthermore, the bark of the tree is said to have many anti-inflammatory properties and used to help strengthen fractured bone (Green-Tree 2009).

Cluster Fig (*Ficus racemosa*)

The Cluster fig is an important tree for Hindus and Buddhists, and can grow over 12 m in height (CRFGInc1996; Shiksharthi and Mittal 2011). According to Shiksharthi and Mittal 2011, the Cluster fig, similar to other figs, require well drained, medium to heavy soils, for successful propagation and cultivation. It grows well in soils that are soils that have pH 6.0-6.5 (Mierzehewski 2014). However, it is unable to thrive in clay soils. Furthermore, Cluster fig trees are often used for fodder and house hold fuel sources. Cluster fig trees are best known for their fruits, which can be marketed or eaten by house hold members (CRGF 1996). Fig fruits are also used to treat heart diseases, and consumed as a laxative to help with digestion (Orwa et al. 2009). The fig tree does not make good timber (Orwa et al. 2009).

Teak (*Tectona grandis*)

Tectona grandis is a hardy tree that can grow up to 46 m in height, and able to withstand many environmental stresses (Rainforest Alliance 2014). Teak grows well on soils that are well drained and fertile with pH that range from 6.5-8 (Orwa et al. 2009). Teak is unable to grow well in infertile lateritic and waterlogged soils (Orwa et al. 2009). Teak grows well when it receives 75-100% sunlight during stages of its growth (World Agroforestry Centre 2011). Teak is considered a highly valuable timber species (Orwa et al. 2009; World Resources Institute 2014), and as a result is not used as a source of fuel wood or fodder (Orwa et al. 2009). Teak timber is used for ship building, intricate cabinet work, paneling, flooring, and any sort of construction that requires durability and strength (ecoForests 2014). Teak is also used in traditional medicine in regions around the world as a cure for headaches, swellings, dermatitis, and gut parasites and worms (World Agroforestry Centre 2011). Teak is incapable of fixing nitrogen (Werner and Muller 1989).

Areca Palm (*Areca catechu*)

Betel nut trees grow in a wide variety of diverse soil types. They need soils that are deep and have a high organic content (Orwa et al.. 2009), but grow best in loam soils or in gravelly laterite soils of red yellow podzolic type (Department of Export Agriculture 2014). The betel tree does not grow well in sticky clay, sandy, alluvial, brackish or calcareous soils (Kerala Agricultural University 2013). The tree requires adequate exposure to sunlight (Artero and Santos 2014) but must have at least 4 full hours of sunlight to produce fruit (Artero and Santos 2014). Seedlings need to be protected against full exposure to sunlight (Department of Export Agriculture 2014). The Betel nut tree is shade tolerant (Department of Export Agriculture 2014) and requires soils that are well irrigated for proper growth (Elevitch and Staples 2006).They are drought intolerant (Staples and Bevacqua 2006). The fruit of the Areca palm is purported to have many Ayurvedic medicinal properties, which include antioxidant, anti-infective, analgesic, anticancer, antidiabetic, hepatoprotective, immunomodulatory, and cardiovascular (Lingappa et al. 2011). The Areca palm is estimated to reach heights of 50 to 80 feet, and has thin trunks that are used to for temporary building construction in Sri Lanka (Balfour 1870).

Coconut Palm (*Cocos nucifera*)
According to Elevitch and Chan (2006), the coconut tree can grow up to a height of 24-30 m and is known for its oblong fruit. The Coconut Palm adapts to all soil types but is commonly found in sandy soils. However, it can also be grown in loamy and clay soils that are well drained. The Coconut Palm prefers soils that have a pH of 5-5.7, but can also tolerate soils that are of pH 8 and even lower, such as pH 4.5. It is drought tolerant. It requires full sunlight for maturation but is able to grow under high levels of shade though yields are affected. The coconut is an excellent source of food, and can provide basic micronutrients, lipids, and sterile water for household consumption. Its husks are used for animal fodder. Coconut trees make poor fuel wood due to high wood moisture content, but are good sources of timber for poles and flooring (Orwa et al. 2009). Furthermore, coconut husks are used to as natural mulch to conserve soil moisture during prolonged periods of drought, and help to prevent week outbreak (Orwa et al. 2009).

Banana (*Musa spp.)*
Banana is a large perennial herb that grows up to 2-9 m in height (Nelson et al. 2006). Bananas prefer soils that are deep, well drained, and loamy, but are able to tolerate clayey soils (Nelson et al. 2006). Furthermore, Bananas grow well in soils that have a pH of 5.5-7.5. The Banana species is drought tolerant, and is able to thrive in full sun and partial shade (Gilman and Watson 2013). According to Nelson et al. (2006), banana is best suited to be planted in home gardens. Their flower, plantain, and fruit add to household food security. They are essential staple foods in many parts of the world and provide micronutrients, such as provitamin A and beta-carotene. Banana leaves are good animal fodder. In addition, flowers, fruits, and roots are used as part of traditional medicines in Pacific cultures. Stalks are mashed and used as poultice for sprains and fractures, while root sap is used to cure mouth irritation in children.

Papaya (*Carica papaya*)
The papaya plant can grow from 5-10 m in height (Aravind et al. 2013). Papayas grow well in fertile and well drained soils (Floridata 2012) that are close to neutral pH (6.0-7.0) (University of Hawaii 2011).The papaya plant requires full exposure to sun but can tolerate some shaded, and is also drought tolerant (Faucon 2007).The fruit of the Papaya tree is a rich source of antioxidant vitamin C, vitamin A, vitamin E, as well as important nutrients, such as magnesium, potassium, and the vitamin B pantothenic acid (Aravind et al. 2013). Furthermore, the papaya is used to treat malaria, dengue fever, and an excellent form of laxative (Aravindetl al 2013). Papaya leaves have high protein content, and good sources of fodder for animals (Adiwimart et al. 2010).

Mango (*Magnifera indica*)
The Mango tree is a long-lived evergreen tree that can reach up to 15-30 m in height (Bally 2006). The Mango tree is able to grow well in a wide variety of soils including soils that are alkaline, calcareous, or even heavy clay varieties (Bally 2006), but require soils that are well-drained and

moist (Gilman and Watson 1994). For optimal growth, the soil pH should range from 5.5-7.5 (Bally 2006). They are moderately drought tolerant, and need full sunlight for growth (Gilman and Watson 1994). The fruit from the Mango tree is edible and add to household food security (Bally 2006), are excellent sources of nutrition. The fruit contain carbohydrates, proteins, fats, minerals, and vitamins A, B_1, B_2, and vitamin C (Bally 2006; Shah et al. 2010). Mango leaves make good fodder though excessive amounts of leaves can be toxic to the animal (Bally 2006). Various parts of the mango fruit is used for medicinal purposes that is used to treat heat stroke, vitamin deficiencies, bilious disorders, blood disorders, and scurvy (Bally 2006; Shah et al. 2010). Mango trees do not make good sources of timber (Bally 2006), and are not nitrogen fixers (T. Das and A. Das 2005).

Guava (*Psidium guajava*)
According to Orwa et al. (2009).The Guava tree is a small tree that can grow up to 10 m in height, and has evolved to adapt to savannah/shrub transitional zones that are disturbed. This tree is able to succeed in all soil types, and grows well in degraded in soils with good drainage. However, it grows best in soils that are rich clay loams. Due to its high adaptability, it also grows well in soils that are slightly or strongly acidic. Furthermore, Guava is a drought tolerant. According to NTBG (2014), the Guava fruit is said to be high in vitamin C and have small amounts of vitamin A. It is also a good source of pectin and dietary fiber. The leaves from the Guava trees are used to treat many disorders, which include diarrhea, coughs, and gastrointestinal disorders (Belemtougri et al. 2006).The Guava fruit also has antibacterial properties and helps to prevent intestinal pathogens, such as Staphyloccocus (Orwa et al. 2009).It is also a good source of fuel wood for household cooking needs, and its timber is used to make tool handles and fence posts (Orwa et al. 2009).

Breadfruit (*Artocarpus altilis*)
The Breadfruit tree can grow up to 12-15 m, and grows well in soils that are deep, fertile, and well drained (Ragone 2006). The Breadfruit tree grows well in Sand, Sandy loams, Loams, and Sandy clay loams soils (Ragone 2006). In addition, it prefers soils that range from pH 6.1-7.4 (Ragone 2006). It is not drought tolerant and requires full sun for proper growth (Ragone 2006).The Breadfruit provides essential nutrients for families living in the Pacific region and other introduced regions. It is excellent source of dietary fiber, potassium, calcium, magnesium, and has trace amounts of thiamin, riboflavin, niacin, and iron (NTBG 2014). According to Ragone (2006), all parts of the Breadfruit are used as animal fodder. Only older trees and unproductive trees are used as fuelwood. The wood of the Breadfruit tree is lightweight and sometimes used to build homes. The leaf tips and latex of the Breadfruit tree is used as a poultice for skin treatments, and sometimes brewed in teas to treat asthma and reduce blood pressure.

Jackfruit (*Artocarpus heterlophyllus*)
According to Elevitch and Manner (2006), the Jackfruit tree can typically reach a height of 8-25 m. It grows well in soils that have a pH of 5.0-7.5, and which are Sandy, Sandy loams, Loams, and Sandy clay loams. Furthermore, the Jackfruit tree is drought tolerant but succeeds better in evenly moist soils. The tree prefers full sun during its various stages of growth. The fruit of the tree is used for household consumption. It can be eaten raw or preserved for later consumption. The nut can also be consumed, but must be cooked by boiling or roasting prior to eating. The leaves and fruit waste are excellent fodder for animals. In addition, the Jackfruit tree wood is classified as a

medium hardwood, and as a result is good timber material for making furniture and cabinet, and is considered on par with timber from the Mahogany tree.

Comparison of tree species with existing soil characteristics with literature recommended soil requirement

Tree Species	Found in Plots	Drought Tolerance	pH tolerance	Existing pH compatibility	Soil Type Tolerance	Existing Soil Type
Albizia saman	A,D,E,F	1	6.0-7.4	Y	All	Sandy loam, Sandy clay loam, Sandy clay, Clay loam
Azadirachta indica	C,D,E,G	1	5.0-8.0	Y	Sandy	Clay, Sandy clay loam, Sandy clay, Loam
Bauhinia tomentosa	A,E	1	5.6-6.5	N	Loamy, Sandy	Sandy loam, Sandy clay
Chloroxylon swientenia	A,D,E,G	1	5-7.8	Y	Sandy, Rocky	Sandy loam, Sandy clay loam, Sandy clay, Loam
Ficus benghalensis	C	1	/	/	Any	Clay
Ficus racemosa	C,D	1	/	/	Loamy, Clayey	Clay, Sandy clay loam
Limonia acidissima	B,F	1	5.0-10.0	Y	Sandy loam	Sandy clay loam, Clay loam
Manilkara hexandra	A,D,E,F ,G	1	/		Sandy	Sandy loam, Sandy clay loam, Sandy clay, Clay loam, Loam
Melia dubia	E,F	1	<7.5	Y	Sandy loam	Sandy clay, Clay loam
Morinda tinctoria	C,D,F,G	0	6.2-6.8	N	Clayey loam, Loam	Clay, Sandy clay loam, Clay loam, Loam
Polyalthia longifolia	E	1	7	Y	All	Sandy clay
Swientenia mahogany	A	1	/	/	Clayey, Loamy, Sandy	Sandy loam
Syzgium cumini	D,F	1	5.6-6.0	N	Loam, Sandy	Sandy clay loam, Sandy clay
Tectona grandis	F	1	6.5-8	Y	All	Clay loam
Terminalia arjuna	A	1	6.5-7.0	Y	Loam	Sandy loam

Note: 0 =absent; 1= present y= yes; n = no / = currently unavailable

APPENDIX 2

Recruitment Script and Questions for Semi-structured Interview

Script for Survey or Semi-structured Interviews
NOTE: Due to the locality of the research, all aspect of the appendices will be translated to the local dialect, Tamil, to ease of participation.
For semi-structure interviews the following amendments will be made:

1. Both the primary student researcher and a graduate student from the faculty of agriculture at the University of Jaffna will visit the local communities surrounding the research area to recruit participants and set up an interview date.
2. The interviewee will be asked to be interviewed for 45 minutes to 1 hour.
3. Interviewees will be informed that they will be taped. If they do not want to be taped, then their wishes will be respected.
4. At the interview the script will be read, explaining the project as detailed below, with added information about how the semi-structured interview will be conducted
5. I will ask respondents whether they can be contacted in the future for further clarification

Hello, my name is Hamsha Pathmanathan. I am a Masters student at the Faculty of Environment and Resource studies at the University of Waterloo, Canada. For my thesis, I am conducting a research study to determine how to best develop an agroforestry system that incorporates the needs of the community so as to improve food security in the region. I am also interested in learning about and understanding traditional farming practices as practiced within your community to determine how to create farming systems that are not dependent on commercially manufactured pesticides and herbicides for success, and are also ecologically diverse. Specifically, I am looking at the experiences of community members who have been farming for generations in order to get an insight on how global climate change has affected farming, how farmers have coped with these changes, and whether they can help me identify tree and crop species that best thrive in the changed climate. I will be conducting this study in collaboration with researchers from the University of Jaffna. The study is divided into two parts. The first part will be a brief survey that will take approximately 20-30 minutes of your time, and will ask about the history of farming in your family, your current farming practices, and the use of traditional methods of crop of pest management when you farm. The second part of this study will be an interview which will also take approximately 45 minutes of your times, and will focus on your current traditional ecological knowledge, you current knowledge about sustainable land management practices, existing knowledge about agroforestry systems, and etc. Your participation in this study is entirely voluntary, and you may skip any question you do not wish to answer. You may choose to stay anonymous or not. If you choose to be anonymous, any personally identifiable information collected during the survey or recorded interview will be kept strictly confidential, under lock and key or in locked files, in my computer. I will only use the necessary data from the survey or interviews for my research study report.

The data files will be turned to my supervisor who will maintain the records for 3 years to meet University of Waterloo archive requirements, and then will destroy all files that contain individual data. Do you have any questions about the research study?
Are we ready to begin?

[After the survey is completed] Thank you for participating in this research study. Your inputs are valuable and will greatly contribute to the understanding of this topic within your region and other regions of the world. If you have any questions with regards to this study later on, please feel free to contact me by email at hpathman@uwaterloo.ca or by phone at 647-716-7153.

Information Letter, Consent Form and Participant Withdrawal Information
Researcher: Hamsha Pathmanathan
Faculty of Environment and Resource Studies, University of Waterloo, 200 University Ave W, ON N2L 3G1
Phone: [Omitted]
Sponsors: University of Waterloo, Waterloo, Ontario, Canada

The Purpose of the Research: This study aims to work in collaboration with local farmers and community members to determine the best crop and tree species to be used in developing an agroforestry system to best meet the needs of the local community. Ultimately, this project aims to create a mosaic of agroforestry systems on a parcel of land in order to establish a model demonstration site for local communities, as well as enhance the environmental services provided by the land, improve soil and crop productivity, carbon sequestration potential, and eliminate food security issues in the region.
Through this collaboration, we hope to rehabilitate the marginal lands for agriculture production in Kilinochchi, Sri Lanka. I am interested in learning about the local agricultural practices as well as planting methods currently used in today's changing climate. The findings from the research will be reported in my master thesis, in academic articles, and at conferences.

You Will be Asked: To answer a set of interview questions that are centralized around the themes of 1) practiced traditional ecological knowledge (TEK); 2) Current knowledge about sustainable land management practices; 3) Existing knowledge about agroforestry systems and practices, such as taungya and home gardens; 4) Community ability to access means of production (MoP) (tractors, seeds, fertilizers) and current cropping practices. This will take no more than 1 hour of your time.

Benefits of the Research: There will be no direct benefits to the research participants. However, the research will help to develop a model agroforestry system that has the potential to be modified to meet the needs of the local communities in rural Sri Lanka. Furthermore, the results from this research can be used by other communities, local and international educational institutions, and other agricultural organization from future research. Furthermore, the collected data can also be used to develop a database that can be used to expand current knowledge on tropical soil management and conservation, so that appropriate technologies and alternative land-use systems can be developed to improve soil fertility and create sustainable livelihoods.

Voluntary Participation: Your participation in the study is completely voluntary and you may choose to stop participating at any time.

Withdrawal from the Study: You can stop participating in the study at any time, for any reason, if you decide. Your choice to stop participating or to refuse to answer any of the questions will not affect your relationship with the researcher, University of Waterloo, or any other group associated with this project. In the event that you withdraw from the study, all the data collected related to your person will be destroyed immediately.

Confidentiality: All the information provided by you during the research including your names will be held in confidentiality by the researcher. All the reports and publications associated with this research will use pseudonyms instead of real names unless otherwise stated by the participant. The data will be collected through handwritten notes and a digital audio recording device. The data collected from you will be stored safely in a locked facility and will only be accessed by me. The collected data will be kept in storage and archived in the facility for up to 3 years. Confidentiality to the participants and the collected data will be provided to the fullest extent lawfully possible.

Questions about this Research? If you have questions regarding this study, or would like additional information to assist you in reaching a decision about participation, please feel free to contact me, Hamsha Pathmanathan, at 1-647-716-7153 or by e-mail (hpathman@uwaterloo.ca). You may also contact my supervisor, Dr. Maren Oelbermann at 1-519-888-4567 ext 37552 or by email (moelbermann@uwaterloo.ca). This research has been reviewed and approved by University of Waterloo Research Ethics Committee. However, the final decision about participation is yours. If you have any concerns about your rights as a participant in this study, please contact Dr. Maureen Nummelin, the Director, Office of Research Ethics, at 1-519-888-4567, Ext. 36005 or maureen.nummelin@uwaterloo.ca.

Legal Rights and Signatures:

I, ____,consent to participate in the above described research project conducted by Hamsha Pathmanathan. I have understood the nature of this study and wish to participate. I am not waiving any of my legal rights by signing this form or releasing the investigator or involved institution from their legal and professional responsibilities. My signature below indicates my consent.

I have read all the information presented in the information letter about the study being conducted by Hamsha Pathmanathan of the Department of Environment and Resource Studies at the University of Waterloo. I have had the opportunity to ask any questions related to the research, and have received satisfactory answers to my questions, and any additional information I wanted.

I am aware that I have the option of allowing my interview to be recorded for an accurate reading of my responses.

I am also aware that excerpts from my interview may be included in the thesis or publications related to this study, with the understanding that all quotes will be made anonymous.

I was informed that I may withdraw from this study at any time without penalty by advising the research.

This project has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Director, Office of Research Ethics at (519) 888-4567 ext. 36005.

Permission for use of audio-taping the interview
I allow the investigator to use an audio-tape to record the interview (please tick): YES / NO

Signature ______________________________________ Date ________________________
Participant

Signature ______________________________________ Date ________________________
Student Investigator

Information Letter about *Strengthening resilience and food security in post-disaster region in Kilinochchi Sri Lanka*

University of Waterloo

Dear Participant,

This letter is an invitation for you to consider participating in a study that I will be conducting as part of my Master's degree at the Department of Environment and Resource Studies at the University of Waterloo under the supervision of Professor Maren Oelbermann. I would like to provide you with more information about my study and the extent of your involvement if you decide to participate.

Sri Lanka has been in war for the past 25 years which has resulted in the degradation of soil and soil nutrients especially in Kilinochchi. Additionally, changing climate has only exacerbated the situation decreasing local availability of food, fibre and fodder, severely impacting food security in this region. Sustainable agroecosystem land management practices such as the adoption of agroforestry practices may address issues surrounding food security and global warming simultaneously. The purpose of this study is to gain a better understanding of current farming practices, available traditional ecological knowledge, and inputs about the best tree and crop species to be used in developing an agroforestry system most beneficial for the local communities of Kilinochchi.

Participation in this study is voluntary. It will involve an interview of approximately 45 minutes to one hour in length to take place in a mutually agreed upon location. You may choose to not answer any of the interview questions if you feel uncomfortable. Additionally, you may also choose to withdraw from this study at any time without any negative consequences by advising the researcher. With your permission, the interview will be audio recorded to facilitate collection of information, and later transcribed for analysis. Once the interviews have been completed, I will send you a copy of the transcript so that you may have the opportunity to confirm the accuracy of our conservation and to add or clarify any points that you wish.

All the information provided by you will be considered completely confidential. Your name will not appear in any thesis or report resulting from this study unless stated otherwise. However, with your permission anonymous quotations may be used. Data collected during this study will be retained for a period of 3 years in a locked office in my supervisor's lab. Only researchers associated with this project will have access to the information. There are no known or anticipated risks to you as a participant in this study.

If you have any questions regarding this study, or would like additional information to assist you in reaching a decision about participation, please contact me at 1-647-716-7153 or by email at hpathman@uwaterloo.ca. You can also contact my supervisor, Professor Maren Oelbermann at (519) 888-4567 ext. 75523 or email moelbermann@uwaterloo.ca
I would like to assure you that this study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, please contact Dr. Maureen Nummelin, the Director, Office of Research Ethics, at 1-519-888-4567, Ext. 36005 or maureen.nummelin@uwaterloo.ca.

I hope that the results of my study will be of benefit to local communities throughout Sri Lanka as well as to the broader research community. I look forward to speaking with you and thank you in advance for your assistance in this project.

Yours Sincerely,

Hamsha Pathmanathan
Student Investigator

Survey of Local Farming Community Members in Kilinochchi (based on the questions written by Meaghan W. for her research in Argentina, and adapted for farmers living in northern Sri Lanka)

This survey is designed to profile community members in rural Kilinochchi and information will be supplemented by observation and through questions.

1. Would you consider yourself a generational farming family? i.e. Were your parents or parent farmers, and their parents etc?

2. Are all adult members of your household farmers?

3. How long have you practiced farming?

4. Do you use any commercially provided pesticides and herbicide to remove weeds and pests?

5. Do you use mineral fertilizers? If so, for how long? If it was a recent switch, why did you make the change?

6. Have you been farming using traditional methods of crop and pest management?

Interview Guide with Themes and Questions for Local Farming Community Members in Kilinochchi, Sri Lanka

I. Existing traditional ecological knowledge

1) Prior to the beginning of the war, what were your farming practices?

2) What type of farming system was used, animals you were dependent on, fertilizers etc for you daily needs?

3) What are the total hectares that you farm and cultivate?

4) How productive are these lands using TEK methods?

5) Do the women use TEK? To what extent?

6) How was TEK passed down to you (if any)? How are you passing it down to your children?

II. Current knowledge about sustainable land management practices

1) How do you define sustainable land management practices?

2) How is farming and ploughing the land different from the past 5 years

3) With the decreasing fertility of the land, how are you procuring food for yourself and your family?

4) What crops are you currently using to seed your field?

a. Are these crops doing well as compared to 5 years ago?

5) In developing an agroforestry system, which combines agricultural crops with native trees, which species do you think will do well in today's climate?

6) Do you have any suggestions for what you would like to see implemented in an agroforestry system that would be beneficial for you and the rest of your community?

III. Existing knowledge about agroforestry systems and practices

1) Do you know or practice any soil regeneration techniques?

2) What type of crop management practices do you use?

3) How do you choose the crops you are going to cultivate for each growing season?

IV. Community ability to access MoP and current cropping practices

1) How accessible are sustainable systems of farming? The tools, fertilizers, and seeds?

2) If they are not accessible, do you practice no-till methods?

3) Are you monocropping your land? Why? Why not?

4) Do you use crop rotations? What crops do you grow together? Why?

5) Do women and children contribute in the farming process? By what means?

APPENDIX 3

Ariviyal Nagar, Kilinochchi Agricultural Campus Master Plan Document Proposed by the University of Jaffna