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ASSESSING THE EFFECTS OF NITROGEN FIXING PLANTS ON SOIL FERTILITY IN NAIKOROKORO VILLAGE IN KADAVU ISLAND, FIJI

by

Isimeli C Loganimoce

This thesis is submitted for the partial fulfillment of

the requirement for the degree of

Master of Science in Marine Science

School of the Marine Studies Programme

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The University of the South Pacific

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July, 2017

DECLARATION

I Isimeli C Loganimoce, confirm that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information derived from the published and unpublished work of others has been acknowledged in text and a list of references is given in the bibliography.

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Name: Isimeli C. Loganimoce

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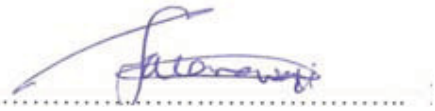
Statement by Supervisor

The current research was conducted under my supervision and I am certain that this is the sole work of Mr. Isimeli C Loganimoce.

Signature…  Dr Apaitia Macanawai

Date: 18 / 07 / 2017

DEDICATION

This Thesis is dedicated to you MUM (*Asinate Nailevu*) for your continuous encouragement and prayers and I thank God for your life

also

to my beloved wife (Litiana Wati Soata) and my lovely children (Asinate Gloria, Isimeli Emmanuel and Mereia Faith) for your endless love, prayers and mainly support during my years of study.

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"*OH come, let us sing to the Lord! Let us shout joyfully to the Rock of our salvation…*
(Psalms 95: 1, New Testament and Psalms & Proverbs)

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ABSTRACT

The plants *Calliandra calothrysus* Meisn and *Mucuna pruriens* (L.) DC. are nitrogen (N) fixing plants and this research aims to measure how planting of them can affect total N, total organic carbon (TOC) and pH levels in Talasiga and Fallow soils in Kadavu, Fiji. The two targeted areas were from the Yavusa (clan) Suesue within the district of Sanima in Kadavu. The research made use of destructive sampling with three treatments replicated seven times. Soil sampled were taken from two depths per plot (D1= 0-15cm and D2= 15-30cm) before and after planting *C. calothrysus* and *M. pruriens* in Talasiga and Fallow area. From the selected soil samples that were used for analysis, revealed higher mean concentration of total N, TOC in the fallow area after incorporating *C. calothrysus* and *M. pruriens*. This result also showed the differences in the levels of total N and TOC before planting *C. calothrysus* and *M. pruriens* in these fallow soils; though after incorporation in fallow soils, there was no significant in the mean levels for all three parameters at either depth. In the Talasiga area, the research discovered a higher mean total N concentration attributed by *M. pruriens* in depth 2. Similarly, significant differences were detected for total N and TOC concentration after planting this nitrogen (N) fixing plants for both depths. However, there was no increase in the nutrient levels for total N and TOC in Fallow soil after planting *C. calothrysus* and *M. pruriens* for both depths. For this study, both *C. calothrysus* and *M. pruriens* can be used as fallow crop as they increased mean N levels at both depths. Moreover, *C. calothrysus* and *M. pruriens* are suitable as Talasiga crops as they increase the levels of total N and TOC for both depths.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Global reviews in the need for the use of nitrogen fixing plants

Soil is a vital resource in any agricultural farming system. The quality of soil is controlled by the physical, chemical and biological components of a soil and their interactions (Knoepp *et al*., 2000) . Healthy soil is full of life and is a fertile base for survival. The current agricultural practices like shifting cultivation, slope land cultivation and commercial farming have led to more pressure on soil (Brookfield & Padoch, 1994). Thus, the levels of nutrients in the soil have become a major constraint to productivity (Carter *et al*., 1997). Some researchers document nutrient depletion due to agricultural developments where soil fertility declined because of reduced fallow period in shifting cultivation systems (Howeler *et al.*, 1998); Muchena and Hilhorst, 2000). Others state that soil fertility can be maintained through biomass transfer of land (Bekunda, Sanginga & Woomer, 2010). However, Arshad & Martin, (2002) reiterated that there are different rates of soil processes occurring between natural and agricultural systems. In agro-ecosystems, there is a periodic disturbance including tillage, weeding, and application of soil amendments, which then determines the rate at which nutrient is being added or removed, whereas addition of nutrients through atmospheric deposition, biological nitrogen fixation and sedimentation is the process within natural ecosystem (Arshad & Martin, 2002). Furthermore, Doran & Zeiss (2000) reported that declining soil fertility is a major challenge for improving yields and profit margin for poor rural farmers.

Agroforestry is a concept of integrated farming systems (Nair & Fernandes, 1985; Leslie & Ratukalou, 2002). This system operates by managing the land in harmony with the laws of nature, combining high tech machines, seed from certified breeding stations, well tested practices of soil and water protection and the latest knowledge of livestock (Ward, 1965; Ministry of Agriculture, 2009). The system rejuvenates the soil using natural resources like sun, increases natural fixation of N, increases SOM (Soil Organic Matter), and assists with pest and weed management, (Leslie & Ratukalou, 2002; Ministry of Agriculture, 2009).

Agroforestry is not a new farming system. It was practiced by our forefathers many years ago, but through development and outside influences, farmers have progressively opted to disregard the farming practice (Clay, 2013). Agroforestry is a resurrected traditional system adapted to address the current problems faced by agricultural farming practices. Some agroforestry practices that are being used around the globe are techniques like scattered farm trees, improved fallow areas, alley cropping, mulching, buffer strips, terracing, windbreaks, live fencing, woodlots, cover cropping, crop rotation, and integrated techniques using nitrogen fixing plants (NFP) (Dixit & Goyal, 2011; Mulugeta, 2014). Moreover, through the increase in the demand of export, cutting and burning of plants have contributed to selective herbicides treatment (FAO, 2008). However, the use of chemical fertilizers has one of the main source of nutrients locally, thus shifting traditional farming practices and their long term benefits to the natural ecosystems (Ceballos *et al*., 2012). In the late 1940s, chemical fertilizers have been used to address the soil health for most commercial farmers (Warren, 1998).

Globally, the governments, international donors and scientists have been encouraging sustainable agro-forestry practices to local farmers to address soil health issues on their farms. Hartemink (2003) did research on some common soil nutrients for a few countries and found that the total inputs of nitrogen (N), phosphorus (P) and potassium (K) were of significance compared to the outputs. Also (Altieri, 1999, 2002) suggested that using traditional NFP from American peasant resulting in the increasing of nutrients levels in any degraded soil. Eco-agricultural landscapes interventions were suggested by (Scherr & McNeely, 2008) through local practices. Van Noordwijk and Tomich (1995) also suggested that improvement of soil fertility can be achieved through implementing tree-crop interaction through agro-forestry technologies for social forestry. Moreover, practices like using N fixing trees and cover crops to replenish soil nutrients and contribute to the metabolic process in soil have been suggested by Bekunda *et al*., (2010). The addition of legumes into farming systems can also contribute to the soil through recycling of residues which then contribute to organic matter (Murungu, 2010; Murungu *et al*., 2011). Nitrogen fixing plants provide bulk of the N to the surfaces of the earth and estimated to fix about 175 million metric tonnes of N per annum (Stewart & William, 1977). However, nutrients are removed by

leaching, gaseous loses, periodic disturbances (tillage and weeding) and through soil erosion in agro-ecosystems (Hartemink, 2006).

1.2 What are Nitrogen fixing plants?

Nitrogen fixing plants are leguminous plants that are planted as cover crop and incorporate into the soil as green manure to help improve soil health (Nair & Fernandes, 1985; Nichols *et al*., 2001). These leguminous plants consume atmospheric N_2 in the ammonia state (NH_3) from the earth's atmosphere to be absorbed by living organism in the soil. Furthermore, NFP provides protein in food and fodder and help out in the N cycle processes in the air and soil (Zundel & Kilcher, 2007). A large proportion of combined N added to the soil each year is contributed by NFP (Moore, 1964).

1.3 Benefits of Nitrogen Fixing Plants

Most NFPs being used by sustainable agroforestry practitioners involves shade cropping systems. This system reduces runoffs, boost water infiltration into the soil and intercept rainfall by planting shade trees in plots on steep slopes. Nitrogen fixing plants helps improve soil fertility and controls soil erosion (Beatty & Good, 2011). In the Pacific Northwest of the USA, NFPs have improved yield, added more N to soil and contributed to intrinsic economic value as timber and fodder (Sprent & Parsons, 2000). Due to NFP's rapid growth rate, the plants can quickly "pioneer" bare or degraded lands in infertile and harsh conditions (Sprent & Parson, 2000; Elevitch, 2008). In addition, NFP suppresses weed (Haines 1978) and soil borne diseases (Fox 1965; Bernard *et al*., 2012). Stewart and William (1977) reported that NFP are cheap supplier of N fertilizers, provide the only alternative to chemical fertilizer and are indispensable for the maintenance of existing soil N levels on earth.

1.4 Some of the common NFPs for tropical environments

Under most tropical conditions, the commonly used NFPs come from four genera: *Casuarina, Albizia* (including *Paraseriathes*), *Leucaena* and *Acacia* which mostly exhibit rapid growth and biomass accumulation (Binkley & Giardina, 1997; Giller, 2001; Nambiar *et al*., 1997). In addition, Baldwin & Creamer (2006) suggested some common N fixing legumes and cover crops for short-term fallow periods such as cowpea (*Vigna unguiculata*), sun hemp (*Crotalaria juncea*), soya bean

(*Glycine max*) and mucuna (*Mucuna pruriens* (L.) DC. In Malawi Africa, farmers are revitalizing their soils by planting of NFP species, *Faidherbia albida*, *(Garrity, 2006; Garrity et al.*, 2010). Over the years, Africa has shifted from a farming practice of N fertilizer application to planting N fixing legumes such as *Cajanua cajan* (pigeon pea), *Arachis hypogaea* (peanuts) and *Glycine max* (soya beans) (Garrity *et al*., 2010).

1.5 Benefits of Mucuna on soil health improvement

Mucuna pruriens is usually known as velvet bean and belongs to the class Magnoliopsida and family Fabaceae (Blanchart *et al*., 2006). It is reproduced by seed and can produce about 1,000 pods per plant with each pod carrying about 5 seeds (Macanawai *et al*., 2013). Ceballos *et al*. (2012) demonstrated that *M. pruriens* improved the soil health and increase maize yield as compared to the application of conventional fertilizer. *Mucuna pruriens* suppressed 50% of weeds by intercropping with maize at different planting spacing (Shave *et al*., 2012). It grows rapidly and improves Carbon and N stocks in soil (Bunch, 1987; Blanchart *et al*., 2006). *Mucuna pruriens* was found to improve soil health and increase taro (*Colocasia esculenta* (L.) Schott) yield in Taveuni, Fiji (Lal, 2014). However, study on effect of *M. pruriens* on soil fertility at different depths of the soil and Talasiga soil in Fiji is relatively unknown.

1.6 Benefits of *Calliandra calothrysus* on soil health

Calliandra calothrysus Meisn. is also a leguminous plant (Chamberlain, 2000). It is originated from Central America and Mexico and grows in different environments from seasonally dry to humid forest. *Calliandra calothrysus* has also been proven to display allopatric distribution (Palmer *et al*., 1994; Chamberlain, 2000). It is cultivated and used widely for fuel, animal folder, green manure and soil conservation in many parts of the humid tropics (Palmer *et al*., 1994). *Calliandra calothrysus* has been introduced to the Pacific, acclimatized and is found growing luxuriantly wild or semi-cultivated in most countries where it is being used as a hedge. In Fiji, under Pacific Network Soil Research Planning partners use vetiver grass and inclusion of leguminous plants like *Calliandra* and *Gliricidae sepium* as low cost sustainable land management to minimize soil erosion and land degradation on marginal and steep lands. However, study on

effect of *C. calothrysus* on soil fertility at different depths of the soil and Talasiga soil in Fiji is relatively unknown.

1.7 Soil Health indicators

Soil health is quantified by the state of a soil's physical, biological and chemical characteristics and processes (Lal, 1998). However, indicators will vary in different sites and the type of assessment performed and that various indicators need to be considered to properly assess the effectiveness of any amendment on soil health (Riley, 2001; Hartemink, 2003).

There are three dominant soil indicators. First are the biological indicators, and includes : organic matter, respiration rate, the living component of soil organic matter (SOM), earthworm count and N cycle (Riches *et al*., 2013). Second are the physical indicators, which include: texture, bulk density, water infiltration and aggregate stability (Hillel, 1982). Lastly are the chemical indicators and includes pH level, Cation Exchange Capacity (CEC) and extractable nutrients which relate to the capacity of the soil to supply nutrients in sufficient quantities (Sanchez & Swaminathan, 2005; Latos, 2009).

In the tropics, most soils are deficient in N and P (Sanchez & Swaminathan, 2005). Furthermore, long term stabilization of total organic carbon (TOC) and N is yet to be fully quantified (Six *et al*., 2002). Many farmers in tropical countries have considered alternative agroforestry systems to enhance soil fertility (Garrity *et al*., 2010), by using NFPs to adding N through fixation, recycling nutrients through litter fall or pruning, or by importing nutrient through biomass transfer. Moreover, fallow crops can also increase SOM (Buckles *et al*., 1998; Latos, 2009). However, it is generally thought that organic compounds and SOM turnover is faster in tropical than temperate environment (Six *et al., 2002*).

1.8 The present study

This research was established on two field trials. The first trial studied the effects of planting *C. calothrysus* and *M. pruriens* in fallow area, changes in the selected soil chemical properties from the time they were planted to maturity and the effects of planting these two NFPs to different land cover. The soil total N levels, pH and the soil TOC at two depths (0-15 cm and 15-30 cm) were measured.

The second trial studied the effect of planting *C. calothrysus* and *M. pruriens* in Talasiga area, changes in selected soil chemical properties from the time they were planted to maturity and the effects of planting these two NFPs to different land cover. The soil total N, pH and the soil TOC at two depths (0-15cm and 15-30cm) were measured. Talasiga area is referred to as a "fire-modified and ultimately fire degraded ecosystem where soil is exposed among a sparse cover of ferns and grass" (Mueller-Dombois & Fosberg, 2013). The type of Talasiga area that is being targeted in this study is the *Pennisetum polystachyon* (mission grass) Grassland.

The project Aim: Assessing how planting of *C. calothrysus* and *M. pruriens* can affect the properties of soil Total Nitrogen, Total Organic Carbon and pH levels.

The following objectives will help achieve the aim:

1. Comparing the Total Nitrogen levels at two different depths in Talasiga area and Fallow areas having natural vegetation before and after planting *C. calothrysus* and *M. pruriens.*
2. Comparing the Total Organic Carbon levels at two different depths in Talasiga area and Fallow areas having natural vegetation before and after planting *C. calothrysus* and *M. pruriens*.
3. Comparing the pH levels at two different depths in Talasiga area and Fallow areas having natural vegetation before and after planting *C. calothrysus* and *M. pruriens*.

CHAPTER 2

STUDY AREA

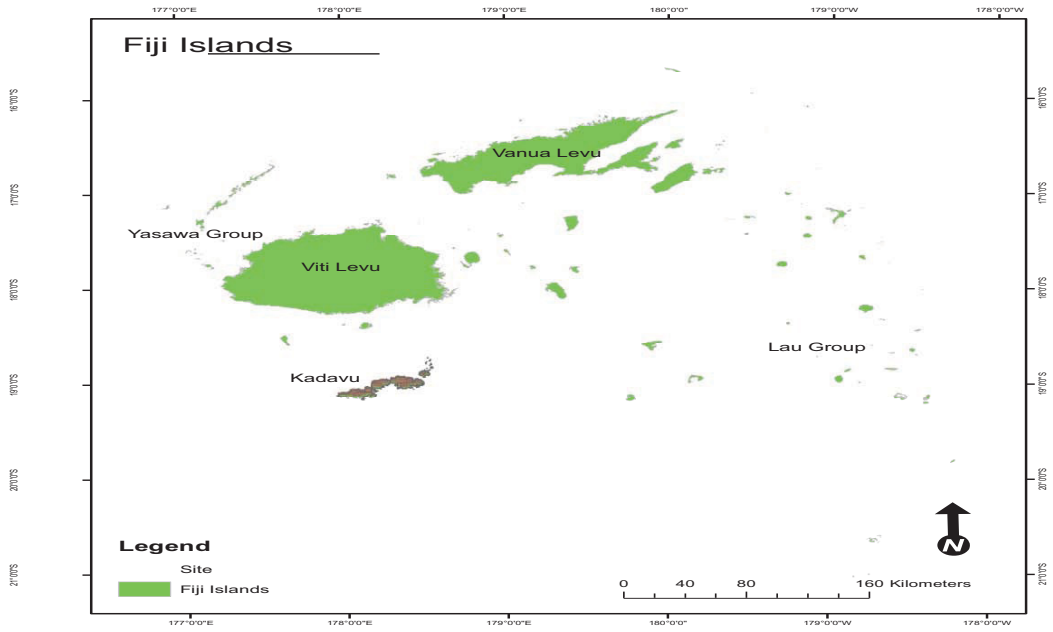

Figure 1: Map of Fiji Island **Source:** ArcGIS ArcMap 10.1 IAS (USP)

2.1 Fiji Islands

Fiji is located 17°49'40.01"S and 178° 1'38.62"E178° 1'38.62"E in the Pacific Ocean. Fiji also includes smaller islands formed from volcanic process and atolls. The main smaller islands are Viti Levu, Vanua Levu, Taveuni and, Kadavu (Rutz, 1978). The total number of smaller island is 844 (Leslie & Ratukalou, 2002). Most of islands are owned by indigenous Fijians, followed by some state and freehold land (Fiji Bureau of Statistics, 2010). Fiji enjoys temperate weather which involves some heavy rain under dominant situations. The "hot & wet" season is October – April and the "cool & dry" is May – September (Naidu, 2009). The annual rainfall is about 2, 800 – 3,600 mm for wet zone and 1,300 – 1,600 mm for dry zone. The normal temperature in Fiji is 25°C - 27°C (Fiji Bureau of Statistics, 2010).

Fiji was practically covered with forest in the early times (Leslie & Ratukalou, 2002). However, development has been rapidly changing the vegetation cover in most places. The current vegetation cover includes native forest trees, normal saline tree species, reeds on slopes and, scrublands, and open grassland after vigorous burning (Leslie & Ratukalou, 2002). This grassland has been termed as

the Talasiga area because vegetation cover is reduced to bare ground (Ratukalou, 1998).

Fiji has population of about 837,271 and 13 provinces (Fiji Bureau of Statistics, 2010). Most of these people are in the urban areas and followed by the villages in their various provinces and districts. The population is mainly dominated by Fijians (475,982) and Indians (313,798), with part Europeans, Rotuman, Chinese and others (47,734) being the recorded minority groups being recorded (Fiji Bureau of Statistics, 2010).

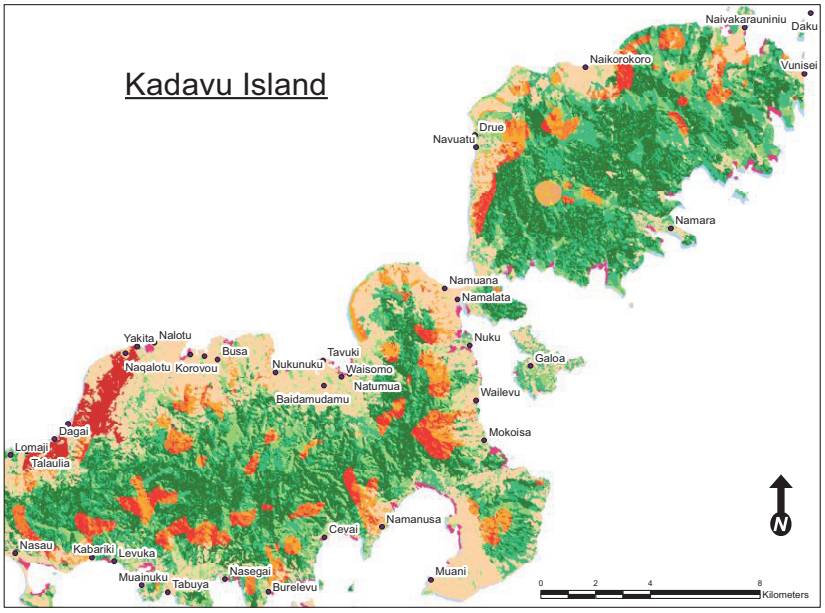

Figure 2: Map of Kadavu **Source:** ArcGIS ArcMap 10.1- IAS (USP)

2.2 Kadavu Island

Kadavu is located 18°59'48.90"S and 178°11'44.24"E within the Pacific and on the south of Viti Levu in Fiji. Kadavu Island is the fourth largest island in Fiji (Sofer, 2015). Kadavu also has few small groups of islands. The mainland and the small group of islands to the east (Ono district) form the large Astrolabe lagoon with the barrier reef surrounding it forming the Astrolabe reef, one of the world's longest barrier reef. Kadavu has a population of about 10,000 in 2007 (Fiji Bureau of Statistics, 2010). The province has a total of 75 villages. There are nine districts in Kadavu which include Nabukelevu, Ravitaki, Yawe, Tavuki, Sanima, Yale, Nakasaleka, Naceva and Ono. The main form of transport around the provinces is

by small boat with an out-board engine. The administrative center and the government station are located in Vunisea, which can be accessed by ferry and by plane from Viti Levu. It takes about six hours to reach Vunisea jetty from Suva or approximately 45 minutes by air from Nadi Airport.

The Vunisea station has a minimal annual rainfall of 2,117mm (Terry & James, 1999). The typical wet season is from May to December and the dry season is from June to November with minimum monthly rainfall of 150mm. The geology of Kadavu is dominated by andesitic rocks which have undergone saprolitic weathering (Thomson, 1889; Terry & James, 1999). The bedrock and overlying regolith is mainly mantled by ultisols (red-yellow podsols and humic latosols) (Terry & James, 1999).

2.3 Natural Resource Use and Dependence

The Kadavu Province contributes to the Fiji government's revenue through tourism and agriculture. The Province host vast numbers of hotel and backpacker for tourists and sells of Kava (*Piper methysticum* G.Forst) and other root crops (Stanley, 2004). The main source of income for people of Kadavu is Kava (yaqona in Fijian) has been commercially successful. Subsistence fishing is also important aspect of the socio-economic of villages in Kadavu and this is similar to other parts of Fiji and the Pacific (The, Tech, & Sumaila, 2014).

2.4 Sanima District

There are six villages within the district of Sanima, Kadavu. They are Namara, Drue, Naikorokoro, Mataso, Naivakarauniniu and Navuatu. The land covers an area of 62.8 km^2 (Wendt et al., 2016). These villages are far apart. Thus their main form of transport is by outboard motor boat and also partly by road from main government station located in Vunisea. The main source of income in this district is kava, taro, and partially the selling of fish.

Location:

The villages within this district are located on the eastern and western side of the main island of Kadavu. Most of the villages prefer outboard boats as their main source of transportation.

Topography

The district ranges from flat to undulating lands on creek banks, to rolling, steep and very steep mountainous lands (Thomson, 1889). Majority of the land is classed as non-arable, but areas that are unsuitable for agriculture are good for forestry and for the protection of water catchments (Sofer, 2015). In this district, the steeper areas are covered with natural thick forest and grasslands. This area is mainly used for yaqona, taro and other subsistence cropping.

Climate

The annual rainfall ranges 2, 000 – 3, 000mm and the annual maximum temperature is 25°- 27°C (Terry & James, 1999). At present, the villages within this district are experiencing a change in weather pattern resulting in low minimum agricultural production.

Land Tenure - Ownership

All lands in the district of Sanima are native owned.

Vegetation

The main vegetation covers within the district are the saline tree species along coastline and reed on slopes and natural forest on hills with more local economic timber species (Eminhizer, 2008). The main issue facing this district is the continuous burning. This evidenced by the presence of Talasiga or scattered patched of grassland.

Present Landuse

The present land use within this district is farming. This involves planting of kava, taro, cassava, vegetables and other subsistence cropping on the flats along the river bank.

2.5 Soils

There are six soil groups present within the district of Sanima.

1) Saline Soils of the Marine Marsh

These saline soils consists of poorly drained Dogo soils and are usually found on beach fronts forested with mangroves (Eminhizer, 2008).

2) Recent Soils of the Beach Strands Dunes and Estuaries

These consist of Yasawa and Nuku soils which usually occur on coastal margins where mangroves are not found and this soil type is usually under coconuts (Tomlinson, 2002).

3) Soils of the Major Flood Plains

These soil types Saliadrau and Navunikodi are found on the flat and undulating part of the main water ways. They are well drained, deep, fine textured alluvium and they occur on broad and flat low terraces or levees (Eminhizer, 2008). The river soil is well drained and subject to flooding. It is formed under a climate with a weak dry season. These soil types are usually used for vegetables, and root crops like cassava, taro and yaqona (Tomlinson, 2002).

4) Soils of the Relict Terraces

These are all steep land soils of the hill country which are usually shallow soils and well drained. They typically support a wide vegetation range including shrubs, reeds, mission grass, ferns and heavy forest. These soils are mostly found and formed on a wide range of climate with a weak, medium and strong dry season (Wendt *et al*., 2016). These soils usually support traditional subsistence cropping like growing of yaqona, root crops, and tree crops. The moderately steep areas that are continuously burnt are mostly under grassland, mainly mission grass, and can be reforested. Areas of very steep land are to be left untouched for protection purposes.

5) Soils of the Plateau

The common soil types of this area were named as Nasegai soils, Lomaiviti soils and Nacula soils are defined as a degraded soil under weeds (Wright, 1965), shrubs and medium to heavy forest on undulating to steep slopes; formed from basalts under a climate with a weak dry season(Thomson, 1889). The land use on these soil types are mainly root crops like taro, cassava, kava and cash crops.

6) Soils of the Secondary Floodplains and Depressions

The common soil types of this group are Namara and Savudrodro soils; and described by Twyford and Wright (1972), as degraded soils under forest, reeds, and Talasiga vegetation on rolling to steep land, developed from a rich andesite and quartz formed under a climate with a weak dry season. This soil type is currently used for planting taro, kava, cassava and other cash crops.

2.6 Study site

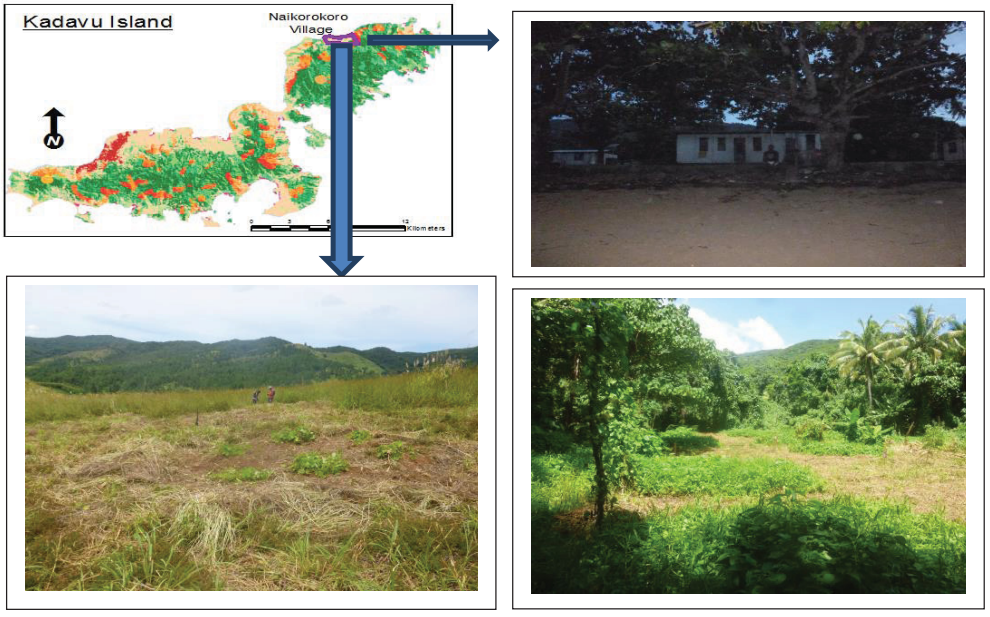

Figure 3. Research site in Naikorokoro Village **Source:** Personal camera

Naikorokoro village is located within Sanima District on Kadavu. The village consists of four clans. They are Suesue, Nasomo, Natokalau and Naiqavitini.

However, the village currently has two tribe and two clans. The Suesue clan is the chief family and the Clan Nasomo represents two tribes - .i.e. Matanivanua and Bati. The total village population is 44 .i.e. 37 adults and seven children. There are 13 houses with only 10 being occupied. The main source of income for the villagers is kava and at times the selling of fish.

The mode of transport is using outboard boat. There is an existing road from Vunisea to Naikorokoro but currently in deplorable condition. The people of Naikorokoro walk a few km to their farms which normally take 45 minutes to one hour each way.

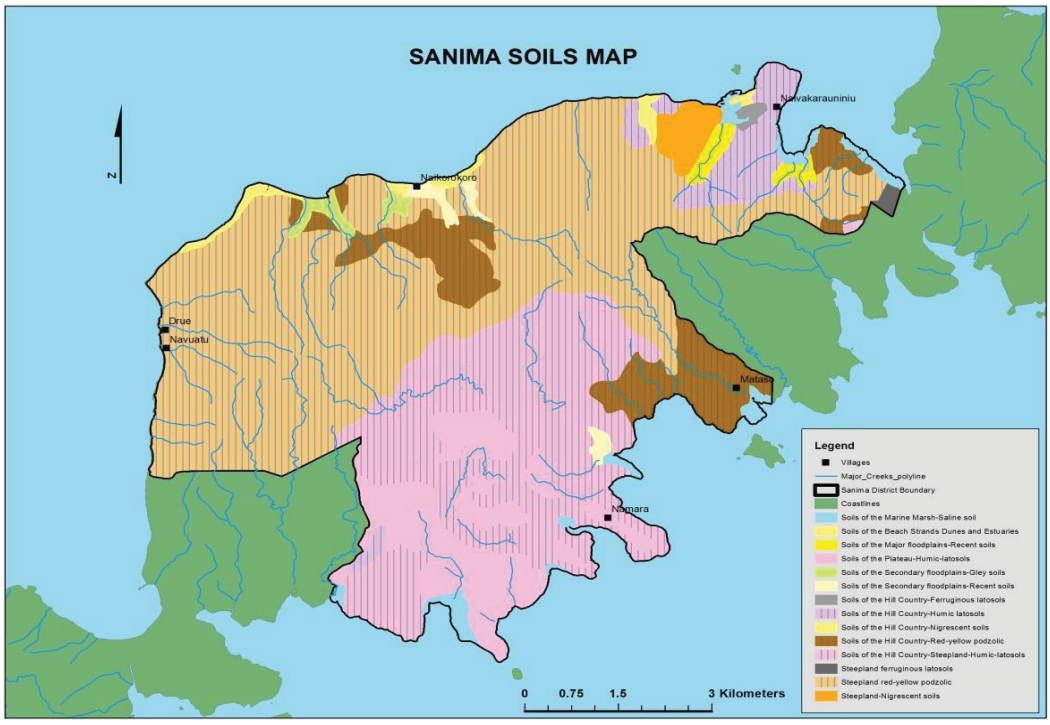

Figure 4: Soil map pf District Sanima, Kadavu, Fiji. **Source:** IAS (USP) - Land Assessment Report (Sanima and Ravitaki)

Table 1: Fallow site detail

Soil Series	Suesue Series
GPS	18°59'8.27"S, 178°11'16.52"E
Classification	Clayloam, floodplains-Gley soil
Topography	Flat to gentle sloping
Drainage	Well drained to imperfectly drained
Current vegetation	Heavy forest
Parent material	Alluvial (Fallow area)
Climate	Perudic and isohyperthermic

Table 2: Talasiga site detail

Soil Series	Suesue Series
GPS	18°58'52.81"S, 178°11'33.79"E
Classification	Sandy clay foam, steep land red yellow podsolic
Topography	Flat to gentle sloping
Drainage	Well drained to imperfectly drained
Current vegetation	Talasiga
Parent material	Alluvial (Fallow area)
Climate	Perudic and isohyperthermic

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the preparation of research demonstration plots, experimental design, sampling methodology, sample treatment and the laboratory procedures for the physical and chemical analysis undertaken.

3.2 Selection of Study sites

Before the commencement of the study, possible research sites were surveyed throughout the district and selected under criteria such as:

- The site should have fallow areas which were left fallow > 2years
- The sites should have Talasiga and fallow areas.
- The site should have minimal use of fertilizer
- The site should be dominant in burning of grassland
- The plot area should have the same soil class
- The experimental sites will be within flat plain, and
- Within the village demarcated land boundaries

The selected village was visited following the normal traditional procedures (sevusevu), followed by an introduction of the research and its objectives. Upon completion of the fieldwork an *i'tatau* (traditional appreciation upon presenting Kava) was presented to the villagers.

3.3.0 Preparation of Experimental Plots

The experimental plots consisted of three treatments- *C. calothyrsus, M. pruriens* and natural vegetation (No Fabaceae spp.), each with 21 plots of 4m x 3m each set up by measuring and dividing the whole plots by tape and marked by posts. The spacing between the main plots was 3m. This space was used as walk-way was cleared and maintained weed-free throughout the study period to minimize nutrient effects on other plots.

Figure 5: Construction of the experimental plots in Talasiga area

3.3.1 Fallow site

Experiment details

1. Three Treatments: *C. calothyrsus, M. pruriens* and Natural vegetation (No Fabaceae spp.). Six *C. calothyrsus* and six *M. pruriens* seeds planted in assigned plots.
2. Seven Replications.
3. No fertilizer application for plots.
4. Using 4m x 3m plots with a seedling spacing of 1m x 1m.
5. Plots spacing was 3m apart to control nutrient effect to other plots.
6. Soil sampling was done before planting and then after the NFPs had matured, i.e. from 24/11/2014 to 24/11/2015.
7. Soil samples were collected from selected replication plots, from three different spots on each plot and were bulked to have a composite sample for each plot using soil auger at the 2 different depths .i.e. Depth 1(0-15cm) and Depth 2(15-30cm).

3.3.2 Experiment layout

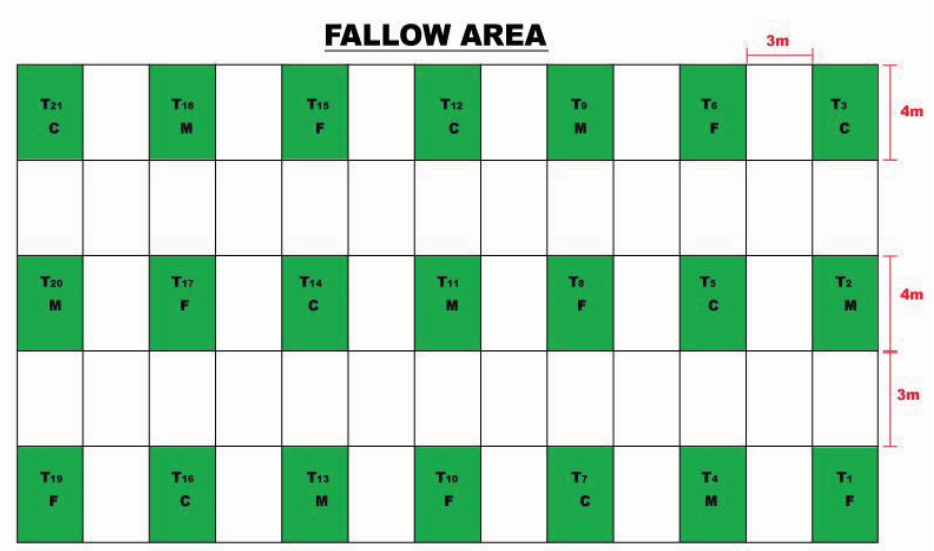

Figure 6: Fallow site experimental layout

3.3.3 Soil sampling Method

Two composite soil samples were collected from each plot before planting the NFPs (*C. calothyrsus* and *M. pruriens*), then after the maturity of these plants and considering the uniformity of the soils, slope and land use. Each composite sample was taken from three spots in each of the two layers (0-15cm and 15-30cm).

Soil samples collected were prepared following the standard methods. Each soil sample was filled in separate plastic bag, labelled and stored in proper container for shipment to Viti Levu for analysis (Singh *et al.,* 2013*)*.

3.3.4 Method of selecting Replication samples to be analyzed.

The experiment set-up is done on a flat plain. The total number of treatments in this experiment plot was 21, however due to financial constraint only five treatments were sampled for analysis. The treatment (T) that was selected for analysis was randomly chosen for collection of soil samples by drawing lots. The selected treatments were: T3C1D1, T3C1D2; T9M3D1, T9M3D2; T12C4D1, T12C4D2; T15F5D1, T15F5D2; T18M6D1, T18M6D2. From the five treatments, a further set of three replications was randomly chosen, namely T3C1D1, T3C1D2; T9M3D1, T9M3D2; T18M6D1, T18M6D2 were selected to calculate for TOC and pH.

The selected treatments were analyzed for total N in Fallow (F) area before and after planting *C. calothyrsus* (C) and *M. pruriens* (M) for analysis were:

T3C1D1, T3C1D2; T9M3D1, T9M3D2; T12C4D1, T12C4D2; T15F5D1, T15F5D2; T18M6D1, T18M6D2.

The selected treatments for analysis of TOC and pH in the Fallow area before and after planting *C. calothyrsus* (C) and *M. pruriens* (M) were:

T3C1D1, T3C1D2; T9M3D1, T9M3D2; T18M6D1, T18M6D2.

3.4 Laboratory Analyses

The soil samples collected were dried at (105°C) and ground to pass a 2mm sieve. The soil pH was measured 30 minutes after mixing 10 g soil with 50 mL distilled water (Daly & Wainiqolo, 1993). The total N will be analyzed using semi-micro Kjeldahl method (Blakemore, 1987). Lastly, the TOC will be determined by the Walkley-Black dichromate method as modified by Nelson & Sommers, (1982), in which the soil organic matter is oxidized by dichromate ($Cr_2O_7^{-2}$) using the heat of dilution of sulfuric acid. The unreduced dichromate is titrated with ferrous ammonium sulfate using diphenylamine as redox indicator.

Figure 7: Participating in soil analysis in the IAS Lab, USP.

4.0 Talasiga site

Experiment details

1. Three Treatments: *C. calothyrsus* (C)*, M. pruriens* (M) and natural vegetation (no Fabaceae spp.). Six *C. calothyrsus* and six *M. pruriens* seeds planted in assigned plots.
2. Seven replications.
3. No fertilizer application for all plots.
4. Using 4m x 3m plots with a seedling spacing of 1m x 1m.
5. Plots were spaced 3m apart to control nutrient effects on other plots.

6. Two composite samples per plot meaning each composite sample taken from 3 spots in each of the 2 layers (0-15cm and 15-30cm) plot.
7. Soil sampling per plot was done before planting the NFPs and then after reached maturity. (i.e. from 25/11/2014 to 25/11/2015).

4.1.0 Experimental layout

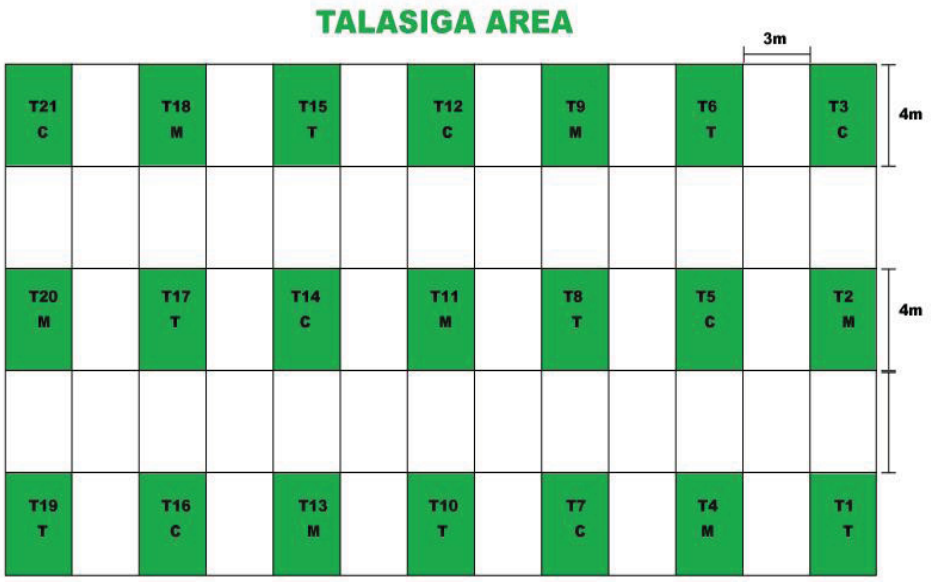

Figure 8: Talasiga site experimental layout

4. 1.1 Soil sampling Method

Two composite soil samples were collected from each plot before planting the NFPs (*C. calothyrsus* and *M. pruriens*), then after the maturity of these plants and considering the uniformity of the soils, slope and land use. Each composite sample was taken from three spots in each of the two layers (0-15cm and 15-30cm).

Collected samples were prepared following the standard methods. The soil samples were labelled in their various plastic bags and stored in proper container for shipment to Viti Levu for analysis (Singh *et al,* 2013*)*.

4.1.2 Method of selecting Replication samples to be analyzed.

The total number of treatments in this experiment was 21, however due to financial constraint only five treatments will used to do my analysis. The plots names were written down in a piece of paper and were randomly handpicked for analysis. Thus T3C1D1, T3C1D2; T6T2D1, T6M2D2; T9M3D1, T9M3D2; T15T4D1, T15T4D2; T21C6D1, T21C6D2 were handpicked to be used for analysis. From the five

treatments, a further randomly set handpicked of 3 treatments T6T2D1, T6M2D2; T15T4D1, T15T4D2; T21C6D1, T21C6D2 were selected to calculate TOC and pH.

The selected treatments for analysis of total N in Talasiga (T) area before and after planting *C. calothyrsus* and *M. pruriens* used for analysis are:

T3C1D1, T3C1D2; T6t2D1, T6t2D2; T9M3D1, T9M3D2; T15t5D1, T15t5D2; T21C7D1, T21C7D2.

The selected treatments for further analysis of TOC and pH levels in the Talasiga (T) area before and after planting *C. calothyrsus* and *M. pruriens* are:

T6M1D1, T6M2D2; T15t4D1, T15t4D2; T21C7D1, T21C7D2.

4.2 Laboratory Analyses

The soil were prepared and analyzed as described in Section 3.4

4.3 Quality Control

The soil samples were analyzed using quality control measures to produce quality results at the Ministry of Agriculture's Fiji Agricultural Chemistry Laboratory, Koronivia Research Station.

4.4 Quality Control Measures

Replicates analysis was carried out on all samples.

4.5 Data Analysis

The laboratory data were analyzed with general statistics software of SPSS 22 Version 3 statistical package. To test for normality, the data was tested using Skewness & Kurtosis, Shapiro-Wilk test, Histogram and Q-Q plots. From these tests, the dependent variables are not approximately normally distributed for each category of an independent variable. In this case, non-parametric methods were used. Since the data as measure of before and after experiment, thus Wilcoxon signed-ranks test will be used initially. Moreover, Mann-Whitney test were used because of the small sample size and the data appears to be skewed as in Figures 1-3. Lastly, Microsoft Office Excel was used to present results in charts with error bars showing differences in treatments.

CHAPTER 4

RESULTS

The results presented in this chapter are from selected treatments from the two experimental areas. i.e. the Talasiga and Fallow sites.

4.1 Nutrient Level before applying NFP in Fallow Area

Table 3: pH levels of the soil within the experiment plots in the Fallow site

Soil description	Treatment	Plot Names	pH_ Before
Fallow	*C. calothrysus*	T3C1D1	5.85
Fallow	*C. calothrysus*	T3C1D2	6.03
Fallow	*M. pruriens*	T9M3D1	5.91
Fallow	*M. pruriens*	T9M3D2	5.97
Fallow	*M. pruriens*	T18M6D1	5.91
Fallow	*M. pruriens*	T18M6D2	6.21

The soil of the Fallow site was moderately acidic. Most crops grow best if soil pH is between 6.0 and 7.5 (Daza *et al*., 2006). These soils were originated from parental material by alteration caused by leaching and weathering as they were also subjected to flooding in the past decade.

4.2 Nutrient level before applying NFP in Talasiga site

Table 4: pH levels of the soil within the experiment plots in the Talasiga area

Soil Description	Treatment	Plot Names	pH_ Before
Talasiga	natural vegetation	T6T2D1	6.07
Talasiga	natural vegetation	T6T2D2	6.36
Talasiga	natural vegetation	T15T5D1	5.84
Talasiga	natural vegetation	T15T5D2	5.96
Talasiga	*C. calothrysus*	T21C7D1	5.91
Talasiga	*C. calothrysus*	T21C7D2	6.22

The soils in the Talasiga area were moderately to slightly acidic. It is being subjected to continuous burning that induced Talasiga vegetation. The area is subjected to medium to low organic matter (OM). Studies have shown that higher soil OM levels are found in soils managed with organic inputs, including animal manure and cover crops, than in soils managed without such inputs (Clark *et al.,* 1998; Becker & Johnson, 2001).

4.3.0 Results for Experiment

1. **General Description for Normality tests for Nutrients levels in Fallow site before planting *C. calothrysus* and *M. pruriens*.**

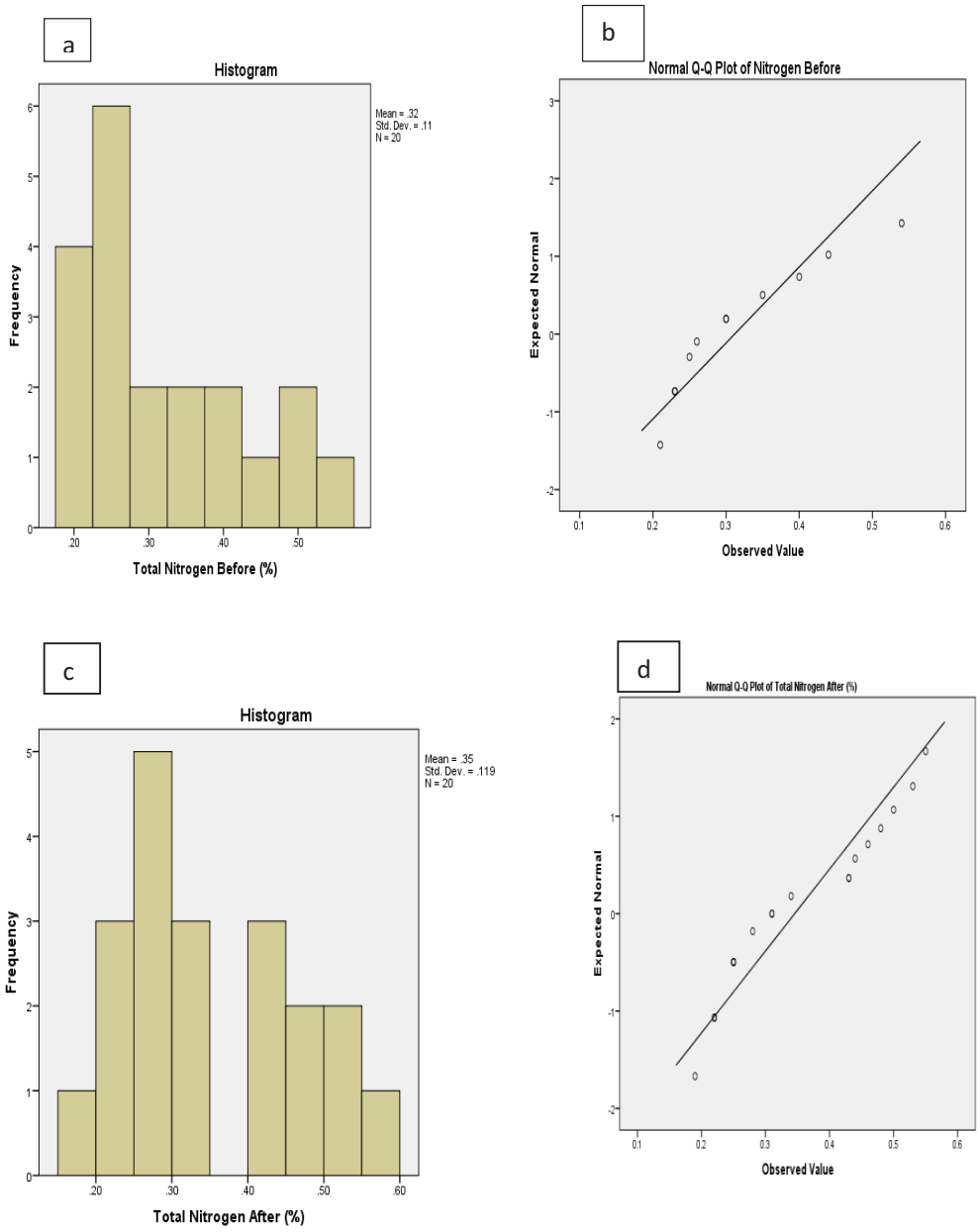

Figure 9: Total N before and after normality graphs

Using Shapiro-Wilk test, there were statistical evidence that the total N before $P \leq 0.056$ and after nearly normally distributed (Table 1(a)).

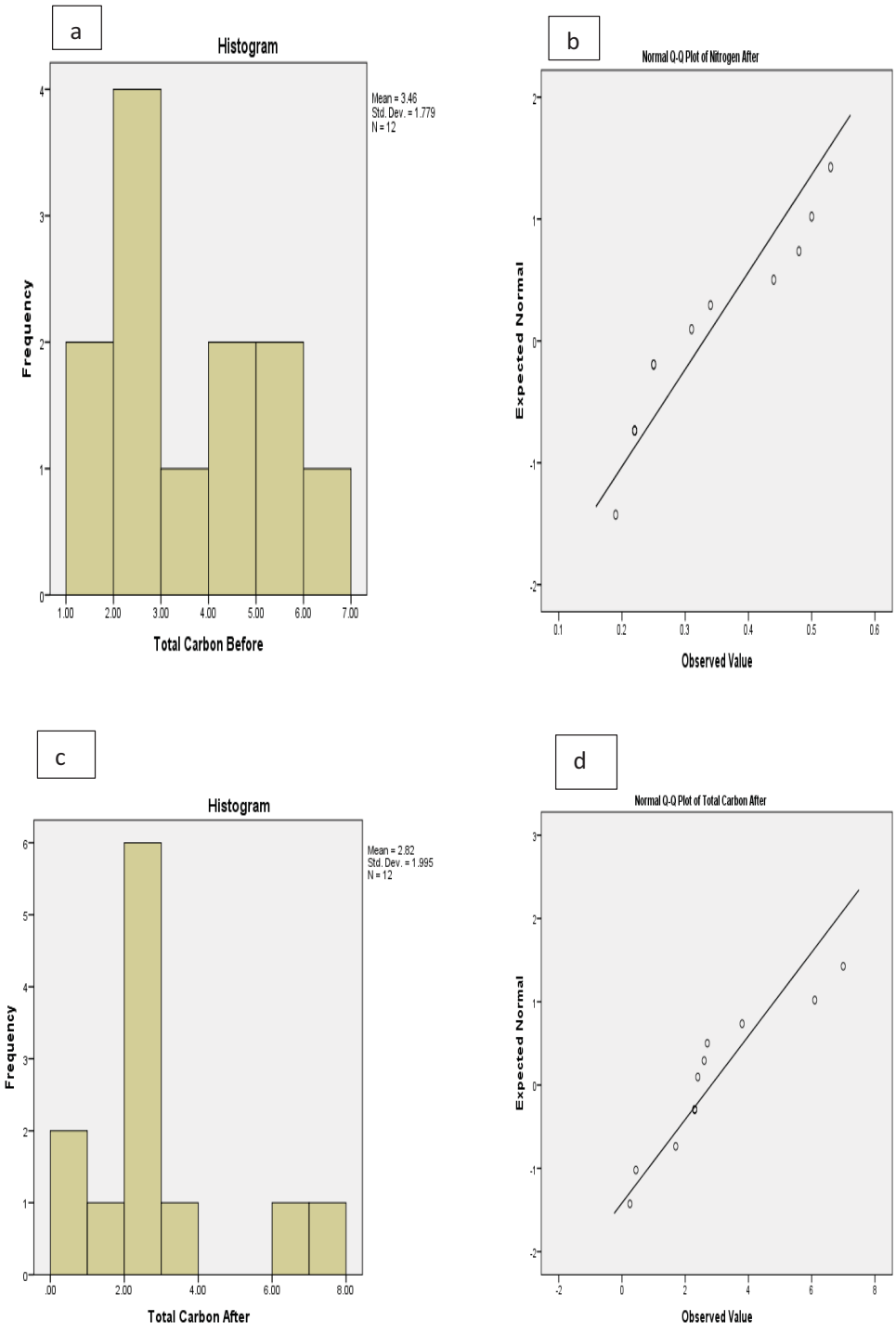

Figure 10: Total C before and after normality graphs

Using Shapiro-Wilk test, there were slight no statistical evidence that total C before $P \geq 0.398$ and after $p \geq 0.062$ are almost nearly normally distributed (Table 1(a)).

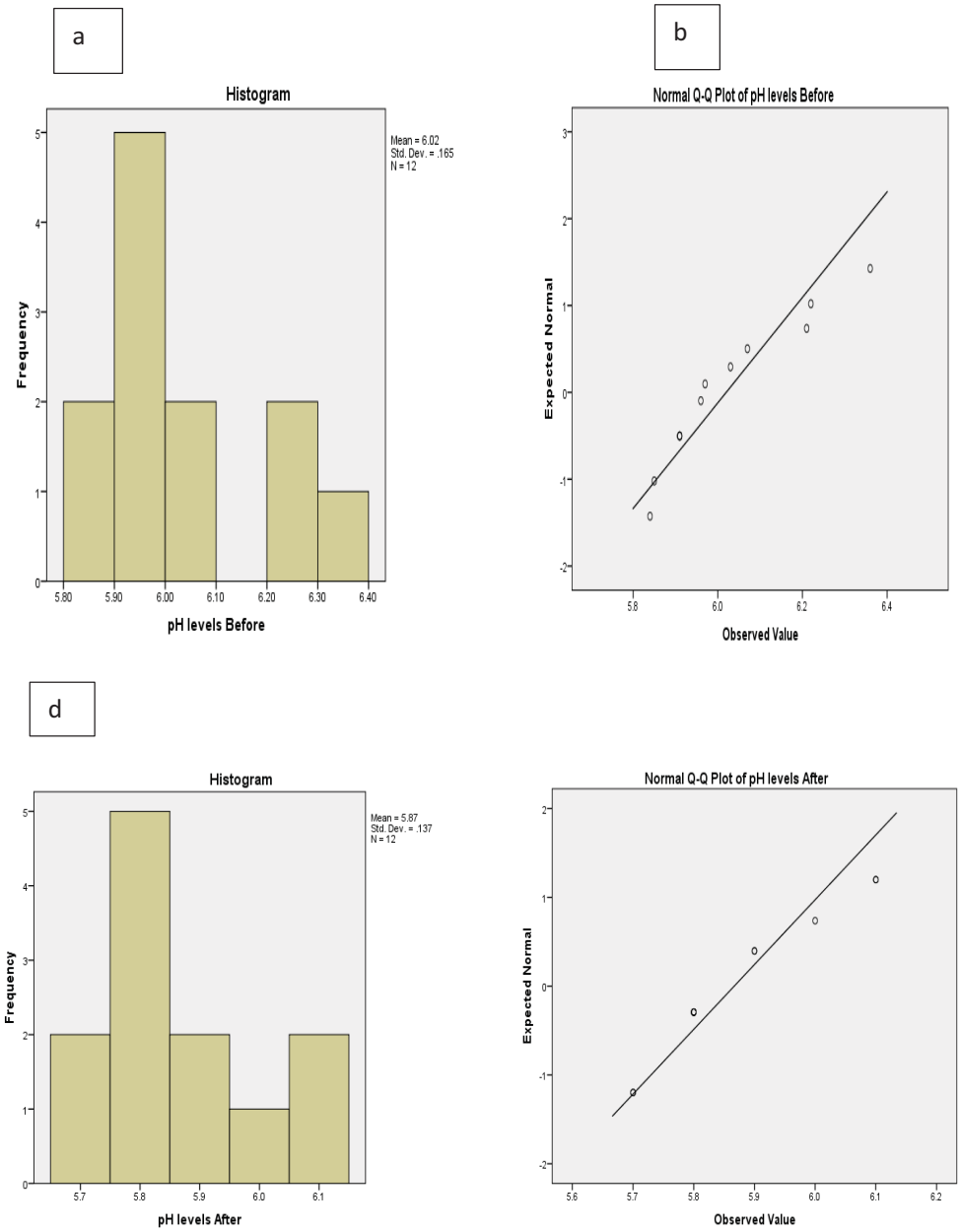

Figure 11: pH before and after normality graphs

Using Shapiro-Wilk test, there were slight statistical evidence that pH level before $P \geq 0.117$and after $P \geq 0.065$ are almost nearly normally distributed (Table 1(a)).

Because of the small size being analyzed and the skewness of the histograms and Q - Q plots (Figure 1 – 3), the data were analyzed using non-parametric test for the level of significance (Table 1(a)).

4.3.1 Nutrient levels before planting *C. calothrysus* and *M. pruriens* in Fallow area

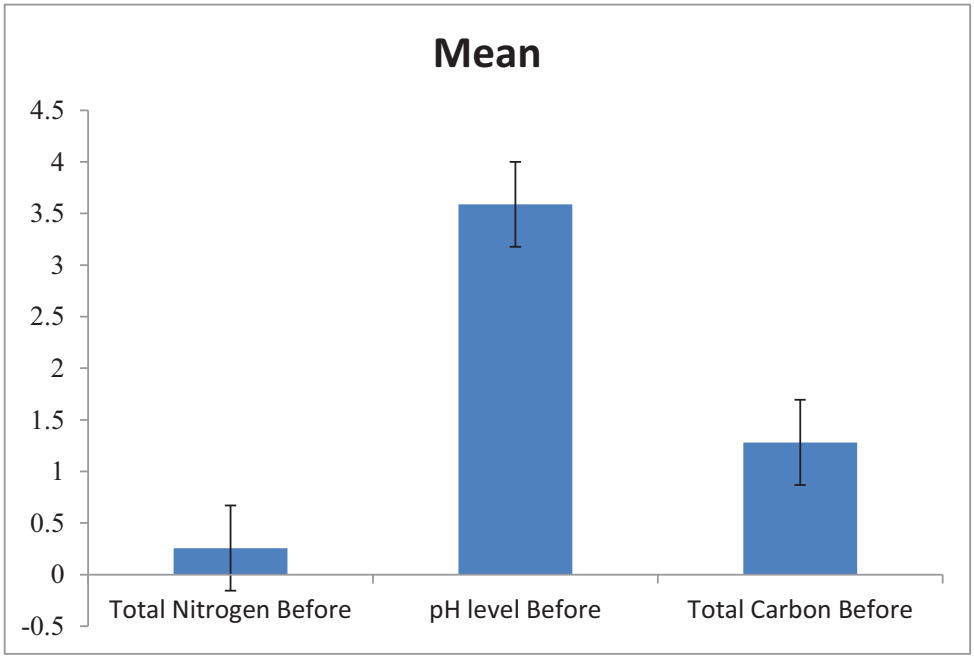

Figure 12: Selected nutrient mean level before planting C. *calothrysus and M. pruriens*

The soil within the fallow site was moderately acidic with a minimum concentration of total N 0.256 % and of TOC was 1.28% (Table 1 (b)).

The Wilcoxon test, revealed a slightly significant difference in total N before and after of $P \leq 0.47$ (Table 3); however, there was no significant difference for pH or TOC before of statistical significance of $P \geq .075$ and $P \geq 0.753$ (Table 3). From the Mann-Whitney test also shows that there was significance in total N before $P \leq 0.20$ (Table 4).

4.3.2 Nutrient levels before and after planting *C. calothrysus* and *M. pruriens* in the Fallow area.

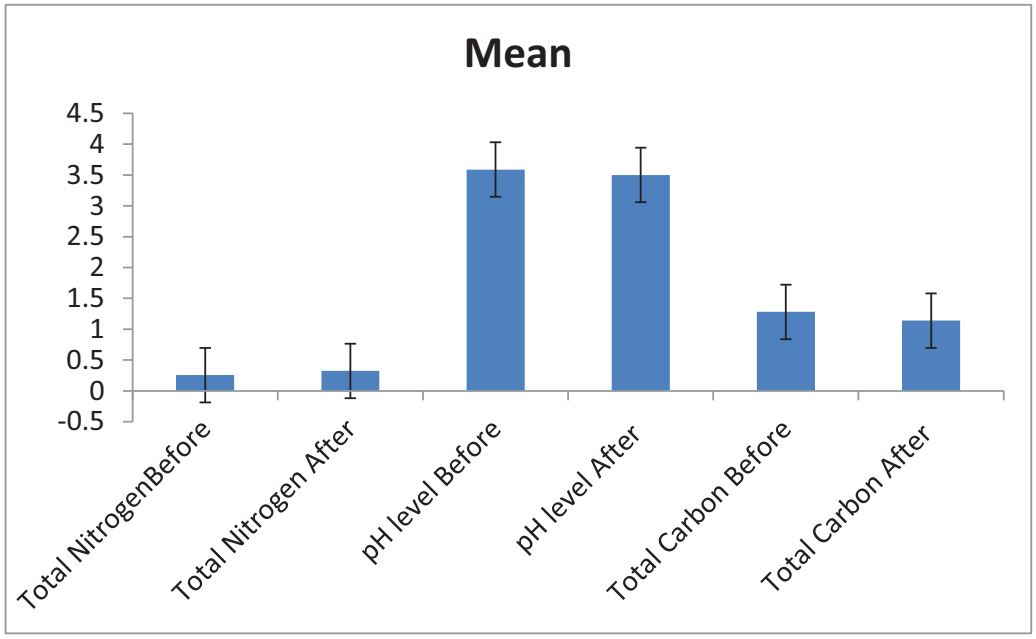

Figure 13: Means of selected nutrient from before and after planting *C. calothrysus and M. pruriens.*

In the fallow area, the Wilcoxon Signed Ranked Test showed that the total N increased from a mean of 0.256% before planting to 0.323% after planting the NFPs (*P*= 0.047) (Table 3), however, TOC and pH were unaffected.

4.3.3 Effects of Total N in depth 1 before and after planting *C. calothrysus* and *M. pruriens* in the Fallow area

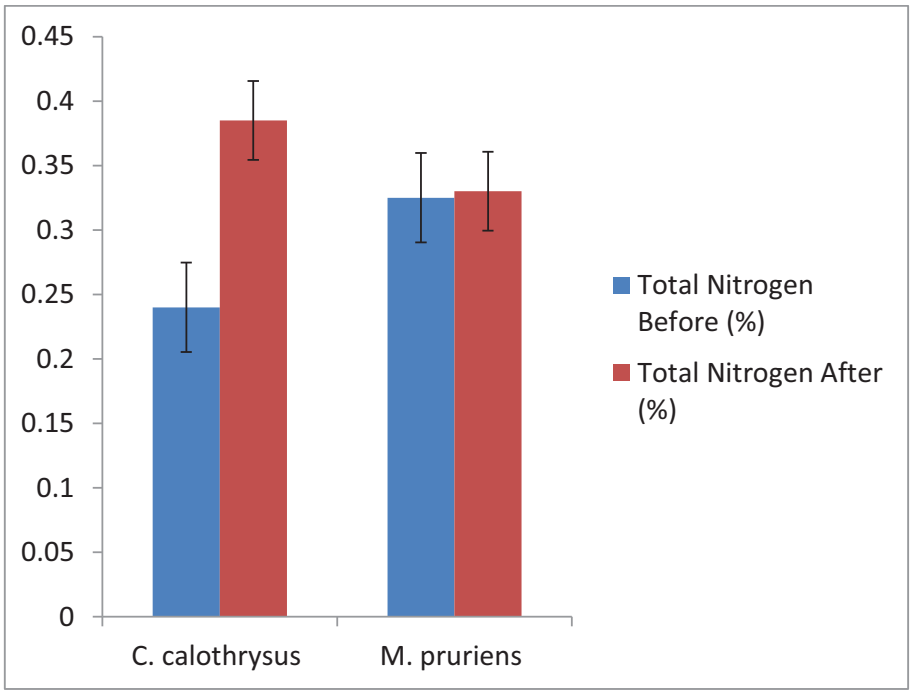

Figure 14: Mean total N after planting *C. calothrysus* and *M. pruriens* in the Fallow area at depth 1.

At depth 1 in the Fallow area, the Mann-Whitney test showed that planting both NFPs increased the total N ($P \geq 0.05$) (Table 5).

4.3.4 Effects on total N at depth 2 before and after planting *C. calothrysus* and *M. pruriens* in the Fallow area

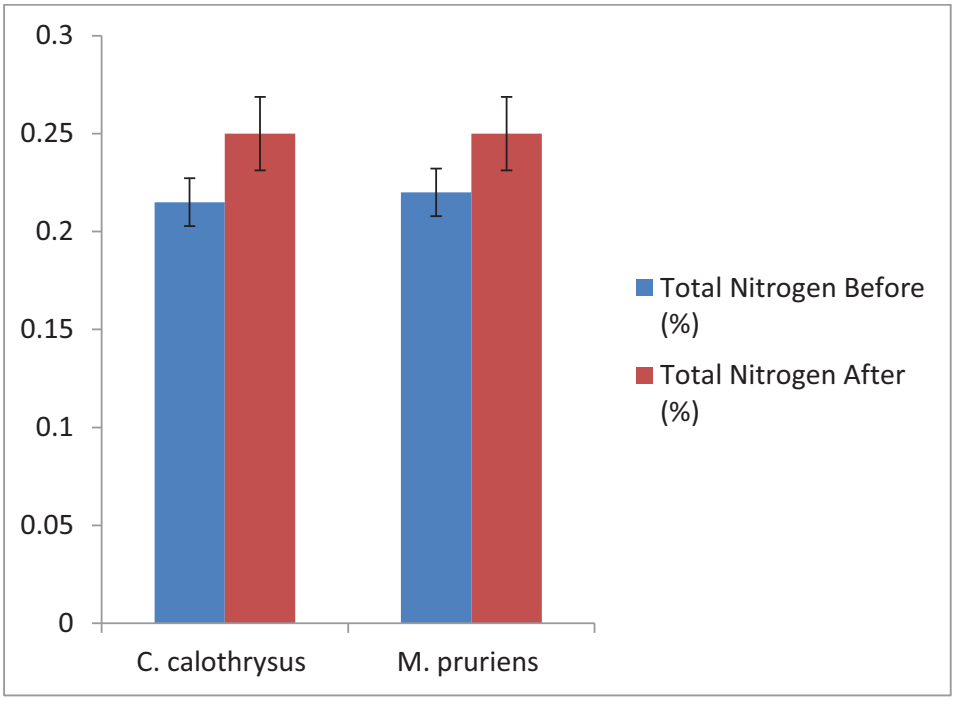

Figure 15: Average mean of total N after planting *C. calothrysus* and *M. pruriens* within fallow in depth 2.

At depth 2 in the Fallow area, planting both NFPs did not significantly change total N ($P \geq 0.05$) *pruriens* (Table 5).

4.3.5 Effects on total N within the two depths after planting *C. calothrysus* and *M. pruriens* in the Fallow area.

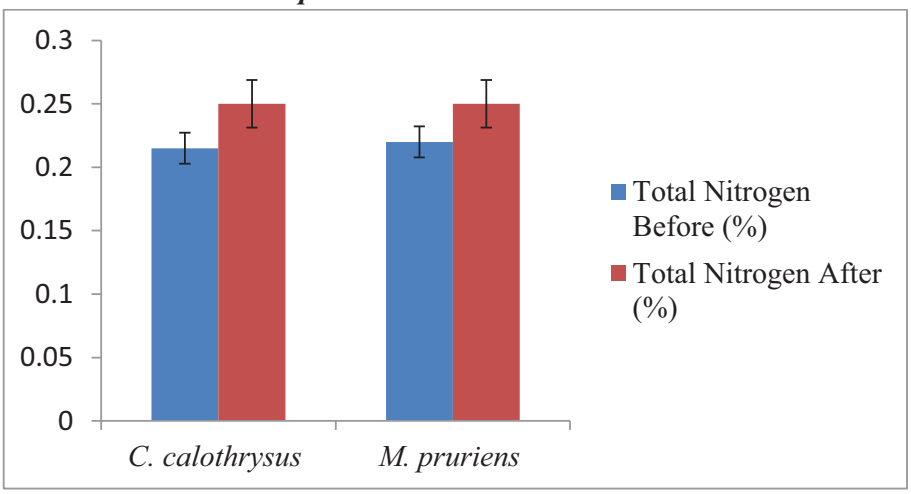

Figure 16: Effect of *C. calothrysus* and *M. pruriens* on total N at the two depths.

At both depths, planting NFPs did not significantly change the total N from its initial concentration ($P \geq 0.05$) (Table 5).

4.3.6 Effects of TOC levels in depth 1 before and after planting *C. calothrysus* and *M. pruriens* in Fallow Area

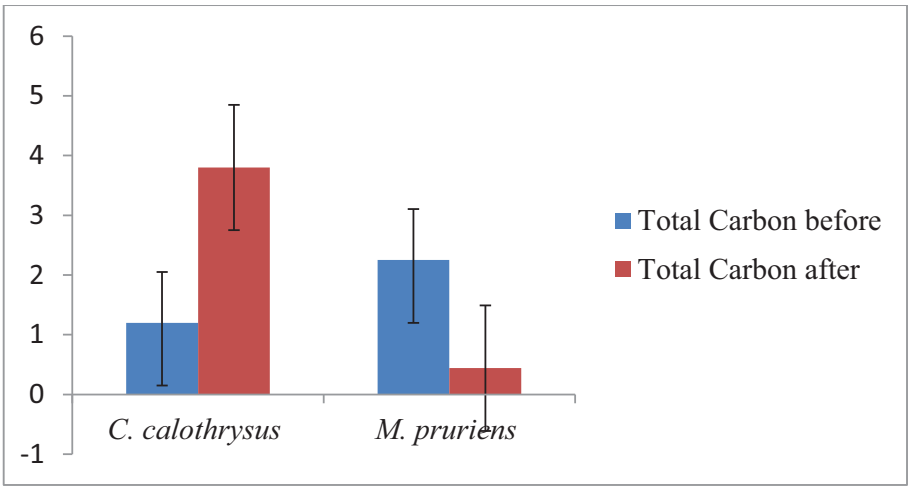

Figure 17: Mean of TOC after planting *C. calothrysus* and *M. pruriens* in the Fallow area at depth 1.

At depth 1 in the Fallow area, TOC increased with *C. calothrysus* and decreased with *M. pruriens;* however, the difference were not statistically significant ($P \geq 0.05$) (Table 5).

4.3.7 Effects of TOC at depth 2 before and after planting *C. calothrysus* and *M. pruriens* in the Fallow area

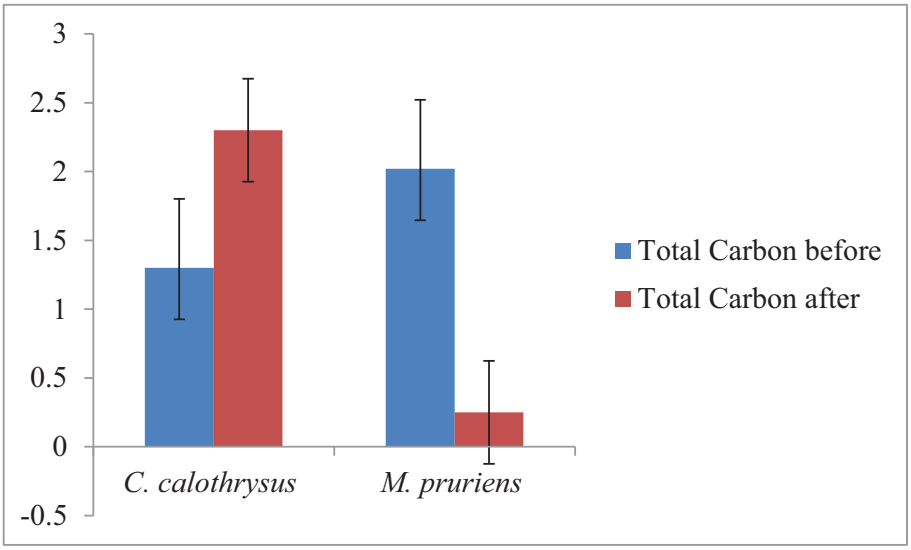

Figure 18: Mean of TOC after planting *C. calothrysus* and *M.pruriens* within fallow at depth 2.

At depth 2 on the Fallow area, the Mann-Whitney test showed that TOC before and after planting NFPs was not significant (Table 5).

4.3.8 Effects on TOC within the two depths after planting *C. calothrysus* and *M. pruriens* in the Fallow area

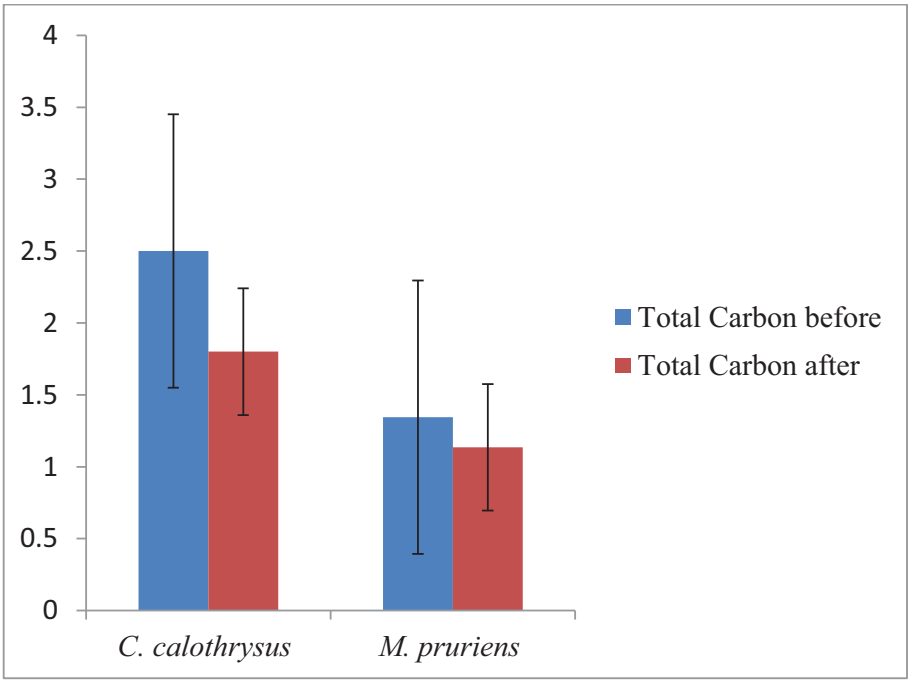

Figure 19: Effect of *C. calothrysus* and *M. pruriens* on TOC at the two depths.

For the two depths in the Fallow area, the Wilcoxon and Mann-Whitney test showed that the TOC before and after planting NFPs was not significant added to the soil by *C. calothrysus* and *M. pruriens* before planting and after planting were of no significance ($P \geq 0.05$) (Table 5).

4.3.9 Effects of pH at depth 1 before and after planting *C. calothrysus* and *M. pruriens* in the Fallow area

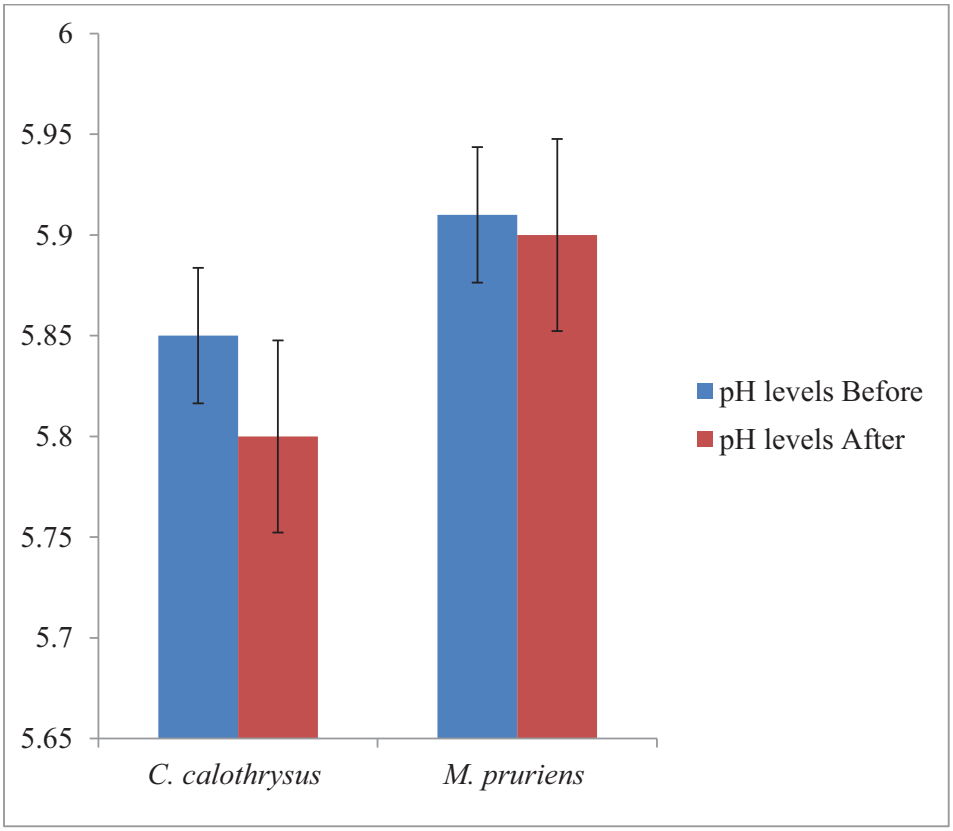

Figure 20: Mean of pH levels before and after planting *C. calothrysus* and *M. pruriens* in the Fallow area at depth 1.

At depth 1 in the Fallow area, the Mann-Whitney test showed the pH before and after planting NFPs was statistically different ($P \leq 0.05$)(Table 5 (b)).

4.4.0 Effects on pH at depth 2 before and after planting *C. calothrysus* and *M. pruriens* in the Fallow area

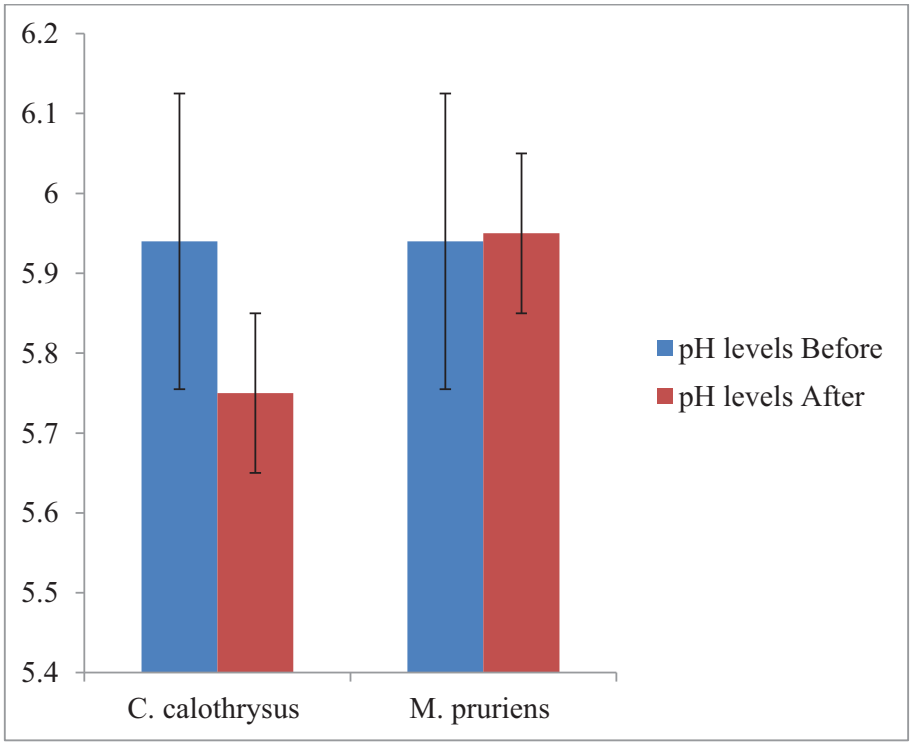

Figure 21: Mean of pH levels after planting *C. calothrysus* and *M. pruriens* within Fallow at depth 2.

At depth 2 in the Fallow area, the Mann-Whitney test showed that the difference in the total N concentration before and after planting the two NFPs was not significant ($p \geq 0.05$) Table 5 (a).

4.4.1 Effects of pH within both depths before and after planting *C. calothrysus* and *M. pruriens* in the Fallow area

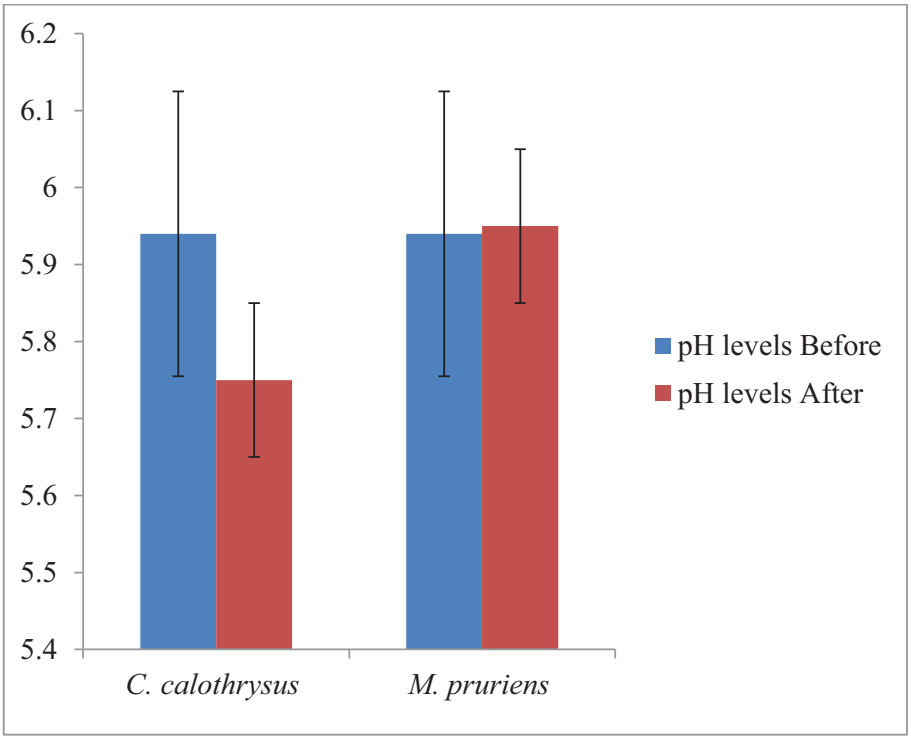

Figure 22: Effect of *C. calothrysus* and *M. pruriens* on pH levels at the two depths.

At the two depths in the Fallow area, the Wilcoxon and Mann-Whitney test showed that he overall before and after effect of planting NFPs on pH was not significant ($P \geq 0.05$) (Table 5 (a).

4.4.2 Status of nutrient levels before planting *C. calothrysus* and *M. pruriens* in Talasiga area.

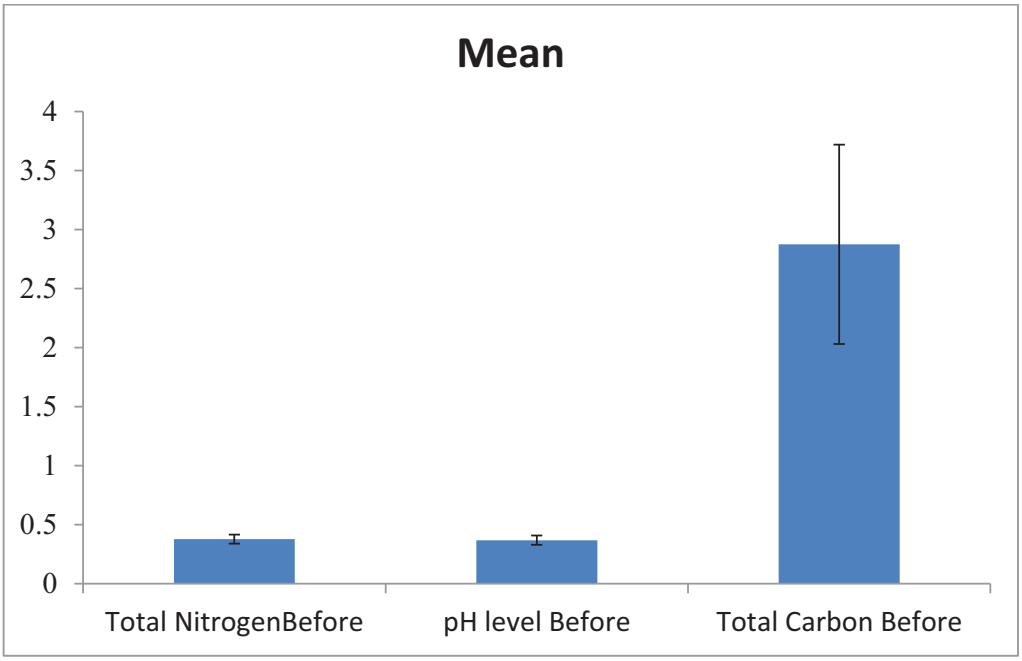

Figure 23: Selected mean nutrient mean levels before planting *C. calothrysus* and *M. pruriens* in the Talasiga area.

In the Talasiga area, the soil within the fallow area was moderately acidic with a mean concentration of total N of 0.378 % and of TOC of 2.875% (Table 7(a)) and a pH value of 6.06 (Table 7(b); Figure 17).

The Mann-Whitney test showed that TOC was statistical significant $P \geq 0.050$ (Table 6) and there was no statistically significant difference for total N or pH ($P \leq 0.012$) (Table 6).

4.4.3 Status of nutrient levels before and after planting *C. calothrysus* and *M. pruriens* in the Talasiga area.

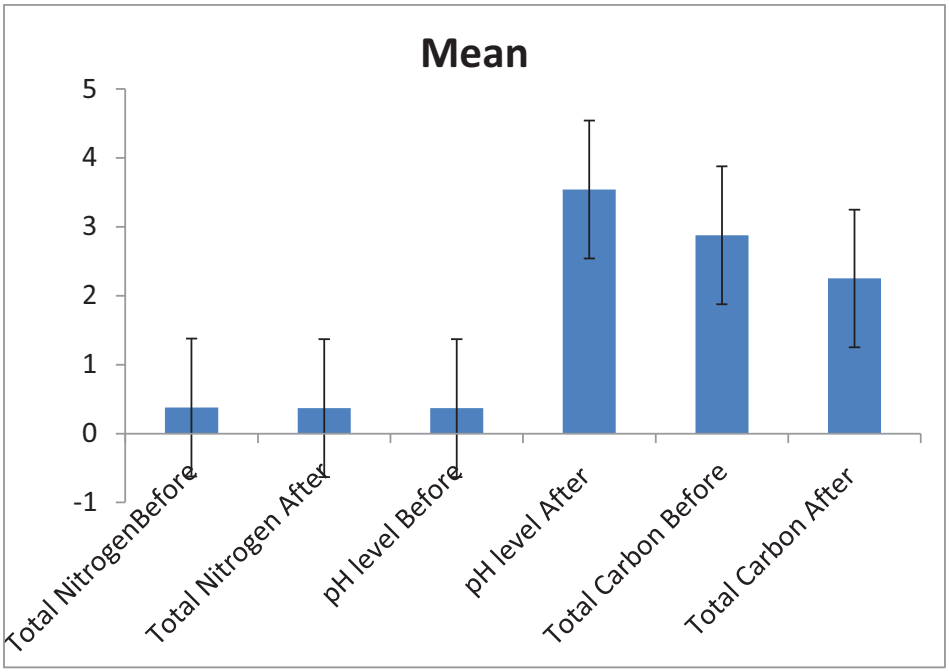

Figure 24: Means of selected nutrient before and after planting *C. calothrysus* and *M. pruriens*.

In the Talasiga area, total N and pH increased, while TOC decreased from their initial values one year after planting NFPs (Table 7(a) (b)). Using Wilcoxon Signed Ranked Test and the Mann-Whitney test the difference for total N and TOC were statistically significant (Table 6), whereas pH effect was not significant ($P \geq 0.05$).

4.4.4 Effects of total N at depth 1 before and after planting *C. calothrysus* and *M. pruriens* in the Talasiga area

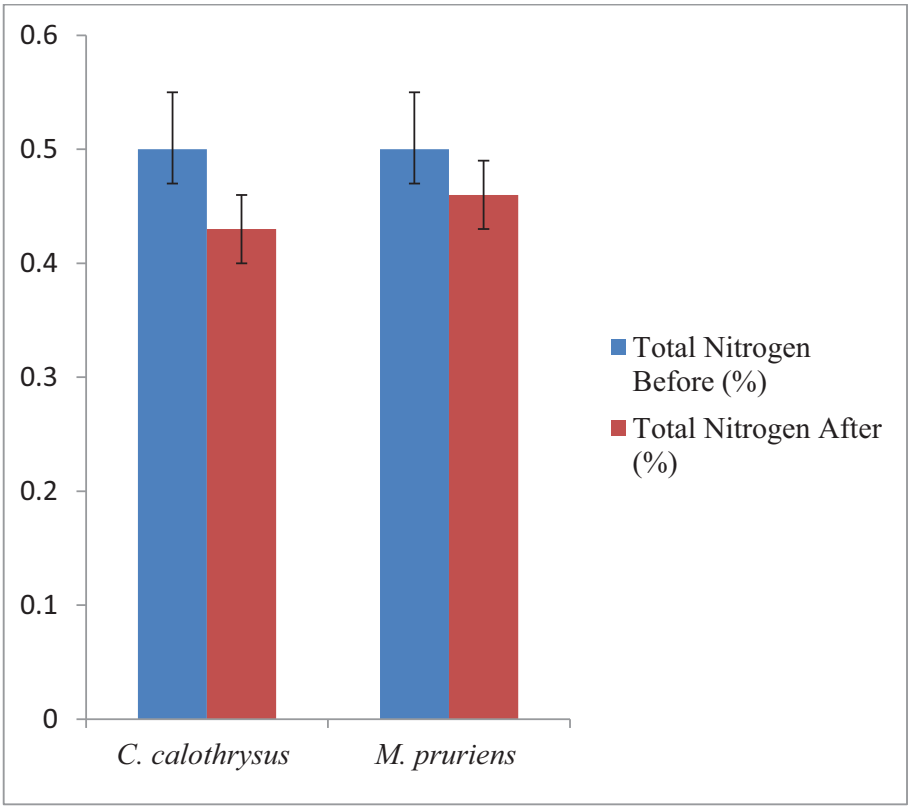

Figure 25: Mean of total N before and after *C, calothrysus* and *M. pruriens* in Talasiga area at depth 1.

At depth 1 in the Talasiga area, the Mann-Whitney test showed that mean total N before and after planting NFPs differed ($P \leq 0.05$) (Table 6, Figure 17).

4.4.5 Effects on total N at depth 2 before and after planting *C. calothrysus* and *M. pruriens* in the Talasiga Area

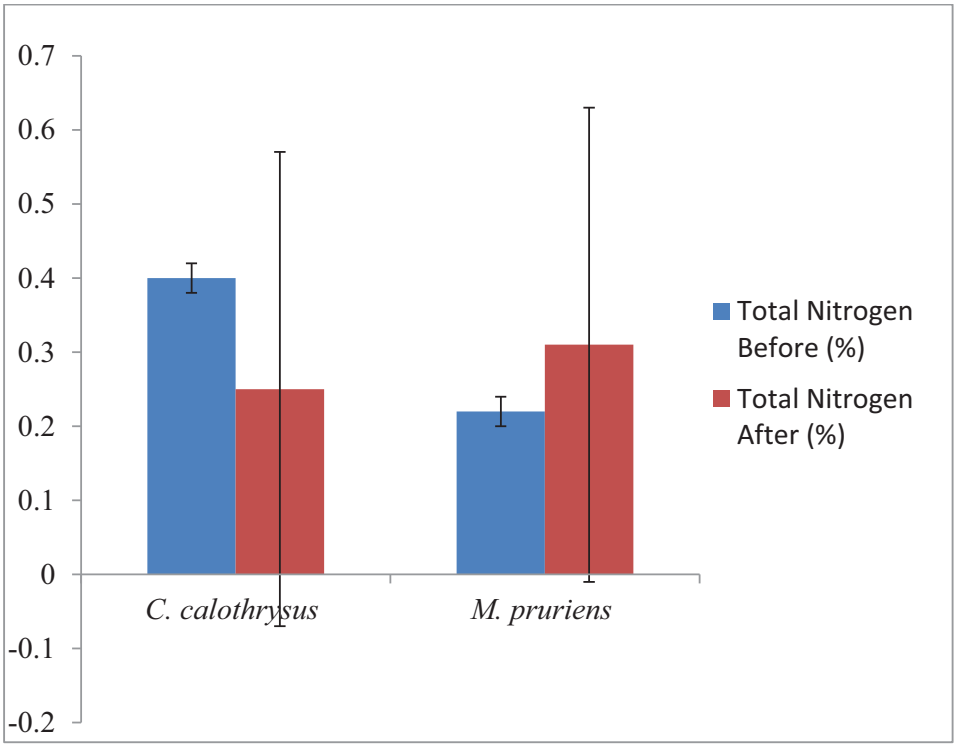

Figure 26: Average mean of total N after *C. calothrysus* and *M. pruriens* within Talasiga area at depth 2.

At depth 2 in the Talasiga area, the Mann-Whitney test and Wilcoxon tests showed that total N changed after planting both NFPs ($P \leq 0.05$) (Table 6). The effect differed between *C. calothrysus* and *M. pruriens.*

4.4.6 Effects on total N within both depths before and after planting *C. calothrysus* and *M. pruriens* in the Talasiga Area

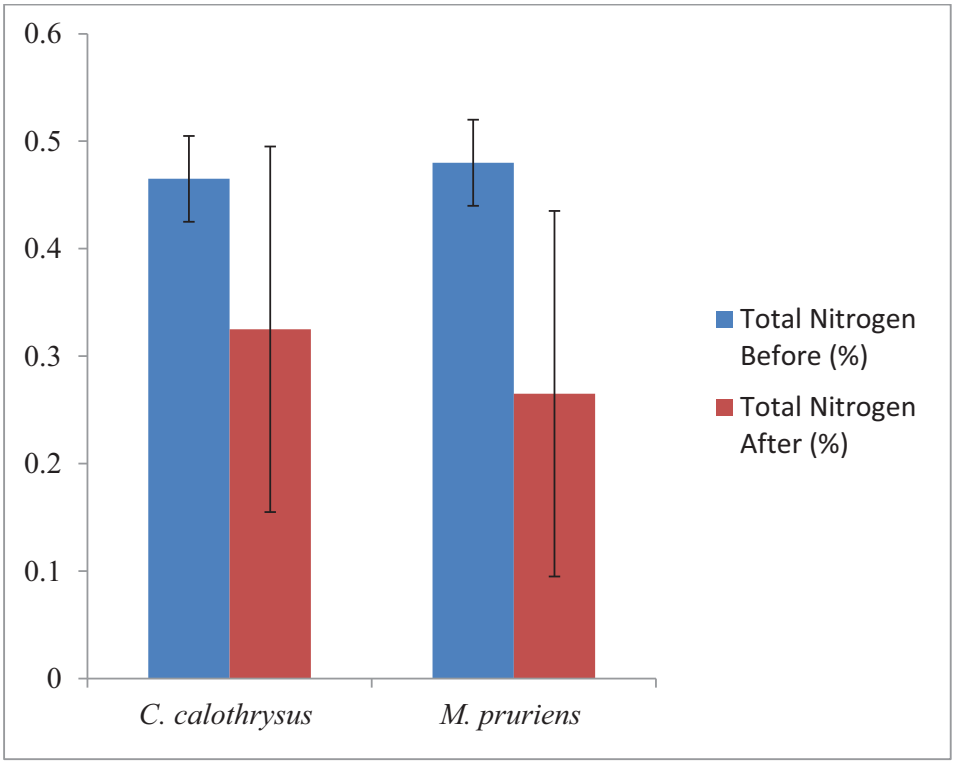

Figure 27: Effect of *C. calothrysus* and *M. pruriens* on total N at the two depths.

At both depths in the Talasiga area, the Mann-Whitney showed that total N decreased significantly ($p \leq 0.05$) for both NFPs (Table 6).

4.4.7 Effects on TOC at depth 1 before and after planting *C. calothrysus* in Talasiga Area

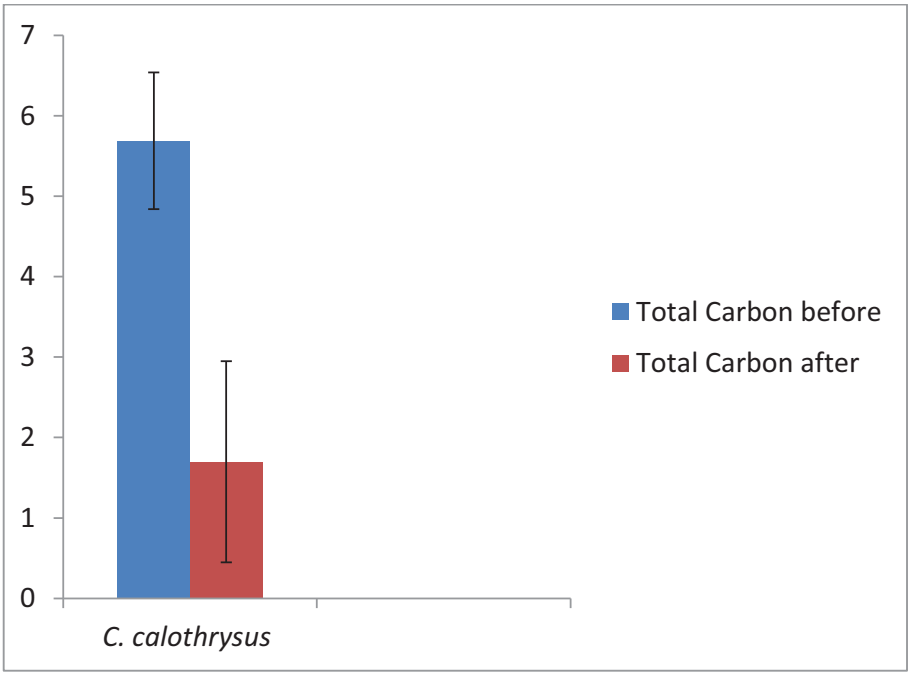

Figure 28: Mean TOC after planting *C. calothrysus* within Talasiga at depth 1.

At depth 1 in the Talasiga area, the Mann-Whitney test showed that the concentration of TOC before and after planting *C. calothrysus* was not significantly difference ($P \geq 0.05$) (Table 6).

4.4.8 Effects on TOC at depth 2 before and after planting *C. calothrysus* in Talasiga Area

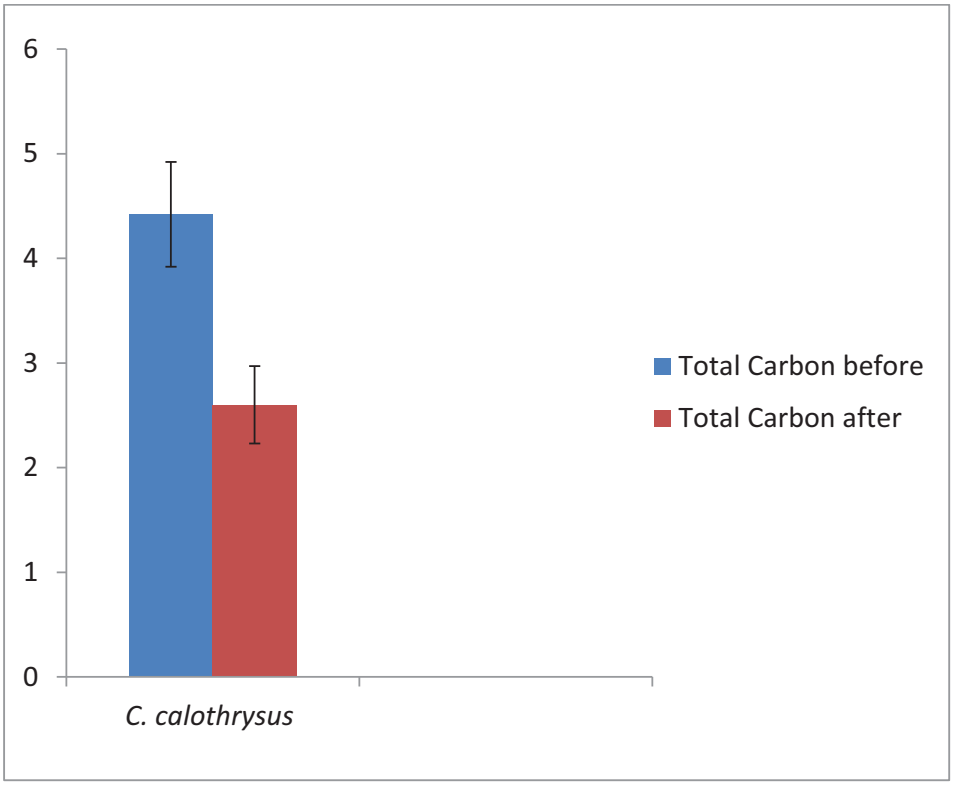

Figure 29: Mean TOC after planting *C. calothrysus* within Talasiga at depth 2.

Within depth 2 in the Talasiga area, the Mann-Whitney test showed that TOC before and after planting *C. calothrysus* was not significantly different ($P \geq 0.05$) (Table 6).

4.4.9 Effects on TOC within both depths before and after planting *C. calothrysus* in the Talasiga Area

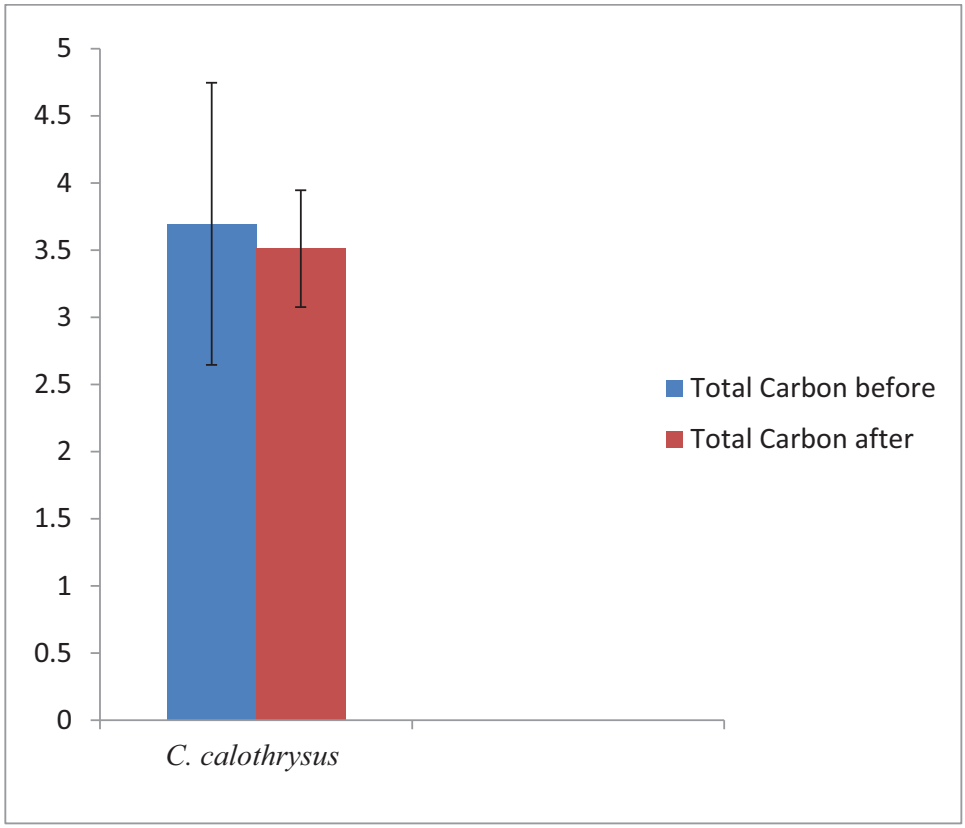

Figure 30: Mean TOC after planting *C. calothrysus* within Talasiga for both depths.

For both depths in the Talasiga area, the incorporation of *C. calothrysus* resulted in no significant change to TOC (Table 6).

4.5.0 Effects on pH at depth 1 before and after planting *C. calothrysus* in Talasiga Area

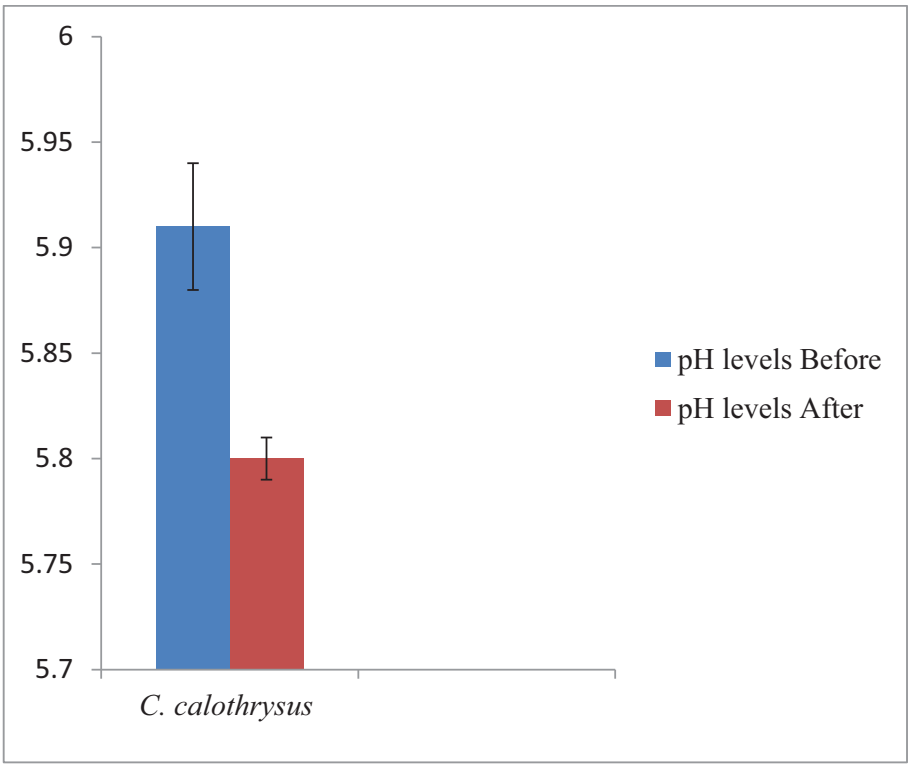

Figure 31: Mean pH after planting *C. calothrysus* within Talasiga at depth 1.

At depth 1 in the Talasiga area, the Mann-Whitney test showed that planting of the two NFPs did not significantly affect pH ($P \geq 0.05$).

4.5.1 Effects on pH at depth 2 before and after planting *C. calothrysus* in the Talasiga Area

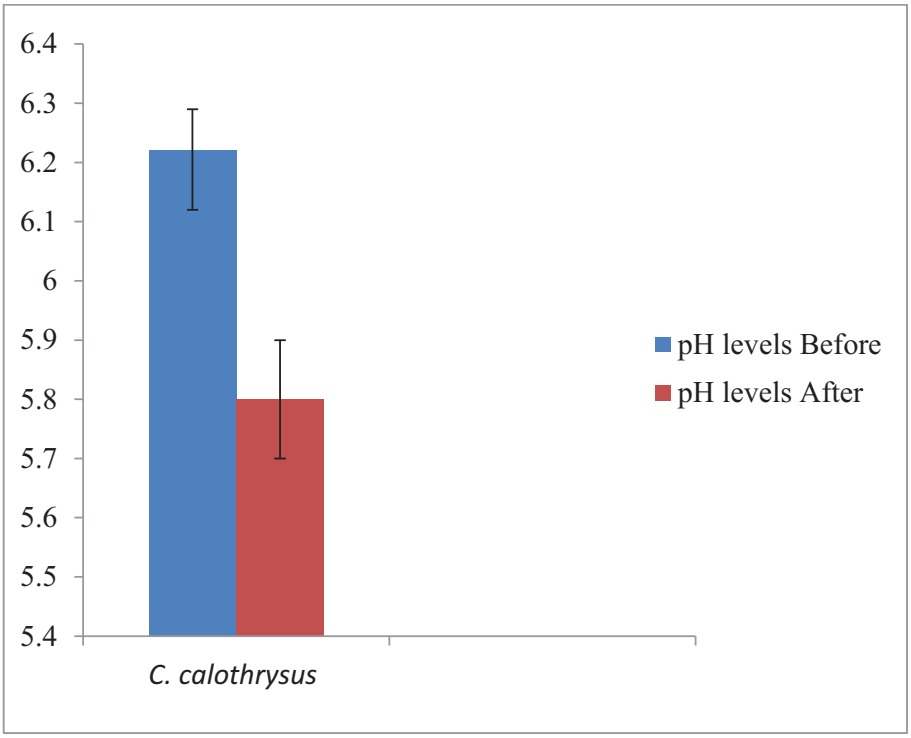

Figure 32: Mean pH after planting *C. calothrysus* within Talasiga at depth 2.

At depth 2 in the Talasiga area, the Mann-Whitney test showed that the pH levels after planting *C. calothrysus* were of not significantly different ($P \geq 0.05$) (Table 6).

4.5.2 Effects on pH within both depths before and after planting *C. calothrysus* and *M. pruriens* in the Talasiga Area

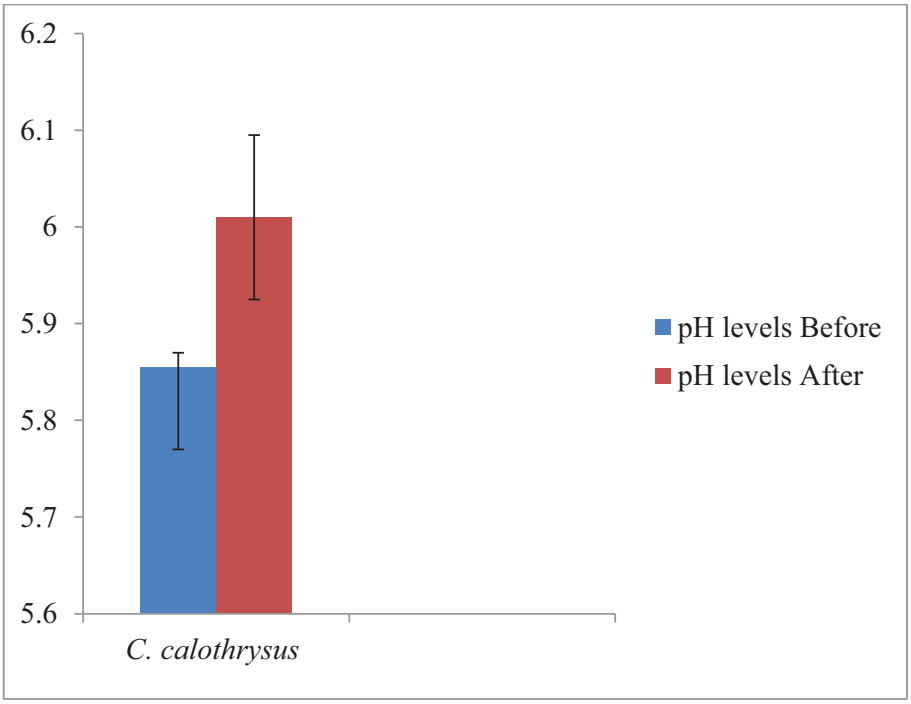

Figure 33: Mean pH *C. calothrysus* within Talasiga at both depths

The planting of both NFPs in the Talasiga area had no significant effect on the pH within both depths (Table 6).

CHAPTER 5

DISCUSSION

Various factors affect soil fertility decline throughout the globe, such as nutrient depletion and nutrient mining, acidification, the loss of organic matter and increase in toxic elements (Anderson & Ingram, 1994; Bekunda *et al*., 2010; Hodges, 2010). These effects result from the increased population causing imbalanced nutrients in the soil and ecosystems in many parts of the world (Smaling *et al*., 1997). Organic farming system is one of the alternatives to conventional agriculture that has contributed to solving the problem of soil fertility (Mader *et al.,* 2002). One form of organic farming practices involve the use of legumes as a cover crop or green manuring (Hole *et al*., 2005) to enhance soil fertility (Lampkin *et al*., 2000).

5.1.0 Status of nutrient levels before planting *C. calothrysus* and *M. pruriens.*

The results obtained from before planting *C. calothrysus* and *M. pruriens* showed significant differences in total N, TOC and pH ($P \leq 0.05$) in fallow area (Table 3). The mean levels for total N and TOC could be attributed the shifting back and forth between inorganic and organics forms as suggested by Hodges (2010). However, this process can also be easily disrupted by the mixing within the soil system of organic residues which have a high C: N ration (Havlin *et al.*, 2010). The soil of this study area was moderately acidic (Horneck *et al*., 2011) and subject to leaching and weathering, as flooding was happening regularly for the last decade.

5.1.1 Effects on total N at depth 1 before and after planting *C. calothrysus* and *M. pruriens* in the Fallow Area

Planting these NFPs in the Fallow area at depth 1 showed no significant difference ($P \geq 0.05$) in in total N. The increase in the means concentration of total N in depth 1 could be attributed to N fixation which provided the N for crop production (Peoples *et al*., 2009). The mean percentage of total N fixed by *M. pruriens* (0.33%) was greater than that of *C. calothrysus* (0.31%). This reflect different responses of the crops to climatic and biological processes in this study area (Ziblim *et al*., 2013). Phiri, Barrios, Rao, and Singh (2001) reported that *C. calothrysus* was significantly affected by land use in the 0 - 5 cm soil layer, thus the continuous cultivation in this area resulted in the reduction in organically bound nutrients through mineralization (Stewart, 1967). The results further showed that there was no significant difference in

the level of total N before and after planting either species for depth 1 in the Fallow area. The low N concentration could be result of the natural vegetation utilizing the already available N and is not being replaced overtime (Ziblim *et al*., 2013).

5.1.2 Effects on total N in depth 2 before and after planting *C. calothrysus* and *M. pruriens* in the Fallow area

At depth 2, planting both NFPs in the fallow area had no significant effect on total N ($P \geq 0.05$). The increase in the means levels of total N in depth 2 could be also be attributed to the fact that leguminous plants are capable of fixing N for crop production (Peoples *et al*., 2009; Ziblim *et al*., 2013). Both of this plant contributed a mean around 0.23% N. Kramberger, Gselman, Janzekovic, Kaligaric, and Bracko (2009) reported that non-legumes can also be used to improve the levels of soil organic C. However, Dinesh, Suryanarayana, Chaudhuri, and Sheeja (2004) confirmed cover cropping and incorporation on a long-term basis can lead to significant buildup of total N in both organic and mineral layers of cover crops sites. This could be the result of leaching because Dinesh *et al*. (2004) reported that after testing *M. pruriens* in a fallow area, there very few maize roots below 20 cm, which resulted in nitrate being susceptible to leaching. Also, the decomposition rate might be another factor which slows the process of decomposition when N is being used up (Lundquist *et al*., 1999). This reduces the amount of C while N is recycled (Lehmann *et al*., 1998).

5.1.3 Effects on total N within both depths after planting *C. calothrysus* and *M. pruriens* in the Fallow area

The results obtained after planting *C. calothrysus* and *M. pruriens* in Fallow area within the two depths showed no significant ($P \geq 0.05$) difference between the level of total N before and after the incorporation of these two NFPs. The results could be the natural vegetation utilizing the available N. However, the mean levels of total N increase for both *C. calothrysus* and *M. pruriens* at both depths. The increase in the mean levels could be attributed to N fixation (Ziblim *et al*., 2013). Also, Barthes et al. (2004) mentioned that the low proportion of C remaining in the topsoil can be priming effect to the enhancement of biological activity resulting in the increase in N. The quality of litter has a major impact on soil fertility with regard to nutrient-supply and SOM, thus high quality organic inputs release nutrients rapidly (Mafongoya *et al*., 1997). Stanford and Smith (1972) reported an increased in SOM,

increased N mineralization potential and reduced nitrate leaching under diversified rotations including leguminous and non-leguminous cover crops.

5.1.4 Effects of Total Organic Carbon levels in depth 1 before and after planting *C. calothrysus* and *M. pruriens* in the Fallow Area

Planting the NFPs in the Fallow area did not increase TOC at depth 1 ($P \geq 0.05$). Rohit Lal (2014) reported that this can be partially explained by C fixation into biological structures as the fallow cover crops established. Whereas Dinesh *et al*. (2004) indicated that long term studies had significant buildup of organic C. This could also be attributed to the C: N ratio of crop residues and other materials applied to the soil of the area overtime before this incorporation was introduced. Ziblim *et al*., (2013) suggested that the result shows that the increase in mean levels could be as a result of the plant residues added to the soil and therefore being the source of organic matter which might release organic C to soil. Moreover, the increase in C can be from the decomposition and mineralization process overtime, thus greater biological activity in the soil within topsoil and subsoil.

5.1.5 Effects on TOC in depth 2 before and after planting *C. calothrysus* and *M. pruriens* in the Fallow area

Planting the NFPs in the Fallow area did not affect the levels of TOC at depth 2 ($P \geq 0.05$). In sub-humid Zimbabwe, there were very few maize roots below 20 cm leaving nitrates susceptible to leaching hindering the decomposition process and minimizing the availability of C, thus minimum level of carbon availability (Whitbread, Jiri, and Maasdorp, 2004). Carsky, Becker, and Hauser (2001) suggested that C originating from *M. pruriens* is limited to the top 30 cm of the soil profile as confirmed by root counts.

5.1.6 Effects on TOC within both depths after planting *C. calothrysus* and *M. pruriens* in the Fallow area

Planting the NFPs in the fallow area did not affect TOC in the two depths ($P \geq 0.05$). This can be attributed by the C fixation into biological structures as the fallow cover crops got established (Lal, 2014). Moreover, there might have been a shortage of energy sources within this area before the NFPs were planted. However, Dinesh *et al*. (2004) indicated significant buildup of organic C and minerals layers (0-10 and 10-20 cm) of soils in long term studies. Lovett, Weathers, and Arthur (2002) suggested

that forest history has an indirect influence on C: N, thus disturbances can differ in species composition and reflects the chemical process in the soil. Generally, TOC in soil is the amount of C found in an organic compound, thus the global estimates of TOC in soil to be 2157- 2293 Pg of C for the upper 100cm (Batjes, 1996).

5.1.7 Effects of pH levels in depth 1 before and after planting *C. calothrysus* and *M. pruriens* in Fallow Area

The results showed no significance ($P \geq 0.05$) difference between the soil samples under *C. calothrysus and M. pruriens* within depth 1. Normally, the changes in pH levels are best documented by the chemical interaction occurring at the soil-root boundaries (Hinsinger *et al*., 2003). Moreover, he stated that no significance changes could be attributed by the spatial variation along the roots axes, thus hindering the changes to be detected. However, the period of this study was a one year period. This can be the major factor of not detecting the changes. Koutika, Hauser, Kamga, and Yerima (2005) suggested that pH levels could only be detected by studies done more than 5-10 years. Also he mentioned that pH levels had no significance in most tropical soil could be attributed by the decrease in organic acid functional group under cover crops but might only increase under *Calliandra* in the 0-10 cm layer. To conclude, the significance ($p \leq 0.023$) of pH levels before intervention from the two NFP (Table 7(a)) could have been attributed to the higher biomass incorporated in the soil from decomposing materials overtime, resulting in the conversion of organic element to inorganic form which increases pH levels (Ziblim *et al*., 2013).

5.1.8 Effects on pH at depth 2 before and after planting *C. calothrysus* and *M. pruriens* in the Fallow Area

The results obtained from the research showed the effects of the average values of pH levels before and after planting *C. calothrysus* (5.82) and *M. pruriens* (5.90) in Fallow area within depth 2 has no significance difference ($P \geq 0.05$). Ziblim *et al*. (2013) stated that pH largely controls plant nutrient availability and microbial reaction. Hussein (1997) reported those essential plant nutrients are available in between pH levels 5.2 – 8.8. The significant changes in the mean soil pH levels could be attributed by the by the addition by the cover crop in this research providing an additional source of cations from lowering soil depths. Followed by the release of these cations at the soil surface through leaching and decomposition activities (Clark *et al*., 1998).

5.1.9 Effects on pH within both depths before and after planting *C. calothrysus* and *M. pruriens* in the Fallow area

The result revealed insignificant ($P \geq 0.05$) difference in the levels of pH levels in planting *C. calothrysus* and *M. pruriens* within the two depths. However, the means levels of pH levels of *M. pruriens* have some significance compared to the *C. calothrysus*. This could be attributed by nutrient availability being supplied by cover crops (Clark *et al*., 1998; Ziblim *et al*., 2013). Furthermore, leaching and decomposition process activities might be the reason of the changes within (0-15cm) compared to (15-30cm) in the low input and organic treatment being applied to this set-up (Clark et al., 1998).

5.2 General status of nutrient levels before and after planting *C. calothrysus* and *M. pruriens* in the Fallow area.

The results obtained after incorporation of *C. calothrysus* and *M. pruriens* into the soil showed a significant ($p \leq 0.047$) differences between the levels of total N obtained before planting and after incorporation. The increase in the mean levels of total N in both *C. calothrysus* and *M. pruriens* could be attributed to the fact that leguminous plants could be fixing nitrogen through the formation of root nodules and can provide the required quantity of N for crop production as reported by (Mengel, Kirkby, Kosegarten, & Appel, 2001; Ziblim *et al*., 2013). Moreover, increase in total N might be the increasing in decomposition and mineralization of biomass. The effects of TOC and pH levels from *C. calothrysus* could have been resulted from differences in the amount and quality of the present soil organic matter and soil microbiological properties that have been overlap by the past substrate input (Lehmann *et al*., 1998; Salamanca, Raubuch, & Joergensen, 2002). The effects of TOC and pH levels *M. pruriens* may be contributed from leaf fall prior to hay being removed (Whitbread *et al*., 2004) and also Barthes *et al*. (2004) agrees to that the results from acceraletated mineralization of native soil carbon and slow mulch decomposition which further shows no significant change ($P \geq 0.05$) found in TOC and pH levels overall in the fallow area.

5.2.1 Status of nutrient levels before planting *C. calothrysus* and *M. pruriens* in the Talasiga area.

The results obtained before planting *C. calothrysus* and *M. pruriens* showed significance ($p \leq 0.05$) in the state of total N, TOC (Table 7 (a). However, pH levels before planting the NFP in this area showed no significance (Table 7 (a)). Generally, N fixation, recycling of nutrients, maintenance of soil structure biological control of plants and many other agricultural processes are mediated by soil microorganism (Lupwayi, Kennedy, & Chirwa, 2011). Zeinab, Mansuresh, & Jamshid, (2013) mentioned that grassland have effects on ecological process by variability of biotic and abiotic factors and interactions. Also, Scurlock and Hall suggested that Soil organic carbon (SOC) or C stocks and fluxes of grassland depend on local environment conditions such as profile characteristics, soil texture, climatic factors and grassland types. Batjes (1996) suggested that significance showed by total N and TOC in soil before planting *C. calothrysus* and *M. pruriens* in this area could be the attributed on the oxidation of superficial soil C stocks, enhancing emission of carbon dioxide. Edwards *et al*., (1999) reported that concentration of SOC generally ranges from 1% to 6% of the total topsoil mass for most upland soils in the tropics. Yara (2016) reported that from studying grassland, N is the most crucial nutrient for influencing grassland yield. From observing this demonstration plots in this Talasiga area for a period of 1 year, N mineralization is main factor in increasing the N in the soil by deposits from microorganism. This is mainly driven too by the increasing concentration of TOC in the surroundings (Batjes, 1996).

The mean average value of pH levels of this area were 6.06. This value is suggested that for permanent grassland is within an optimum of pH level 6.0 to 6.5 (Daza *et al*., 2006). This is also agreed by (Authority, 2016) that keeping the pH level above 6.0 in grassland improves N recycling and reduces total N requirements.

5.2.2 Effects on total N at depth 1 before and after planting *C. calothrysus* and *M. pruriens* in the Talasiga area

The results obtained after planting *C. calothrysus* and *M. pruriens* in Talasiga Area from Depth 1 showed significant difference ($P \geq 0.05$) between the levels of total N obtained before and after incorporation. The significance could be attributed to the N mineralization caused by the decomposition overtime from parental material in the

deeper layer in the soil. However, (Chapman *et al*., 2013) suggested that net mineralization can also vary spatially and temporally. These include the temperature, soil moisture and quality of organic matter. Also, N mineralization is main factor contributing to this site as it is burned continuously from the villagers. Effects of *M. pruriens* in this area are significant. This could be attributed to effectiveness of this leguminous cover crop enhancing N stocks within 0-15cm to a research he did in Kenya (Ngome, Becker & Mtei, 2012) stated that this. He further clarified; this can only be possible provided that soil conditions and rainfall are right.

Seresinhe and Manawadu (n.d) reported that using *C. calothrysus* in Guinea grass, nitrogen percentage and N yield increased. Moreover, this is attributed by the association of the legume crop to grassland and the abundance of the grass cover in this area thus affecting soil chemical responses overtime.

5.2.3 Effects on total N at depth 2 before and after planting *C. calothrysus* and *M. pruriens* in the Talasiga area

The incorporation of *C. calothrysus* and *M. pruriens* in the Talasiga area had statistical significances ($P \leq 0.05$) for depth 2 after using Mann-Whitney test and Wilcoxon test (Table 6). As mentioned earlier that this application of NFP are effective due to their association of the cover crop and also the decomposition and mineralization process that deposits N (Batjes, 1996; Ngome *et al*., 2012). These deposits then increase the level of N in the soil.

5.2.4 Effects on total N within both depths before and after planting *C. calothrysus* and *M. pruriens* in the Talasiga area

The results showed a significant ($P \leq 0.05$) difference in the Talasiga area within both depths after planting *C. calothrysus* and *M. pruriens*. This is mainly attributed the N mineralization, association of cover crops and legume crops in this area as mentioned earlier (Acosta, 2009). However, Zeinab, Mansureh, & Jamshid (2013) suggested that light soil texture can cause washout and transfer to a lower surface layer.

5.2.5 Effects on TOC at depth 1 before and after planting *C. calothrysus* in the Talasiga area

The results revealed no significance difference in TOC after planting *C. calothrysus* in Talasiga area within Depth 1. In this Talasiga area or grassland in general, the

presence of fire can mainly affect the carbon stocks in the soil (Silver, Ryals & Eviner, 2010). From this research, this area has been subjected to frequent vegetation fire for every 5 times a year. Moreover, the type of management done to this area could be the main factor to which the decrease of the TOC before planting this NFP.

5.2.6 Effects on TOC at depth 2 before and after planting *C. calothrysus* in the Talasiga area

The results showed there were also no significant differences in TOC at depth 2 after planting *C. calothrysus* in this area. This could also be area being subjected to continuous burning for past year, thus decreasing the TOC as also suggested by (Batjes, 1996; Silver *et al*., 2010).

5.2.7 Effects on TOC within both depths before and after planting *C. calothrysus* in Talasiga Area

The results revealed that were no significance from planting *C. calothrysus* in the two depths. This can mainly be attributed by the continuous burning that have done in this area for the past years.

5.2.8 Effects on pH at depth 1 before and after planting *C. calothrysus* in the Talasiga area

The results showed no significance ($P \geq 0.05$) difference in the levels of the pH levels in depth 1 after planting *C. Calothrysus* in this Talasiga area. This can be attributed by decomposition of organic matter by microorganism releasing CO_2, thus mixing with soil water forming carbonic acid. Moreover, pH levels can be attributed by the decrease in organic acid functional group under cover crops but might only increase under *Calliandra* in the 0-10 cm layer.

5.2.9 Effects on pH at depth 2 before and after planting *C. calothrysus* in Talasiga area

The result showed also that there was no significance in pH levels. As mentioned earlier, the contributing factor could also be higher biomass incorporated in the soil from decomposing materials overtime, resulting in the conversion of organic element to inorganic form which increases pH levels (Ziblim *et al*., 2013). Moreover, process of weathering of minerals and root activity in the lower layers causing the soil to acidify.

5.3 Effects on pH within both depths before and after planting *C. calothrysus* in the Talasiga area

From the results, it clearly showed that the average mean levels of pH levels after planting *C. Calothrysus* in both depths increased. This can be attributed to the higher biomass incorporated in the soil from decomposing materials overtime, resulting in the conversion of organic element to inorganic form which increases pH levels (Ziblim *et al*., 2013). However, there were no significance detected in both depths these could have been attributed to the weathering of minerals and the decomposition of organic matter.

5.3.1 General status of nutrient levels before and after planting *C. calothrysus* and *M. pruriens* in the Talasiga area.

From the results, total N in this Talasiga or grassland area showed significant differences after planting. This could be attributed by the N return through litter decomposition (Zeinab *et al*., 2013).

Furthermore, light soil texture could also source of washout and transfer to a lower surface layer. However, there was no significance found in TOC and pH. This can be contributed be a reflection of the parent material. Thus, the soil is subjected to high organic matter decomposition rates and the leaching action of intense rainfall (Obi, 1999). Furthermore, through denitrification, soil pH levels are and soil pH levels decrease overtime through leaching from high amounts of rainfall affected (Panpan *et al*., 2012).

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Effects on total N, TOC and pH levels at two different depths in Fallow areas having natural vegetation before and after planting *C. calothrysus* and *M. pruriens.*

The results obtained from the research showed significant effect of *C. calothrysus* and *M. pruriens* on the soil as it led to an increase in the levels of total N after incorporating the organic material into both depths in the soil. The levels of TOC and pH did not show any significant change for both depths too. However, it can be concluded that both of this NFP could be used in fallow to increase the levels of nitrogen in deficient soils.

6.2 Effects on total N, TOC and pH at two different depths in Talasiga areas having natural vegetation before and after planting *C. calothrysus* and *M. pruriens*.

The results obtained from this set-up indicated that *C. calothrysus* and *M. pruriens* could also be used to improve levels total N and TOC in Talasiga area. This is showed by the significant effects of these NFPs as it led to an increase in levels of total N and TOC. The pH levels did not have any significance in this area. However, significance was detected on the average mean levels for both depths.

6.3 Recommendation for future researchers

From this research, the following recommendations can be made:

1. To present clearer results, future research needs to analyze a greater number of samples size to strengthen the evaluation of the effectiveness of *C. calothrysus* and *M. pruriens* in the Talasiga area and Fallow areas.
2. Future researches should compare the nutrient levels before and after using *M. pruriens* in Talasiga area.
3. Research on nematodes should be conducted in during such studies to evaluate the process of degradation and mineralization of organic matter due to the trophic relations.
4. More ecological and agronomical researchers in Talasiga areas is encouraged.

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APPENDIX

Table 1 (a)

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
N_before	.212	12	.142	.865	12	.056
N_after	.236	12	.063	.860	12	.049
pH_before	.203	12	.187	.890	12	.117
pH_after	.270	12	.016	.870	12	.065
OC_before	.176	12	.200*	.932	12	.398
OC_after	.275	12	.013	.868	12	.062

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 1 (b)

N_before		*N_after*		*pH_ before*		*pH_after*	
Mean	0.256	Mean	0.323	Mean	3.588	Mean	3.5
Standard Error	0.016613248	Standard Error	0.035903	Standard error	0.97699744	Standard Error	0.95289
Median	0.23	Median	0.265	Median	5.88	Median	5.75
Mode	0.23	Mode	0.25	Mode	0	Mode	0
Standard deviation	0.052535702	Standard deviation	0.113534	Standard deviation	3.08953718	Standard deviation	3.013304
Sample	0.00276	Sample	0.01289	Sample	9.54524	Sample	9.08
Kurtosis	-0.638333783	Kurtosis	-0.02089	Kurtosis	-2.2737479	Kurtosis	-2.2748
Skewness	0.908744795	Skewness	1.053124	Skewness	-0.4806059	Skewness	-0.48174
Range	0.15	Range	0.33	Range	6.21	Range	6
Minimum	0.2	Minimum	0.22	Minimum	0	Minimum	0
Maximum	0.35	Maximum	0.55	Maximum	6.21	Maximum	6
Sum	2.56	Sum	3.23	Sum	35.88	Sum	35
Count	10	Count	10	Count	10	Count	10
Confidence Level (95.0%)	0.037581777	Confidence Level (95.0%)	0.081217	Confidence Level (95.0%)	2.21012176	Confidence Level (95.0%)	2.155588

OC_before		*OC_after*	
Mean	1.28	Mean	1.139
Standard error	0.41276	Standard error	0.442127
Median	1.25	Median	0.345
Mode	0	Mode	0
Standard d	1.305263	Standard d	1.398129
Sample	1.703711	Sample	1.954766
Kurtosis	-0.30338	Kurtosis	-0.73025
Skewness	0.621664	Skewness	0.842701
Range	3.81	Range	3.8
Minimum	0	Minimum	0
Maximum	3.81	Maximum	3.8
Sum	12.8	Sum	11.39
Count	10	Count	10
Confidence level (95.0%)	0.933729	Confidence level (95.0%)	1.000161

Table 2

	Total N before	*Total N after*	*pH before*	*pH after*	*TOC before*	*TOC after*
Mean	0.256	0.323	3.588	3.5	1.28	1.139
Standard Error	0.016613248	0.035902646	0.976997	0.95289034	0.41276036	0.442127307

Table 3

Test Statistics[a,b]

	N_after - N_before	pH_after - pH_before	TOC_after - TOC_before
Z	-1.990[c]	-1.782[d]	-.314[d]
Asymp. Sig. (2-tailed)	.047	.075	.753

a. Soil_Description = Vosa

b. Wilcoxon Signed Ranks Test

c. Based on negative ranks.

d. Based on positive ranks.

Table 4

Test Statistics[a]

	N_before	N_after	pH_before	pH_after	TOC_before	TOC_after
Mann-Whitney U	19.500	40.000	14.000	14.000	1.000	7.000
Wilcoxon W	74.500	95.000	35.000	35.000	22.000	28.000
Z	-2.318	-.761	-.645	-.668	-2.722	-1.774
Asymp. Sig. (2-tailed)	.020	.447	.519	.504	.006	.076
Exact Sig. [2*(1-tailed Sig.)]	.019[b]	.481[b]	.589[b]	.589[b]	.004[b]	.093[b]

a. Grouping Variable: Soil_Description

b. Not corrected for ties.

Table 5 (a)

Test Statistics[a]

	N_before	N_after	pH_before	pH_after	OC_before	OC_after
Mann-Whitney U	4.500	6.500	3.000	1.000	.000	1.000
Wilcoxon W	14.500	16.500	6.000	4.000	3.000	11.000
Z	-1.016	-.438	-.470	-1.476	-1.852	-1.476
Asymp. Sig. (2-tailed)	.309	.661	.639	.140	.064	.140
Exact Sig. [2*(1-tailed Sig.)]	.343[b]	.686[b]	.800[b]	.267[b]	.133[b]	.267[b]

a. Grouping Variable: Treatment_2

b. Not corrected for ties.

Table 5 (b)

Test Statistics[a]

	N_after - N_before	pH_after - pH_before	OC_after - OC_before
Z	-1.327[b]	-2.278[c]	-1.020[c]
Asymp. Sig. (2-tailed)	.184	.023	.308

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

c. Based on positive ranks.

Table 6

Test Statistics[a]

	N_before	N_after	pH_before	pH_after	OC_before	OC_after
Mann-Whitney U	.500	.000	1.000	3.000	.000	3.000
Wilcoxon W	15.500	15.000	7.000	9.000	6.000	9.000
Z	-2.522	-2.619	-1.528	-.674	-1.964	-.655
Asymp. Sig. (2-tailed)	.012	.009	.127	.500	.050	.513
Exact Sig. [2*(1-tailed Sig.)]	.008[b]	.008[b]	.200[b]	.700[b]	.100[b]	.700[b]

a. Grouping Variable: Depth

b. Not corrected for ties.

Table 7 (a)

N_before		*N_after*		*pH_ before*		*pH_after*	
Mean	0.378	Mean	0.368	Mean	3.636	Mean	3.54
Standard error	0.038029	Standard error	0.039827	Standard error	0.990697	Standard error	0.964273
Median	0.4	Median	0.37	Median	5.875	Median	5.75
Mode	0.5	Mode	0.31	Mode	0	Mode	0
Standard deviation	0.120259	Standard deviation	0.125945	Standard deviation	3.132859	Standard deviation	3.049299
Sample	0.014462	Sample	0.015862	Sample	9.814804	Sample v	9.298222
Kurtosis	-1.67263	Kurtosis	-1.79227	Kurtosis	-2.26987	Kurtosis	-2.27171
Skewness	-0.12897	Skewness	-0.13497	Skewness	-0.47598	Skewness	-0.47802
Range	0.32	Range	0.34	Range	6.36	Range	6.1
Minimum	0.22	Minimum	0.19	Minimum	0	Minimum	0
Maximum	0.54	Maximum	0.53	Maximum	6.36	Maximum	6.1
Sum	3.78	Sum	3.68	Sum	36.36	Sum	35.4
Count	10	Count	10	Count	10	Count	10

Contd..

OC_before		*OC_after*	
Mean	2.875	Mean	2.25
Standard error	0.845283	Standard error	0.804743
Median	3.375	Median	2.05
Mode	0	Mode	0
Standard deviation	2.673018	Standard deviation	2.54482
Sample variance	7.145028	Sample variance	6.476111
Kurtosis	-1.98014	Kurtosis	-0.01253
Skewness	-0.03257	Skewness	0.999891
Range	6.46	Range	7
Minimum	0	Minimum	0
Maximum	6.46	Maximum	7
Sum	28.75	Sum	22.5
Count	10	Count	10

Table 7 (b)

Soil description and plot names	**pH_ before**	**pH_after**
Talasiga-T6T2D1	6.07	6.1
Talasiga-T6T2D2	6.36	6.1
Talasiga-T15T5D1	5.84	5.9
Talasiga-T15T5D2	5.96	5.7
Talasiga-T21C7D1	5.91	5.8
Talasiga-T21C7D2	6.22	5.8
Average	**6.06**	**5.9**