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INFLUENCE OF MUCUNA *(Mucuna pruriens)* FALLOW CROP ON SELECTED SOIL PROPERTIES AND TARO YIELD IN TAVEUNI, FIJI

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DECLARATION OF ORIGINALITY

Statement by Author

Except otherwise acknowledged in the text, this thesis represents the original research of the author. The material contained herein has not been submitted, either in part or in full for any degree at this or any other university.

_______________ Date: ___/___/ 2013

(Rohit Lal)

Statement by Supervisor

I hereby confirm the declaration of originality of this work by the author, Mr. Rohit Lal (S9810050), who worked under my direct supervision.

___________________ Date: ___/___/2013

Dr. Danilo F. Guinto

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ABSTRACT

A field study was undertaken to evaluate the comparative effects of grass and mucuna fallow types over 6 and 12 months duration with additional applications of lime and rock phosphate in Taveuni, Fiji. A separate fallow trial was established to investigate the effects of 6 months grass and mucuna fallow on the yield and yield components of taro. A comparative gross margin analysis for taro grown on both the fallow types was carried out.

Mucuna fallow had significantly higher ($P<0.05$) biomass production and accumulated higher levels of N, P, K and Ca in its foliage. However, there were no significant ($P>0.05$) differences between grass and mucuna fallow on the changes in soil properties over time. Under both fallow types, as the fallow duration increased from 6 to 12 months, total soil OC, N, K, bulk density and earthworm numbers increased significantly ($P<0.05$). Furthermore, application of lime over 12 month fallow duration significantly ($P<0.05$) improved soil pH and Ca levels. Application of rock phosphate had no significant ($P>0.05$) effect on taro yield and soil phosphorus levels under both fallow types and duration.

Taro grown under mucuna fallow significantly out-yielded those grown under grass fallow system (11.8 vs. 8.8 t/ha). Overall taro grown under mucuna fallow had 33.5% higher yield than taro grown under grass fallow. Taro leaf area, plant height, leaf number and leaf length significantly differed ($P<0.05$) between the two fallow types at 120 DAP. Significant associations ($P<0.05$) were found to exist between taro yield and leaf area ($r = 0.75$), taro yield and leaf number ($r = 0.52$), and taro yield and leaf length ($r = 0.32$).

Weed suppression in taro grown under mucuna was significantly greater ($P<0.05$) than that grown under natural fallow of grass.

CHAPTER 1

INTRODUCTION

Despite taro (*Colocasia esculenta* also known as 'dalo' in Fijian and 'talo' in Samoan) being the staple diet for the Fijians for centuries, its cultivation as a highly significant export crop began only in 1993 when the taro leaf blight caused by the fungus *Phytophthora colocasiae* devastated the taro industry in the neighbouring country of Samoa (McGregor, 2011). Fiji took advantage of the situation in Samoa and was soon supplying the same variety of taro internationally.

Fiji, Tonga, Solomon Islands, Kiribati and Samoa collectively produced 125,000 tons of taro in 2007 of which only 10,000-12,000 tonnes valued at USD14 million were exported (FAO, 2012a). Fiji currently accounts for 95% of these exports and 70% are grown in the island of Taveuni (Wikipedia, 2012). Despite Fiji's ranking as the 14^{th} biggest producer of taro in the world, it is the second biggest exporter of fresh taro globally (McGregor, 2011). The main taro export destinations are Australia and New Zealand while small quantities are sent to the USA and Japan (Onwueme, 1999).

With the increase in demand for exports, the number of growers increased over the years. The traditional shifting cultivation practices changed to more intensive mono-cropping systems favouring a single variety of taro for the specialized market. The traditional slash and burn system gave way to systemic herbicide-based land clearing. In order to meet food demands and income for the growing population, fertiliser use was inevitable with limited agricultural land area (FAO, 2008a).

With the same piece of land being continuously cultivated, nutrient loss through crop harvest and topsoil erosion has led to significant yield losses (Prasad, 2000). The export industry requires taro corms to be between 1-3 kg but currently about 40% of the produce is below minimum standard.

The study undertaken by Dr. Richard Markham of ACIAR has confirmed that there is declining trend in soil fertility on the island of Taveuni (Ministry of Agriculture, 2009). Over the years inorganic fertiliser use surged, thus doubling the cost of production and narrowing farmer's profit margin. According to Tei-Tei Taveuni (2010), a prominent farmer group, the land has been farmed for more than 30 years in Taveuni, and the expensive chemical fertilisers are not improving yields. Furthermore, the costs of inorganic fertilisers have increased significantly over the last five years.

Nutrition depletion threatens food and income security of rural farmers. Declining soil fertility is a major challenge for improving yields and profit margin for poor rural farmers (Doran *et al*., 1996). Continuous intensive cultivation of land causes declining soil fertility and increases chances of soil erosion (Sullivan, 2003). Yates *et al*. (2011) confirmed that yields also decline due to weed and pest infestation.

According to Hartemink (2003), productivity of the soil can be sustained by internal (local) and external inputs. Crop production can only be sustained if nutrient removals are balanced by replenishment and when soil erosion is controlled. Since the 1940's, the common trend in addressing declining crop yields was to use chemical fertilisers (Ceballos *et al*., 2012). However, chemical fertilisers have not replaced the function of organic matter and other management practices, rather excessive use of these fertilisers created environmental pollution, including soil and water acidification, contamination of ground and surface water resources, increased emission of greenhouse gases and soil degradation (FAO, 2012b). Furthermore, chemical fertiliser costs have increased over the years which in return increases production costs (Boateng, 2005).

Previously, traditional farming practice such as fallow cropping, cover crop, crop rotation, alley cropping, mixed cropping, multiple cropping and shifting cultivation techniques were used to maintain soil fertility levels. Unfortunately, the introduction of chemical fertilisers to address rapid demand for food crops labelled these practices as inefficient and a slow way to generate soil fertility, without realising their biological benefits to the ecosystem (Ceballos *et al.*, 2012).

Under subsistence system, farmers use shifting cultivation techniques with long natural fallow periods for rejuvenating the lost nutrients but increased population pressure and demand for more agricultural production has reduced this fallow period leading to depletion of soil organic matter (Bandy *et al.*, 1993). Juo and Lal (1977) suggested that replacing natural fallow with legumes will be the most sustainable way of addressing declining yields. Legume based short duration fallow crop such as mucuna (*Mucuna pruriens*) has the potential to restore soil organic matter in a shorter span of time (Carsky *et al.*, 1998 & Sakala *et al.,* 2003). Boateng (2005) confirmed that mucuna fallow system improved the soil's physical, chemical and biological properties while also improving crop yields.

This research focused on addressing declining taro yields in Taveuni, Fiji, through the use of mucuna beans (*Mucuna pruriens)* as a fallow crop. A detailed study was done to compare the impacts of mucuna and typical grass fallow with and without lime and rock phosphate applications on selected soil properties and taro yield.

1.1 Objectives

The aim of this research is to study the effect of mucuna fallow on improving soil health and taro yield in Taveuni, Fiji.

The four objectives are:

1. To study the effect of mucuna and grass fallow type and duration with and without lime and rock phosphate treatments on selected soil properties in Taveuni, Fiji.

2. To compare the effects of 6-month mucuna and grass fallow durations with and without the application of lime and rock phosphate on taro yield.

3. To study relationships between yield components and corm yields at peak vegetative stage of the taro plant.

4. To compare the costs and benefits of the two fallow types (mucuna and grass fallow) on taro yield.

CHAPTER 2

LITERATURE REVIEW

The reviewed literature has been divided into seven subsections. The first section gives an overview of Fiji, its taro industry, and description of taro soil types. The next two sections focus on declining soil fertility and solutions to address the problem. The other two sections review fallow crops and its benefits. The use of mucuna as an improved fallow crop is discussed in the sixth section, while reported soil health indicators to measure changes in soil properties are named in the final section.

2.1 Background to Fiji

The Fiji group of islands lies in the southern hemisphere between latitudes 15 to 22 degrees south and longitudes of 174 degrees east and 17 degrees west (Wikipedia, 2011). Fiji consists of 332 islands spread across 1.3 million square kilometres of Economic Exclusive Zone and its total land mass is 18,333 square kilometres (Berdah, 2005). The two major islands are Viti Levu with 10,429 square kilometres and Vanua Levu 5,556 square kilometres. Taveuni is the third largest island in the group with 470 square km of land mass (Fiji Government Online Portal, 2009). The climate is of typical oceanic type with the southeast trade winds prevailing. The hot, wet months are from November to April. The annual rainfall of the island ranges from 2400-4500 mm (All Fiji, 2011).

2.1.1 Fiji's taro industry

Taro is Fiji's largest agricultural export after sugar (FAO, 2012a). Fiji's annual taro export for the last few years has been around 10,000 tonnes, earning about FJD 19–20 million annually with about 65% going to New Zealand and the balance to Australia and the USA (McGregor, 2011).

Taveuni accounts for 70% of Fiji's taro exports (Sun Fiji Newsroom, 2009). The variety grown in Taveuni is the same as the variety that was grown in Samoa before the taro leaf blight incidence and is called 'Tausala ni Samoa'. The taro exports increased from 3,000 tons in 1994 to 10,000 tons in 2009 (Ministry of Primary Industries, 2010). However, the island's taro exports stagnated during recent years due to declining productivity and increasing production costs (McGregor, 2011).

2.1.2 Taveuni soils

Twenty-three soil series have been surveyed and described on the island. Many of the soils have been derived from volcanic ash (Leslie, 1997). The soils are classified as Andisols (previously called Andepts), having low bulk density with the exchange complex dominated by amorphous materials. Many of the soils belong to the Hapludand or Hyperudand great groups. The soil belongs to the Andisol order because of andic soil properties (Morrison *et al.,* 1986). According to Leslie (1997), the Taveuni soils have the following properties:

a. Acid oxalate extractable aluminium is 2 % or more
b. Bulk density of the fine earth, measured in the field moist state, is less than 0.9 g/cm^3.
c. Phosphate retention is more than 85 %.

2.2 Declining soil fertility

The major factors contributing towards declining soil fertility are: insufficient usage of fertilisers, reduction in soil organic matter, and inadequate consideration of crop nutrient needs (Kumwenda *et al.,* 1997). The increase in fertiliser prices has forced farmers to limit its use (Ministry of Agriculture, 2010). In addition, continuous mono-cropping and poor husbandry practices have decreased yields and profitability margins (Silatoga, 2012).

The physical, biological, and chemical characteristics of a soil such as its organic matter content, acidity, texture, depth, and water retention capacity all influence fertility (Gruhn *et al.*, 2000). The quality of soil is essential in determining the sustainability and yield of the above ground components (Doran and Parkin, 1994). When crop residues are removed from the intensively cultivated fields, organic matter is significantly reduced leading to declining yields (Minten and Ralison, 2003). According to Lal (1997), degradation occurs when soil cannot perform one of the several principal functions:

1. Sustain biomass production and biodiversity including preservation and enhancement of the gene pool.
2. Regulate water and air quality by filtering, buffering, detoxification and regulate geochemical cycles.
3. Support socio-economic structure, culture and aesthetic values and provide engineering foundation.

Soil degradation is the loss of actual or potential productivity and utility, and it implies a decline in the soil's inherent capacity to produce economic goods and perform environmental regulatory functions (Latos, 2009). Degraded soils become either acidic or saline. Leaching of bases by percolating water causes soil acidity (Fenton, 2003). In addition, extended use of most ammonia-based fertilisers will also lower pH (Lal, 1997).

According to Hartemink (2003), some of the guidelines that can be used in assessing soil degradation are:

1. Clear signs of soil degradation that can be observed in the field. These could be erosion, slaking of the soil surface, salt accumulation at the surface or compacted and dense soil layers.
2. Trends in soil properties like declining pH, N, P, K and other nutrients.
3. Trends in crop yields.

2.3 Solutions to declining soil fertility

2.3.1 Traditional low input system

Traditionally, farmers' sustained yields and soil organic matter though shifting cultivation, prolonged fallow periods, crop rotation, mixed cropping and application of animal and green manure (Kumwenda *et al*., 1997). A study in Samoa proved that application of dadap and grass mulches at the rate of 30 t/ha can increase taro yields by 65% and 54% respectively (Weeraratna, 1990). However, the huge amount of mulch required makes it too laborious and uneconomical for the farmers to use.

2.3.2 Nutrient replenishment

Soil amendments such as inorganic fertiliser are used to maintain soil fertility (Wiliams, 2006). Smaling and Braun (1996) indicated that over application of fertilisers neither increases crop uptake nor induces higher yields; however they reduce profits and increase environmental pollution. On the other hand, under-application of fertilisers can reduce crop growth rates, reduce yields and can increase soil mining and erosion (Lal, 1997). According to Ceballos *et al*. (2012) fertilisers have not replaced the function of organic matter and other management practices, in return it has increased soil erosion and pollution problems leading to decline in land productivity and contamination of water sources.

2.3.3 Mulch-based cropping system

Mulch-based cropping system reduces soil erosion and plays an important role in rejuvenating soil quality. The principles of this system are to keep the soil permanently covered by organic matter residues (Seguy *et al.*, 2003). The mulch-based nutrient cycling resembles those observed in natural ecosystems (Scopel *et al*., 2002). Leaves and petioles from *Leucaena leucocephala, Sesbania grandiflora, Gliricidia sepium and Erythina spp.* can be used as organic mulches.

Ashgar and Tiraa (1985) concluded that application of 15 tonnes/ha (dry weight basis) of mulch from *Erythrina spp.* can significantly increase crop yields.

2.3.4 Fallow crops

The use of green manures and fallow crops to maintain soil fertility has been known since the origin of agriculture (Williams, 2006). Fallow cropping is practiced mainly to manage soil fertility, soil quality, water, weeds, pests, diseases, biodiversity and wildlife in agro-ecosystems (Lu *et al*., 2000). Several studies have shown that improved fallow crops can be valuable components of more sustainable agriculture systems (Lu *et al.,* 2000). Growing fallow crop increases carbon inputs and soil organic matter compared with bare fallow (Sainju *et al*., 2006). Improved fallow management technologies can help accelerate soil restoration and intensify crop production (Hartemink, 2003). Planted fallow if properly managed will add substantial amounts of fixed nitrogen and organic matter to the soil, recycle nutrients from the subsoil, provide effective ground cover against erosion, suppress weeds and pests, and improve soil physical condition (Latos, 2009).

2.4 Types of fallow crops

2.4.1. Non-legume traditional fallow

In the tropics farmers use slash and burn farming practice followed by long fallow periods (Ceballos *et al.*, 2012). This system was viable with low population density and subsistence farming system but with the increase in population density and demand for more food and land resources, this approach is no longer viable (Bandy *et al.*, 1993). In areas of acute land shortage, farmers cannot afford to leave their land fallow for longer periods and in such areas legumes and food crops have to be intercropped simultaneously or in relay cropping pattern (Latos, 2009). In addition, Gerold (1988) suggested that one year of legume fallow has the same impact as four years of traditional weed fallow. According to Sainju *et al.* (2002), a mixture of legumes and non-legume fallow crops would provide both C and N inputs in sufficient amounts that help to improve soil quality and productivity.

2.4.2. Improved legume-based fallow crops

Chikowo *et al.* (2004) described improved fallow practices as a system of planting with fast growing species purposely selected for their fertility enhancement properties during short duration fallow period. Leguminous cover crops for fallow management are recommended because of their biological nitrogen fixing capabilities (Fosu, 2002). To develop sustainable agriculture, planted fallow has been replaced by alley cropping or cover cropping (Tian *et al*., 1999). The natural fallow system when replaced with legume-based fallow crop enhances sustainability and reduces deforestation (Juo and Lal, 1977). Soil organic matter managed in the planted fallows would improve soil fertility for sustainable crop production (Woomer *et al.,* 1994). Soil organic matter retains nutrients and provides buffering and water holding capacities (Swift and Sanchez, 1984). Mineralisation of decomposing fallow crop provides nutrients such as N, P and K in weathered soils (Tabatabai, 1996).

2.5 Benefits of improved fallow crops

2.5.1. Soil and water conservation

The mulch from chemically or mechanically killed fallow crop in minimum-till cultivation system increases water infiltration, reduces water evaporation from the soil surface and reduces soil erosion (Latos, 2009). Soil cover reduces soil crusting and subsequent surface water runoff during rainy periods (Sullivan, 2003).

2.5.2. Pest management

Fallow crop increases biodiversity in the farm, attracting beneficial insects and natural enemies which automatically regulate pest populations (Schutter and Dick, 2002).

2.5.3. Economics of fallow crop

The most important benefit of legume fallow crops is nitrogen fertiliser savings (Hartemink, 2003). The benefits of a good legume fallow crop can offset its establishment costs and income lost while the land is fallowed (Sullivan, 2003).

2.5.4. Organic matter and soil structure

According to Latos (2009) fallow crops increase soil organic matter. Increased levels of organic matter also increase soil humus and plant nutrient availability (Buckles *et al*., 1998).

2.5.5. Nitrogen production

Prior to the invention of the Haber-Bosch process to manufacture inorganic nitrogen fertiliser from ammonia, most nitrogen supplied to the soil evolved through biological nitrogen fixation (Woomer *et al*., 1994). The amount of nitrogen released to the soil depends on the species grown, the total biomass produced, and the percentage of nitrogen in the plant tissue (Buckles *et al*., 1998).

2.5.6. Increase in soil biological activity

Microorganisms decompose organic matter from fallow crop and during this process; nutrients are released to the succeeding crop (Dalal, 1998). The microbial population in the soil rapidly increases to decompose the newly incorporated plant material (Latos, 2009). Thus, soil quality is strongly influenced by microbe-mediated processes (Angers e*t al.,* 1993).

2.5.7. Weed suppression

The mulch from fallow crop forms a dense mat on the soil surface which reduces light transmittance to the weed seeds and thus reduces its germination percentage (Teasdale, 1996). Although some weed seeds may germinate, they are unable to penetrate this dense mat and in due process they exhaust their stored energy needed for growth (Boateng, 2005). Some fallow crops have allelopathic effects on other weeds even after their death (Blackshaw *et al.,* 2005).

2.6 Some of the recommended fallow species for tropical environments

Baldwin and Creamer (2006) recommended the following legumes for short-term fallow and cover cropping:

Cowpea (*Vigna unguiculata*)

Mucuna (*Mucuna pruriens*)

Sun hemp (C*rotalaria juncea*)

Soya bean (*Glycine max*)

2.7 Mucuna as an improved fallow crop

Several authors have commended mucuna as an improved fallow crop for maintaining soil fertility (Ceballos *et al.*, 2012). Mucuna, commonly known as velvet bean or magic bean, is a vigorous annual climbing legume, which originated from southern China and eastern India (Carsky *et al.,* 1998). The plant belongs to the Fabaceae family which has about 100 species of annual and perennial legumes (Buckles, 1995). Mucuna spp. has traditionally being used as a fallow crop to restore soil fertility, a cover crop to suppress weeds, and as a forage plant. Mucuna was first reported in Bali, Java, and Sumatra in the 17^{th} century to recuperate worn-out fields (Burkill, 1966).

2.7.1 Benefits of mucuna as a fallow crop

A sole crop of mucuna bean adds about 155-200 kg/ha of nitrogen in the soil (Buckles *et al.*, 1998). Their study also confirmed that velvet bean "complex" accumulated large quantities of calcium (140 kg/ha on average, 70 % of it in the litter), potassium (100 kg/ha, 82 % in the live sub-fractions) and phosphorus (15-20 kg/ha, 45 % in the litter). In the south-eastern United States mucuna has been proven for suppression of plant-parasitic nematodes and other soil borne pathogens (Hartemink, 2003). In addition, mucuna fallow system improves soil's physical, chemical and biological properties (Boateng, 2005).

2.7.2 Mucuna life cycle and growth morphology

The plant is an annual, twining, climbing shrub with long vines which can reach over 15 m in length. The leaves are trifoliate, ovate, reverse ovate, rhombus shaped or widely ovate. The main roots grow to a depth of 2-3 m. The young leaves and seeds are known for its extreme itchiness (Ceballos *et al.,* 2012). The crop responds to shorter day lengths (photoperiodic) and flowering is stimulated by cooler night temperatures (21°C) (Duke, 1981). Most species can withstand droughts, low soil fertility and soil acidity (Hairiah *et al*., 1993).

2.7.3 Characteristics of mucuna

In a study in Ghana, Fosu *et al.* (2004) stated that dry matter yields for mucuna ranged from 5 to 15 t/ha depending on the amount of rainfall and fallow duration. In optimum conditions pod yields can reach 2 tonnes/ha (Ceballos *et al.,* 2012). Buckles *et al.* (1998) described mucuna as one of the best fallow crops based on the following characteristics:

- Very vigorous growth
- Non-palatability to cattle
- Shade tolerance

- High biomass production
- Low labour and chemical requirements for its establishment
- Easy establishment and low seed rate
- High drought tolerance
- Presence of allelopathic chemicals to enhance competitive ability against weed growth
- Tolerance to pest and diseases
- Good control against soil erosion

2.8 Soil health indicators

The quality of the soil is determined by its chemical, physical, and biological components and their interactions (Lal, 1997). However, these indicators will differ depending on the site and the level of complexity at which measurements are likely to be made (Riley, 2001). Thus, it is impractical to develop a single short list which is appropriate for all purposes. Hartemink (2003) also emphasised that a range of possible indicators should be used rather than the use of a single indicator.

2.8.1 Biological indicators

Soil biological indicators include soil organic matter, respiration rate, soil microbial biomass, earthworm count and mineralisable nitrogen (Latos, 2009). According to Feller *et al.* (2001) soil organic matter benefits plants and soils by:

- Supplying nutrients on decomposition,
- Increasing nutrient retention,
- Improving soil structure, aggregation and aeration,
- Increasing water holding capacity of the soil,
- Increasing biological activity in soil,
- Decreasing soil erosion,
- Regulating soil temperature.

2.8.2 Chemical indicators

Crop yields are directly dependent on the soil's ability to supply required nutrients in sufficient quantities (Sanchez and Swaminathan, 2005). The soil's pools of nutrients can be altered by addition of chemical fertilisers, or by the addition of organic matter in the form of mulches, compost and animal manure (Stocking, 2003). Chemical indicators such as CEC, soil pH, and extractable nutrients can be used to measure the soil's capacity to supply nutrients (Latos, 2009).

2.8.3 Physical indicators

Soil physical indicators include texture, bulk density, water infiltration rates and aggregate stability (Hillel, 1982). The ability of the soil to sustain plant growth depends on its physical properties. All these indicators change with land use practices and organic matter additions (Hartemink, 2003).

This study was based on two field trials. The first trial studied the effect of fallow duration (6 and 12 months) and type (mucuna and grass fallow) with and without soil amendments (rock phosphate and lime) on the changes in selected soil chemical, physical and biological properties. Soil chemical properties include changes in soil total organic carbon levels over time, changes in soil pH, and changes in soil nutrients such as N, P, K, Ca and Mg. The biological properties focused on the changes in the earthworm numbers over time. The physical properties focused on changes in soil bulk density over time.

The second trial compared the effect of 6 month mucuna fallow, liming and rock phosphate application on taro yield. Based on the results from this study, the relationship between growth parameters and corm yields at peak vegetative growth stages of the plant was assessed.

CHAPTER 3

MATERIALS AND METHODS

3.1 Research location and site characterisation

Two sets of trials were conducted on Lal Bahadur's field at Delaivuna, Taveuni, Fiji, approximately 20 km from government stations along the south coastal road. Table 1 shows the trial site and soil characterisation as described by Morrison *et al.* (1986). The soil belongs to the Andisol (Soil Taxonomy) or Andosol (FAO/UNESCO) soil order (Leslie, 2012). The farmer's field was identified with the assistance of Ministry of Agriculture staff, based on farmer's interest and availability of land. The field was deforested in the early 1970's and a coconut plantation was established at a spacing of 10 m x10 m. Copra derived from this field was sold at the local market. However, from 1996 the field was under intensive cultivation with taro until recently when the farmer realised that 40% of his crop was below exportable weight. The first trial (Experiment 1) evaluated the effect of mucuna and grass fallow system with soil amendments at 6 and 12 month duration on selected soil physical, chemical and biological properties. The second trial (Experiment 2) measured the effect of 6 month grass and mucuna fallow duration on the succeeding taro crop. Both the experiments were laid out in randomized complete block design with four blocks.

Table 1. Trial site characterisation

Soil series	Waiqere series
Classification	Acrudoxic Hapludand, medial, isohyperthermic (Soil Taxonomy); Humic Andosol (FAO/UNESCO)
Physiography	Flat terrace in rolling country, 155m above mean sea level
Topography	Flat site sheltered surrounded by hills
Drainage	Well drained
Current vegetation	Annual weeds under coconut plantation
Parent material	Basaltic ash
Climate	Weak dry season (June-October), annual rainfall of 4000 mm with average annual temperature of 24^{o}C

3.2 Laboratory analyses

Baseline soil samples from both the sites at the depth of 0-20 cm were collected and sent to the Koronivia Research Station for analysis of soil pH, total N, Olsen P, total organic carbon and exchangeable bases (Ca, Mg and K). Soil sample was air dried and sieved through a 2 mm sieve. The soil pH was measured 30 minutes after mixing 10 g soil with 50 ml distilled water (Daly and Wainiqolo, 1997). Total N of the sieved soil was analysed using the semi-micro Kjeldahl method (Blakemore *et al*., 1987). Total organic carbon was determined by the Walkley-Black dichromate method (Nelson and Sommers, 1982). Exchangeable bases (Ca, Mg and K) were determined from neutral 1M NH_4OAc extracts of the air dried soils (Daly and Wainiqolo, 1997). Olsen P in solution was determined colorimetrically using the Murphy and Riley (1961) method as described by Blakemore *et al*. (1987). Bulk density (physical indicator) was determined using undisturbed samples from a depth of 0-5 cm using a core sampler. Earthworm count (biological indicator) was done on the field at a depth of 0-20 cm.

3.3 Experimental design and treatments for Experiment 1 (Soil properties trial)

Experiment 1 was laid out in a split-split plot arrangement using randomized block design. The plots were randomised using GenStat (Appendix 2). Each main plot was 12 m x 18 m with 2 metres walk way between adjacent main plots. The gross experimental plot was 26 m x 78 m. The main plot treatments were fallow durations (D1 = 6-month fallow and D2 = 12-month fallow durations). Each main plot was split to accommodate 2 fallow types (F1 = Mucuna fallow and F2 = traditional grass fallow). Traditional grass fallow was achieved by leaving the land idle and allowing it to regenerate its own vegetation. Then, the split plots were further split to accommodate 3 soil amendments (T1 = Rock phosphate at 885.7 kg/ha, T2 = lime at 2.5 ton/ha, T3 = control). The treatment combinations for fallow duration, fallow type and soil amendments for this experiment are outlined in Table 2. The application rate for rock phosphate was calculated using the formula: rock phosphate required = (required nutrient rate x 100)/fertiliser nutrient analysis). According to Hartemink (2003), taro removes 91 kg/ha nitrogen, 31 kg/ha phosphorus and 215 kg/ha potassium from the soil at harvest. Fenton (2003) suggested that 2.5 tons/ha of lime would improve soil pH and crop yields in soils with low pH, thus 2.5 ton/ha of lime was applied to treatment plots. Mucuna seeds were collected from Taveuni Coconut Centre and were planted in the selected randomised plots at 0.5 m x 0.5 m spacing. All the soil amendments were applied to corresponding treatment plots 1 month after planting fallow crops.

Table 2. Treatment combinations for Experiment 1 (soil properties trials)

Treatments	Combinations
T1	6 month mucuna fallow with rock phosphate at 885.7 kg/ha
T2	6 month mucuna fallow with lime at 2.5 ton/ha
T3	6 month mucuna fallow
T4	12 month mucuna fallow with rock phosphate at 885.7 kg/ha
T5	12 month mucuna fallow with lime at 2.5 ton/ha
T6	12 month mucuna fallow
T7	6 month grass fallow with rock phosphate at 885.7 kg/ha
T8	6 month grass fallow with lime at 2.5 ton/ha
T9	6 month grass fallow
T10	12 month grass fallow with rock phosphate at 885.7 kg/ha
T11	12 month grass fallow with lime at 2.5 ton/ha
T12	12 month grass fallow

3.4 Treatments for Experiment 2 (The effect of mucuna and soil amendments on taro yield)

The second experiment was arranged in split plots using randomised complete block design (Appendix 3). The main plot treatments were F1 = 6-month mucuna fallow and F2 = 6-month grass fallow. The sub-plot treatments were T1 = rock phosphate at 885.7 kg/ha, T2 = rock phosphate at 442.9 kg/ha, T3 = lime at 2.5 tons/ha, T4 = lime at 1.25 tons/ha, T5 = combination of rock phosphate (442.9 kg/ha) and lime (1.25 ton/ha) and T6 = control (no soil amendments). The treatment combinations for this experiment and field layout are outlined in Table 3. Buckles *et al.* (1998) confirmed that velvet bean "complex" accumulated large quantities of calcium (140 kg/ha on average, 70% of it in the litter), potassium (100 kg/ha, 82% in the live sub-fractions) and phosphorus (15-20 kg/ha). Using these as a basis, the two treatments for lime and rock phosphate were selected with full and half the required rates. The randomised field layout for this experiment is outlined in Appendix 3. The treatments were randomised using Genstat Discovery Edition.

Table 3 Treatment combinations for Experiment 2

Treatments	Combinations
T1	Mucuna fallow with rock phosphate at 885.7 kg/ha
T2	Mucuna fallow with rock phosphate at 442.9 kg/ha
T3	Mucuna fallow with lime at 2.5 tons/ha
T4	Mucuna fallow with lime at 1.25 tons/ha
T5	Mucuna fallow with rock phosphate at 442.9 kg/ha and lime at 1.25 tons/ha
T6	Control-Mucuna fallow without any soil amendments
T7	Grass fallow with rock phosphate at 885.7 kg/ha
T8	Grass fallow with rock phosphate at 442.9 kg/ha
T9	Grass fallow with lime at 2.5 tons/ha
T10	Grass fallow with lime at 1.25 tons/ha
T11	Grass fallow with rock phosphate at 442.9 kg/ha and lime at 1.25 tons/ha
T12	Control- Grass fallow without any soil amendments

3.5 Husbandry practices

The mucuna fallow crop was planted at 0.5 m x 0.5 m spacing in the selected main plots and all the soil amendments were applied randomly to the split plots 1 month after planting the fallow crop. The grass fallow was established by leaving the soil idle over time.

After 6 months, the fallow crops were sprayed with 36% glyphosate (150 ml/14 L water) and Tausala Ni Samoa variety of taro (pink taro) was planted at a spacing of 1 m x 1 m. Each main plot had 36 taro plants (6 x 6) but only the inner 16 plants were used as data plants (4 x 4). The whole trial had 1944 taro plants. Weed control was done using paraquat as and when required. No other fertiliser was applied. The crop was harvested at 7 months after planting.

3.6 Data collection

3.6.1. Experiment 1

In Experiment 1, changes in selected soil properties over time were measured. Soil samples were collected at two monthly intervals and were sent to Koronivia Research Station for analysis. Samples were collected from four random spots within a split-split plot. Changes in total soil organic carbon levels, pH, N, P, K, Ca and Mg were analysed. Changes in earthworm (Plate 1a) numbers over time was used as a soil biological indicator and was measured bimonthly from each treatment plot by randomly placing a 1 m x 1 m quadrat on each plot and digging soils down to 20 cm depth within the quadrat and counting the number of earthworms. Changes in bulk density (Plate 1b) over time were used as a soil physical indicator. Undisturbed soil samples were collected bimonthly using a core sampler and the samples were oven dried at 105^0C until constant weight was obtained. Soil volume and mass were used to calculate the bulk density.

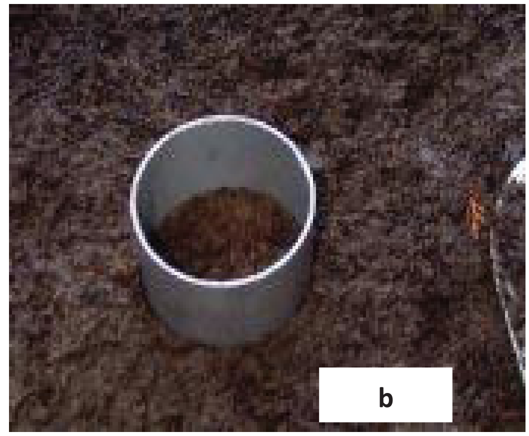


Plate 1. (a) Earthworm and (b) core sampler for measuring bulk density

3.6.2. Experiment 2

In this experiment taro growth and yield-related parameters were examined. Taro growth parameters such as leaf length, plant height, number of leaves and leaf area were measured at monthly interval. Plant height was measured as the total distance from the soil surface to the point where petiole connects to the second leaf. Leaf length was measured as the total distance from the apex of the leaf to the point where leaf connects to the leaf petiole. Leaf numbers were counted based on number of active leaf at monthly interval. Leaf area was calculated by tracing the leaf area of the second youngest leaf on graph paper and area was determined by counting the grids that intersected with the leaf. Weed numbers were counted two months after planting taro using 1 m x 1 m quadrat. Quadrats were randomly placed in each plot and weed types and numbers were counted.

Taro was harvested 7 months after planting and yields were recorded for each plant and plot (Plate 2 a, b). All costs incurred and benefits associated with taro yield were recorded for the entire trial period.

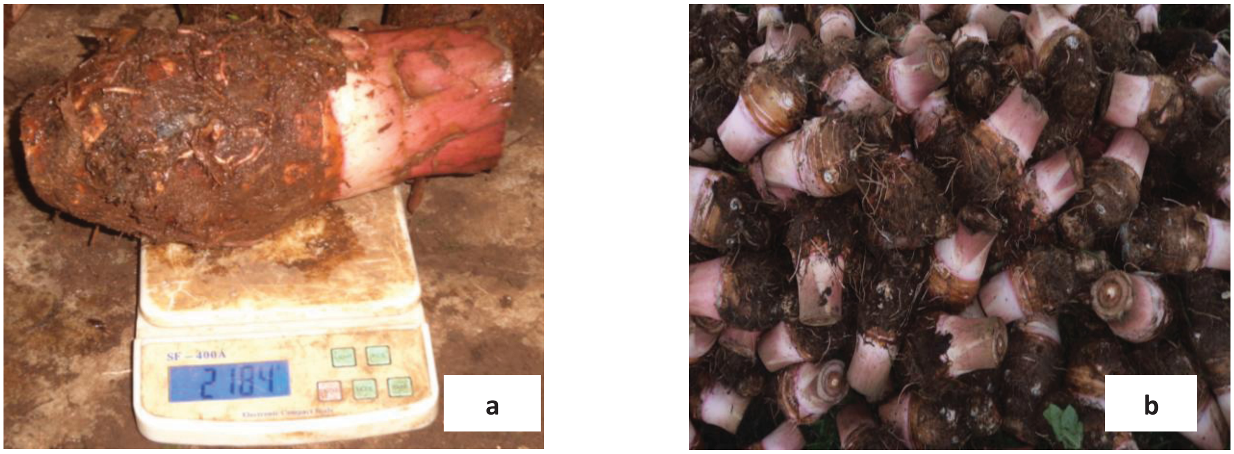


Plate 2. (a) Individual corms weighed at harvest and (b) selected marketable corms

3.7 Analysis of data

Data were analysed with Genstat Discovery Edition statistical package. Analyses of variance were performed on all parameters collected. Least significant difference (LSD at $P \leq 0.05$) was used to compare treatment means and their interactions. Simple graphs were plotted to show the changes in soil properties over time. Correlation analysis was done to determine relationships between the selected soil properties. Bivariate and multiple regression analyses were done to relate growth parameters with corm yields at peak vegetative growth period.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results for Experiment 1

4.1.1 Biomass Accumulation and Nutrient Content of Grass and Mucuna Fallows

The dry matter yield and the macro-nutrient content of the two cover crops under the 6 and 12 month fallow durations are given in Table 4a. Biomass production (dry matter basis) under mucuna fallow treatment significantly ($P<0.05$) out-yielded that of grass fallow treatment in both 6 and 12 month fallow durations (Appendices 22 and 36). As the fallow duration increased, the biomass accumulation also increased. In a study in Ghana, Fosu *et al.* (2004) stated that dry matter yields for mucuna ranged from 5 to 15 t/ha depending on the amount of rainfall and fallow duration. In separate studies Lathwell (1990) and Sanginga *et al.* (1996) reported mucuna dry matter yields of 6.7 t/ha and 7.7 t/ha respectively. Anthofer and Kroschel (2005) found that mucuna biomass after 30, 60 and 90 DAP were 163 kg/ha, 1472 kg/ha and 4003 kg/ha.

At 6 month fallow duration mucuna cover crop tissue analysis showed significantly ($P<0.05$) higher total N and P contents than the grass fallow (Appendices 42 & 43), whereas, total contents of K, Ca and Mg were significantly higher in grass biomass (Table 4a, Appendices 39-41). At 12 months fallow duration mucuna cover crop tissue analysis showed significantly ($P<0.05$) higher total N and Ca contents than the grass fallow (Appendices 25 & 26), whereas, total contents of P, K and Mg were significantly higher in grass biomass (Table 4a, Appendices 23, 24 & 27). As the fallow duration increased N accumulation also increased. Maobe *et al.* (2010) concluded mean nutrient concentration in the mucuna sample was 1.6% N, 0.36% Ca and 0.16% Mg. In addition, Boateng (2005) stated that N, P, K and Ca nutrient composition of mucuna was 1.58%, 0.27%, 1.76% and 0.38% respectively. Ngome *et al.* (2011) confirmed that N, P and K levels in mucuna biomass ranged from 3.3-4.6%, 0.32-0.34% and 0.25-0.32% respectively. Furthermore, Tian *et al.* (1992) found 6% N in mucuna vegetation. Hall *et al.* (2006) stated that N, P, K and Mg composition of traditional weed fallow was 1.7%, 0.12%, 2.78% and 0.23%, respectively.

Table 4a Amount of dry matter production versus macro-nutrient % of the grass and mucuna fallow types

Fallow Duration	Fallow Type	Dry Matter (t/ha)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
6 months	Grass fallow	5.91 *b**	0.16 *b*	0.14 *b*	1.68 *a*	0.48 *a*	0.34 *a*
	Mucuna fallow	11.92 *a*	0.28 *a*	0.20 *a*	1.36 *b*	0.37 *b*	0.19 *b*
	LSD (5%)	**0.73**	**0.02**	**0.02**	**0.15**	**0.03**	**0.04**
12 months	Grass fallow	18.08 *b*	2.10 *b*	0.32 *a*	2.00 *a*	0.71 *b*	0.46 *a*
	Mucuna fallow	31.5 *a*	2.70 *a*	0.22 *b*	1.45 *b*	1.07 *a*	0.29 *b*
	LSD (5%)	**1.69**	**0.14**	**0.02**	**0.19**	**0.15**	**0.02**

* Within a fallow duration column means followed by the same letter are not significantly different from each other at 5% significance level. The data are means from 12 Mucuna and 12 grass plots.

The macro- nutrient accumulation by the grass and the mucuna fallow types are shown in Table 4b. At both fallow durations mucuna fallow crop significantly accumulated ($P<0.05$) higher levels of N, P, K, Ca as compared to grass fallow crop (Appendices 31-34 for 6 month fallow and 42-45 for 12 month fallow). However, Mg accumulation between the two fallow crops was not significant ($P>0.05$, Appendices 35 and 46).

Buckles *et al*. (1998) reported that mucuna accumulated 300 kg N/ha in Northern Honduras. In West Africa, researchers noted mucuna contained 150-183 kg N/ha (Steinmaier and Ngoliya, 2001). Furthermore, Martini (2004) stated that nitrogen accumulation in mucuna biomass at 60 DAP, 90 DAP and 120 DAP were 170.8 kg/ha, 303.1 kg/ha and 421 kg/ha respectively. The duration of the fallow crop and time of sowing influenced the biomass production and nutrient uptake (Buckles *et al.,* 1998). The longer the crop duration, more dry matter production occurred and this was also evident in this study.

Goh and Chin (2007) and Ngome *et al.* (2011) concluded that mucuna fallow crop fixed 70% N from the atmosphere and the remaining was taken up from the soil. However, Chikowo *et al.* (2004) stated that mucuna fallow crop fixed 96% of the accumulated N. Sanginga *et al.* (2001) noted that 91% of total N was fixed by mucuna cover crop. Based on their studies it could be assumed that mucuna fixed 70-90% of total N from the atmosphere and this could be the explanation of high total N uptake in this study.

Table 4b Nutrient uptake by the grass and mucuna fallow types

Fallow Duration	**Fallow Type**	**Nutrient Uptake (kg/ha)**				
		N	**P**	**K**	**Ca**	**Mg**
6 month	Grass	44 *b* *	9 *b*	99 *b*	285 *a*	20 *b*
	Mucuna	145 *a*	23 *a*	162 *a*	144.6 *b*	23 *a*
	LSD (5%)	**10**	**3**	**15**	**4**	**3**
12 month	Grass	376 *b*	58 *b*	366 *b*	130 *b*	82 *a*
	Mucuna	836 *a*	68 *a*	465 *a*	327 *a*	90 *a*
	LSD (5%)	**57**	**7**	**55**	**38**	**8**

* Within a fallow duration column means followed by the same letter are not significantly different from each other at 5% significance level. The data are means from 12 mucuna and 12 grass plots.

4.1.2 The effect of fallow duration, fallow types and selected soil amendments on selected soil properties

The interactive response of different fallow duration, fallow types and soil amendments is given in Table 5. Significant differences ($P<0.05$) for organic C and total N were found to exist between the fallow durations; however, no significant difference was detected for fallow types and soil amendments for organic C and total N (Appendices 7 & 9). Sainju *et al.* (2007) reported that non-legume cover crop was better than legumes and N fertilisation in enhancing the level of soil organic C.

Under the 6 months fallow duration, lime application to grass fallow resulted in significant increase ($P<0.05$) in soil pH (from 5.3 to 5.6); however, the same application to mucuna did not (Table 5). This can be partially explained by the opposing reactions of acid-neutralising effect of lime and acidifying effect of organic matter mineralisation through production of organic acids. Greater biomass and subsequent greater organic matter production resulted under mucuna fallow as opposed to grass fallow. An increase in soil pH from lime application under both the fallow types is thought to have accelerated microbial activity and thus mineralisation. Higher organic matter production under mucuna fallow results in increased mineralisation and organic acid production. Consequently, the soil pH does not increase significantly. However, the opposite is true under the grass fallow, where organic matter production is comparatively lower and hence the effect of acid neutralisation by lime is more pronounced resulting in a significant increase in soil pH. Further, the carbon dioxide produced by roots and microbial respiration can dissolve in soil solution, potentially forming carbonic acid and lowering the pH. Acidification of legume rhizosphere has also been related to greater uptake rate of cations than that of anions, since they acquire nitrogen from the atmosphere through nitrogen fixation rather than by nitrate uptake (Aguilar and van Diest, 1998; Marschner and Romheld, 1983; Jarvis and Hatch, 1985). Hinsinger (1998) and Marschner (1995) associated acidification of legume rhizosphere with specific properties of legumes, which normally acidify the rhizosphere even under nitrate supplied conditions.

Under the 12 month fallow duration, both the fallow types that were applied with lime resulted in significantly ($P<0.05$) higher soil pH. However, there were no significant differences ($P>0.05$) in pH between 6 and 12 months grass fallow applied with lime treatments but both the 6 and 12 month grass fallow treated with lime had significantly ($P<0.05$) higher soil pH than the control (grass fallow). In contrast, there were significant differences ($P<0.05$) between 6 and 12 month mucuna fallow treated with lime. With mucuna fallow, as the fallow duration increased, lime became effective in increasing soil pH levels. This can be attributed to the decline in the biomass production of mucuna as well as an increase in the acid neutralising effect of lime over time.

Total soil organic carbon levels significantly increased ($P<0.05$) as the fallow duration increased from 6 to 12 months but there were no significant ($P>0.05$) differences amongst the two fallow types at both durations and additional applications of lime and rock phosphate.

Changes in Olsen available soil P over time with different fallow types, fallow duration and application of lime and rock phosphate were not significant ($P>0.05$) (Table 5).

There were significant differences ($P>0.05$) in total nitrogen levels between 6 and 12 month fallow durations across all the treatments but there were no significant differences ($P>0.05$) between the fallow types, lime and rock phosphate application. Total nitrogen levels increased with increase in fallow durations.

Exchangeable bases (Ca, Mg and K) mostly increased with the duration of the fallow from 6 to 12 months; however, they did not differ between fallow types or with additional application of soil amendments. Calcium increased with the application of lime under both the fallow durations and fallow types. Magnesium levels remained fairly constant across all the treatment combinations except under mucuna with no additional application where it was recorded to be lowest. Potassium levels significantly increased with the increase in the length of the fallow duration across all treatments but there were no significant differences amongst treatments within the two fallow durations. This can also be attributed to higher organic inputs to the soil over time.

Soil bulk density significantly increased with increasing fallow duration across all treatment combinations (Appendix 11) but there were no significant difference amongst all the treatments at the same fallow duration. This can be attributed to the soil not being mechanically manipulated over a longer period of time.

Table 5 Influence of different fallow duration, fallow type and soil amendment combinations on selected soil properties

Fallow duration	Fallow type	Soil amendment	pH (Water)	Total OC (%)	Total N (%)	C:N Ratio	Olsen P (mg/kg)	Exchangeable cation (cmol(+)/kg)			Bulk density (Mg/m^3)
								Ca	Mg	K	
Initial soil properties			**5.3**	**8.7**	**0.72**	**12.08**	**4.6**	**5.86**	**3.32**	**0.36**	**0.58**
6 Months	Mucuna	Rock Phosphate	5.3 *e**	8.20 *b*	0.68 *bc*	12.10	4.05	4.47 *c*	3.43 *ab*	0.18 *bcd*	0.57 *c*
		Lime	5.4 *de*	7.32 *b*	0.61 *c*	12.06	5.65	5.33 *abc*	2.05 *ab*	0.14 *d*	0.62 *c*
		Control	5.4 *cde*	7.47 *b*	0.62 *c*	12.11	4.95	4.18 *c*	2.00 *b*	0.16 *cd*	0.61 *c*
	Grass	Rock Phosphate	5.4 *cde*	6.90 *b*	0.57 *c*	12.11	4.72	4.55 *c*	2.65 *ab*	0.15 *d*	0.62 c
		Lime	5.6 *ab*	7.45 *b*	0.62 *c*	12.06	3.45	5.77 *abc*	3.48 *a*	0.14 *d*	0.62 *c*
		Control	5.5 *bcd*	7.40 *b*	0.61 *c*	12.08	3.05	4.95 *bc*	2.20 *ab*	0.14 *d*	0.59 *c*
12 Months	Mucuna	Rock Phosphate	5.4 *bcde*	11.07 *a*	0.92 *a*	12.11	3.50	6.10 *abc*	3.45 *ab*	0.27 *ab*	1.03 *ab*
		Lime	5.5 *abc*	11.20 *a*	0.90 *a*	12.49	4.00	6.31 *abc*	2.92 *ab*	0.25 *ab*	1.00 *ab*
		Control	5.4 *bcde*	10.27 *a*	0.87 *a*	11.82	4.50	4.06 *c*	2.63 *ab*	0.22 *abcd*	0.95 *b*
	Grass	Rock Phosphate	5.5 *bcd*	10.15 *a*	0.90 *a*	11.44	4.75	7.60 *ab*	3.51 *a*	0.29 *a*	0.98 *ab*
		Lime	5.7 *a*	10.25 *a*	0.80 *ab*	12.81	3.75	7.89 *a*	2.98 *ab*	0.24 *abc*	1.05 *a*
		Control	5.4 *cde*	10.05 *a*	0.87 *a*	11.57	3.50	5.19 *abc*	3.13 *ab*	0.27 *ab*	1.05 *a*
LSD (5%)			0.17	1.78	0.15	1.07	2.90	2.71	1.47	0.09	0.10

* Column means followed by the same letters are not significantly different from each other at 5% significance level.

4.1.3. The effect of fallow duration and type on Olsen phosphorus

The changes in Olsen available soil P under different fallow types and fallow duration at 20 cm depth are shown in Figure 1. The levels of Olsen P increased with the duration of the fallow cover crop from the initial bare fallow. However, there were no significant differences in soil P levels between fallow durations or fallow types. Hamblin (1980) reported that only small changes in phosphorus levels occur over time. Furthermore, application of rock phosphate to both the fallow types had no significant effect on the soil P levels. Phosphate rock dissolution in soils is determined by soil properties such as soil acidity, high CEC, low levels of calcium and phosphate soil solution and high organic matter content (IFA, 2013). Soils with lower pH have high rock phosphate dissolution. Secondly, crop species also determines rock phosphate dissolution and uptake (Utomo, 1995). Short term annual crops are less effective in absorbing phosphorus during the first year of application. Thirdly, management practices also determine rock phosphate dissolution (Chien & Menon, 1995). Rock phosphate should be finely ground and incorporated into the soil. The rock phosphate used in this experiment was coarse and was broadcast on the soil surface, thus solubility was low.

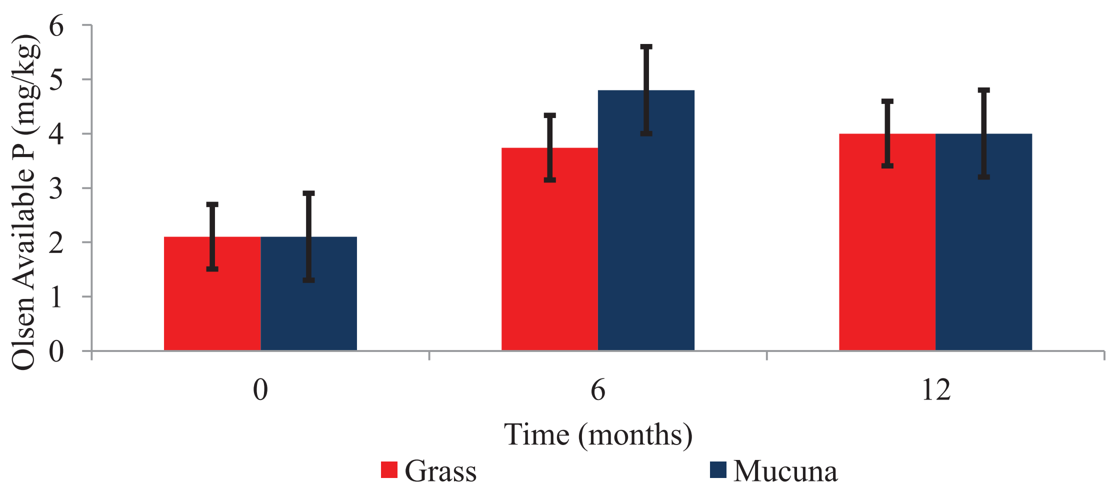


Figure 1. Effect of fallow duration and type on Olsen Phosphorus

4.1.4 The effect of fallow duration and type on total soil nitrogen

The changes in total soil N under different fallow types and fallow duration are shown in Figure 2. The levels of total soil N increased with the duration of the cover crop fallow from the initial bare fallow. There were significant differences ($P<0.05$) in soil total N levels between fallow durations (Appendix 9). This can be attributed to the greater quantity of biomass production over time under both the fallow types. Wyland *et al.* (1996) and Reganold *et al.* (1987) reported increased soil organic matter, increased N mineralisation potential and reduced nitrate leaching under diversified rotations including leguminous and non-leguminous cover crops. Dinesh *et al.* (2006) confirmed cover cropping and incorporation on a long term basis (12 years) led to significant build up of total nitrogen in both the organic (fresh litter layer and fermented humus layer) and mineral layers (0-10 and 10-20 cm) of soil. Total N levels in the organic layers and mineral layers of cover crop sites range from 1.42-2.32% and 0.23-0.49% respectively, while in the control site corresponding levels were 1.03-1.27% and 0.11-0.18%.

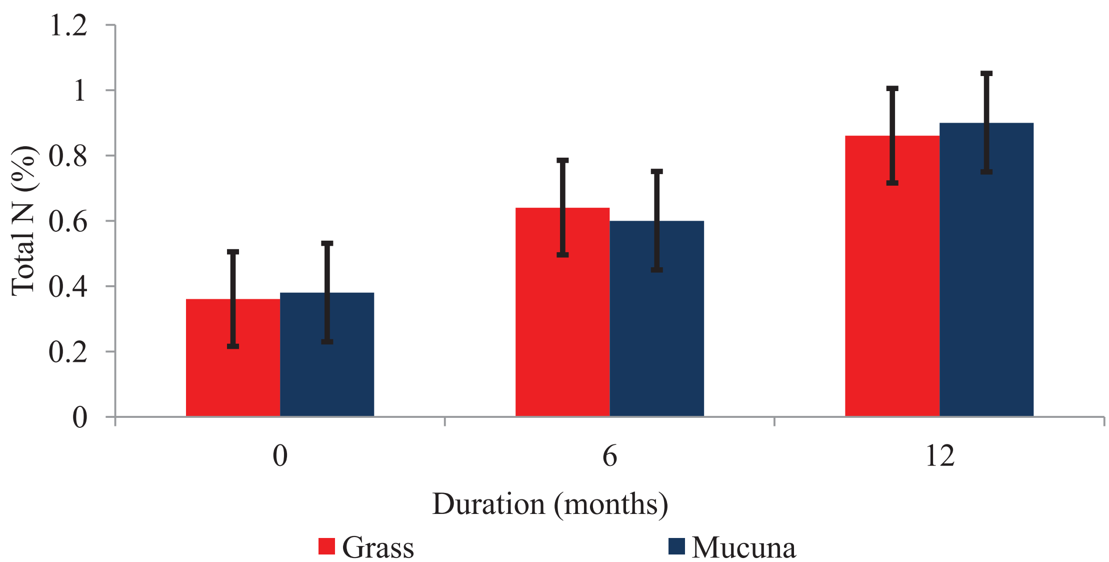


Figure 2. Effect of fallow duration on total soil N

4.1.5 The effect of fallow duration and fallow type on total soil organic carbon levels

The changes in total soil organic carbon level under different fallow types and fallow duration are shown in Figure 3. The levels of total organic C decreased slightly after 6 months of fallow duration. This can be partially explained by carbon fixation into biological structures as the fallow cover crops got established. There were significant differences ($P<0.05$) in soil total organic C levels between 6 and 12 month fallow durations (Appendix 7). This can be attributed to the greater quantity of biomass production over time under both the fallow types. Dinesh *et al.* (2006), indicated long term studies (12 years) had significant build-up of organic carbon (fresh litter layer and fermented humus layer) and mineral layers (0-10 and 10-20 cm) of soils in the interspaces of coconut plantation in India. Dinesh *et al.* (2004) concluded organic carbon levels increased by 1.9-4.6 g/kg. This was higher than the increase of 0.5-1.0 g/kg reported by Kuo *et al.,* (1997) in soils with continuous 6 year winter cover crop of cereal rye or annual rye grass. Furthermore, Latos (2009) reported significant improvements in soil carbon levels in the 0-30 cm layer in cover crop sites occurred after a 10 year fallow duration.

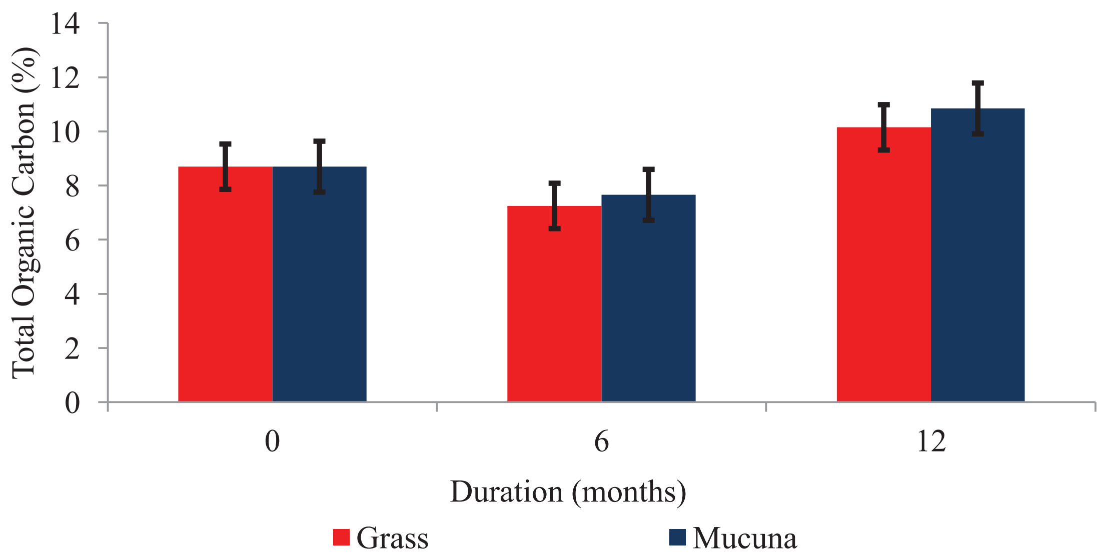


Figure 3. Effect of fallow duration and fallow type on total soil organic carbon levels

4.1.6 The effect of fallow duration on total earthworm count

Fallow crops, by providing energy and nutrients, encourage the growth and activity of an earthworm population that play a key role in transforming and liberating plant nutrients in the soil (Meelu *et al.*, 1994). The changes in total earthworm count over different fallow durations are shown in Table 6. Earthworm counts significantly increased with the length of the fallow duration across all treatment combinations ($P<0.05$, Appendix 12b). Increase in fallow duration increased cover crop biomass which might have provided suitable temperature, good moisture regime and aeration conducive to survival and breeding of earthworms (Boateng, 2005). In addition, this can partially be attributed to the increase in soil pH and bulk density (Brady and Weil, 2008).

Table 6. Effect of fallow duration on total earthworm count

Fallow Duration	Earthworm counts	
	Log10 Transformed	Back Transformed
0	1.08 *b*	12 *b*
6	1.16 *b*	18 *ab*
12	1.39 *a*	31 *a*
LSD (5%)	0.18	17

4.1.7 The relationship between selected soil properties

4.1.7.1 Effect of soil pH on earthworm count

The relationship between soil pH and earthworm counts is given in Figure 4. The positive association between soil pH and earthworm numbers ($r=0.63$) is significant ($P<0.05$). It can be concluded that as the soil pH increases, there is a significant increase in earthworm population, indicating a more biologically active soil. Earthworms are very sensitive to acid pH and prefer a soil pH of near neutral for maximum activity (Brady & Weil, 2008). In addition, studies by Jennifer *et al.* (1992) have proven that earthworms are often less abundant at lower soil pH. However, it is not known if earthworms physiologically cannot tolerate low pH or if low pH soils lack nutrient that are necessary for earthworm's survival. This was further confirmed by Raty and Huhta (2003).

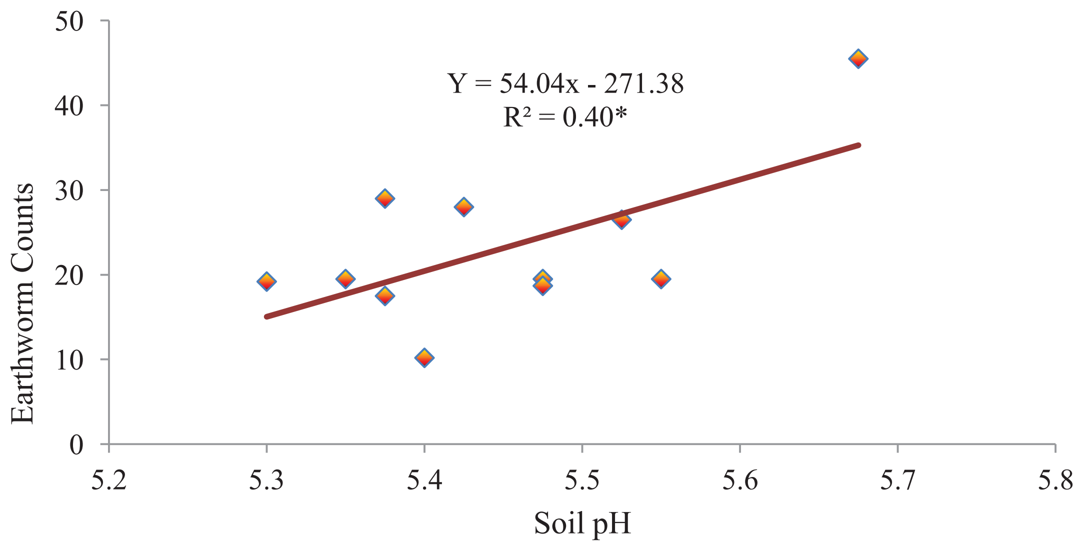


Figure 4. Effect of soil pH on earthworm counts

4.1.7.2 The relationship between soil bulk density and earthworm counts

The relationship between soil bulk density and earthworm counts is given in Figure 5. The positive association between soil bulk density and earthworm numbers (r = 0.74) is highly significant ($P<0.05$). The trial site naturally had very low bulk density. After 12 months of fallow, the mean bulk density significantly increased from 0.61 Mg/m^3 to 1.01 Mg/m^3. Increase in earthworm numbers may be due increased soil moisture and greater biomass accumulated by cover crops over a period of 12 months. Abundance of earthworm casts on the soil surface can affect soil physical properties. Brown *et al.* (2000) stated that earthworm casts deposited on the burrow walls, within the burrow, or on the soil surface, usually contain more clay and less sand particles than the surrounding soil because of selective ingestion, with this effect being more prominent in endogeic species (topsoil dwellers that form semi-permanent burrows). Earthworm casts usually have higher bulk density than the uningested soil, unless the soil is very compacted and has a high pH, contain more nutrients, and have higher levels of microbial activity (Edwards and Bohlen, 1996; Joschko *et al.,* 1989). However, Iordache and Borza (2012) reported significant inverse relationship between soil bulk density and earthworm population, but their study was based on soils with bulk densities ranging from 1.28 to 1.46 Mg/m^3. Numerous researches have been performed to establish the changes appearing in soil chemical properties as a result of earthworm activity or to emphasize the influence of some soil chemical indices on earthworms but there are fewer studies about how some physical properties of soils influence earthworm populations and their activity and vice versa (Marhan and Scheu, 2005; Iordache and Borza, 2010; Edwards *et al.,* 1995; Estevez *et al.,* 1996).

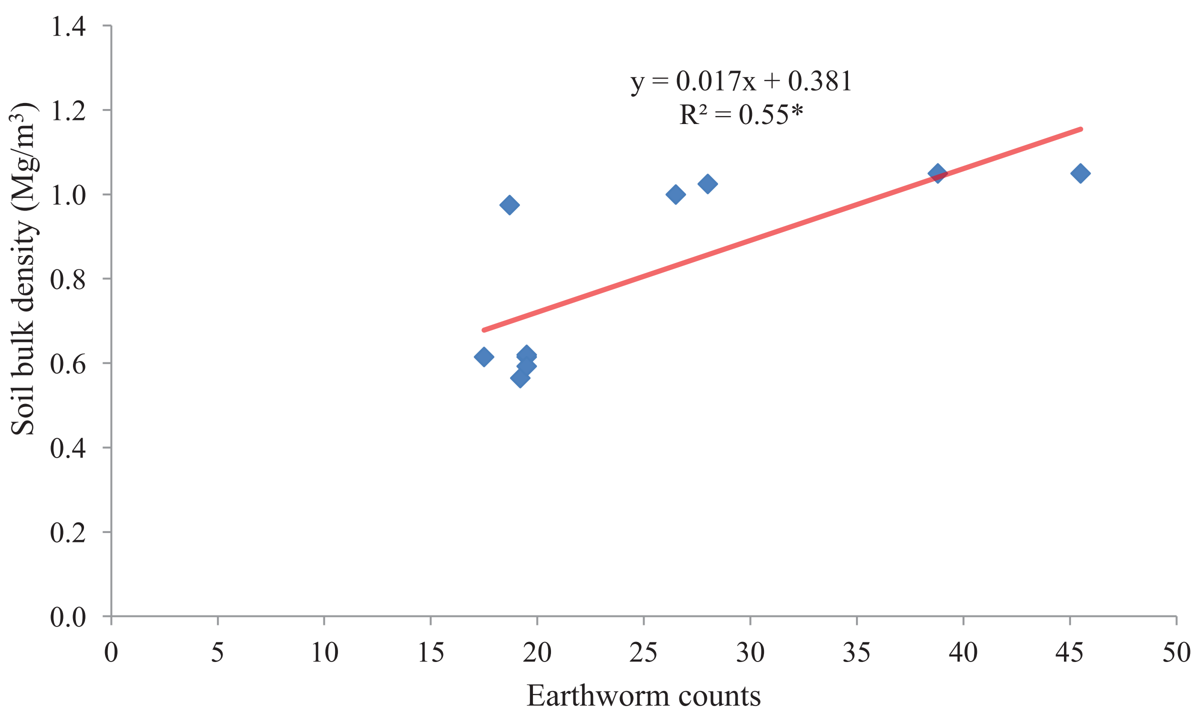


Figure 5. Relationship between earthworm counts and bulk density

4.1.7.3 The effect of soil exchangeable Ca on soil pH

The relationship between soil exchangeable Ca and pH is shown in Figure 6. The positive association between soil exchangeable Ca and soil pH (r = 0.76) is highly significant (P<0.00). With an increase in soil exchangeable Ca levels, the pH also increases. Mucuna fallow crop has deep rooting system which can mine nutrients from subsoil layers and later release it to the soil surface through its leaf litter (Hairiah *et al*., 1993). In addition the plots were applied with lime at the rate of 2.5 ton/ha which may have led to increase in soil pH. This increase in pH provides a favourable soil environment for solubility of most plant nutrient elements, earthworm activity and hence, plant growth (Simmons *et al.,* 1988).

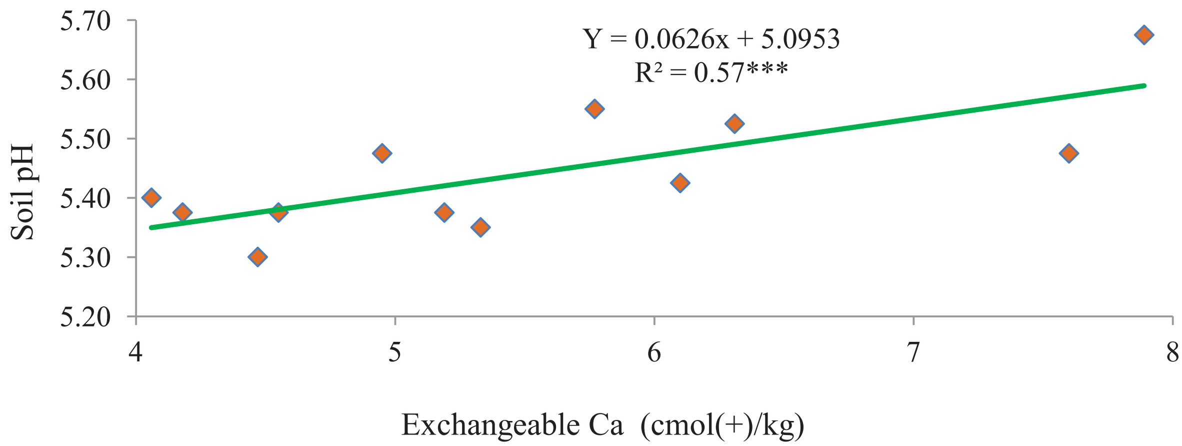


Figure 6. Relationship between soil exchangeable Ca and pH

4.1.7.4 Relationship between soil organic carbon levels and earthworm population

The relationship between soil organic carbon levels and earthworm population is shown in Figure 7. The positive association between soil organic carbon and earthworm population (r = 0.65) is highly significant (P<0.002). This can be attributed to a greater amount organic matter accumulation over time as surface mulch, which provides an abundant food source together with maintaining higher soil moisture content; conditions favouring high earthworm population (Brady and Weil, 2008; Iordache and Borza, 2012).

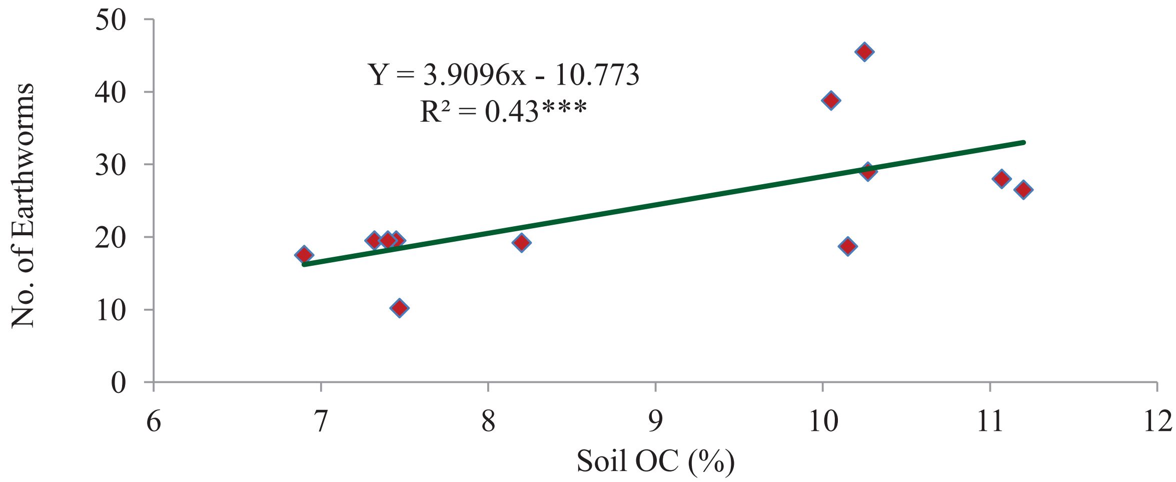


Figure 7. Relationship between soil organic carbon levels and earthworm population

4.2 Results and discussion for Experiment 2

4.2.1 Yield and Yield Components

Knowledge of physiological processes of taro growth, development and partitioning into yield components is necessary for maximising yield. The taro yield related components that contribute to growth and corm yield are leaf number, leaf length, leaf area, leaf area index, plant height and number of suckers. Yield components do not influence crop yield independently but are interrelated (Fageria *et al*., 2006; Fageria *et al*., 2007). It is important to understand the formation of yield components during the crop growth cycle and their association with corm yield and management practices that influence yield component and consequently corm yield (Fageria *et al.*, 1997). These components are easily measured in the field and contribute to yield based on their number, size and weight. Final yield of the corm cannot be measured until the crop is harvested; however, regression and correlation analysis can be used to forecast corm yields at harvest based on measurements from yield components.

4.2.2 Leaf area

The mean leaf area of taro grown over a period of 180 days, under the two fallow systems is shown in Figure 8. Mean leaf area of taro grown under mucuna fallow system was significantly greater (P<0.05), than taro grown under grass fallow system (Fig. 8). Leaf area is a valuable index for identifying taro growth and development since it is related to active photosynthesis function of the crop (Fageria *et al.*, 2006). Leaf area increased gradually after planting, reached its peak at 120 days after planting (DAP) and started to decline afterwards. Mucuna fallow type produced greater leaf area, which contributed to higher yields. Decline in the leaf area after 120 days of planting is due to decrease in the rate of leaf production, leaf number and leaf size. This can be attributed to the shift from maximum vegetative growth at around 120 days to corm development phase thereafter.

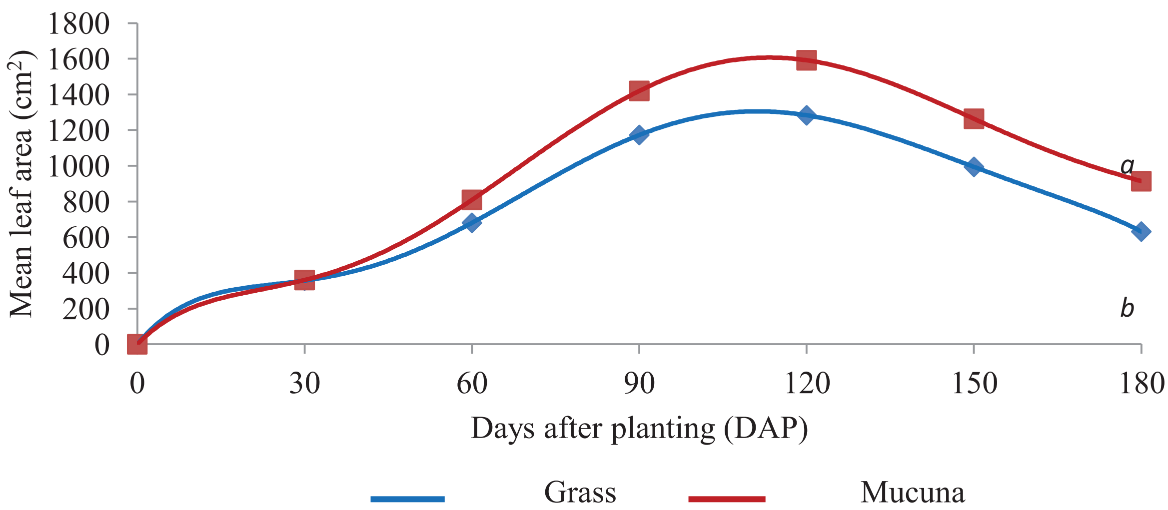


Figure 8. Mean taro leaf area grown under the two fallow systems

4.2.3 Relationship between taro leaf area and corm yield

Relationship between taro leaf area and corm yield is shown in Figure 9. The association between taro leaf area and corm yield (r = 0.75) is highly significant (P<0.05) (Fig. 9). This strong association can be attributed to photosynthetic capacity of the plant which is largely dependent on the extent of canopy cover formation. The canopy formation also largely regulates weed cover as well as evapotranspiration. Since it is a direct relationship, it can be concluded that the higher the leaf area at maximum vegetative growth stage (120 DAP), the greater the corm yield that can be expected. Leaf area at maximum vegetative growth stage (120 DAP) can soundly be used as a yardstick to predict taro yield of the variety grown under similar conditions. Reddy *et al.* (1968) also studied the relationship between corm yield and certain leaf measurements in taro and stated that total leaf area is highly correlated with corm weight.

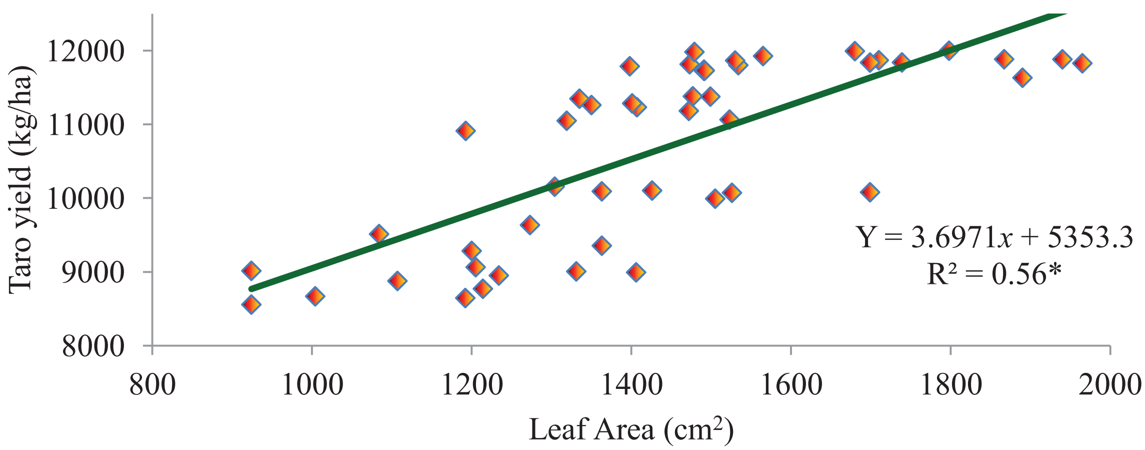


Figure 9. Relationship between taro leaf area at peak vegetative stage (120 DAP) and corm yield (180 DAP)

4.2.4 Taro plant height

Mean plant height of taro grown under mucuna fallow system was significantly greater ($P<0.05$) than taro grown under grass fallow system. The taro crop under both fallow types reached its peak at 120 DAP (Fig. 10). However, mucuna fallow type attained higher mean plant height compared to grass fallow type. Mean plant height of taro plants grown under grass fallow type declined rapidly after 120 DAP as compared to taro plants grown under mucuna fallow type.

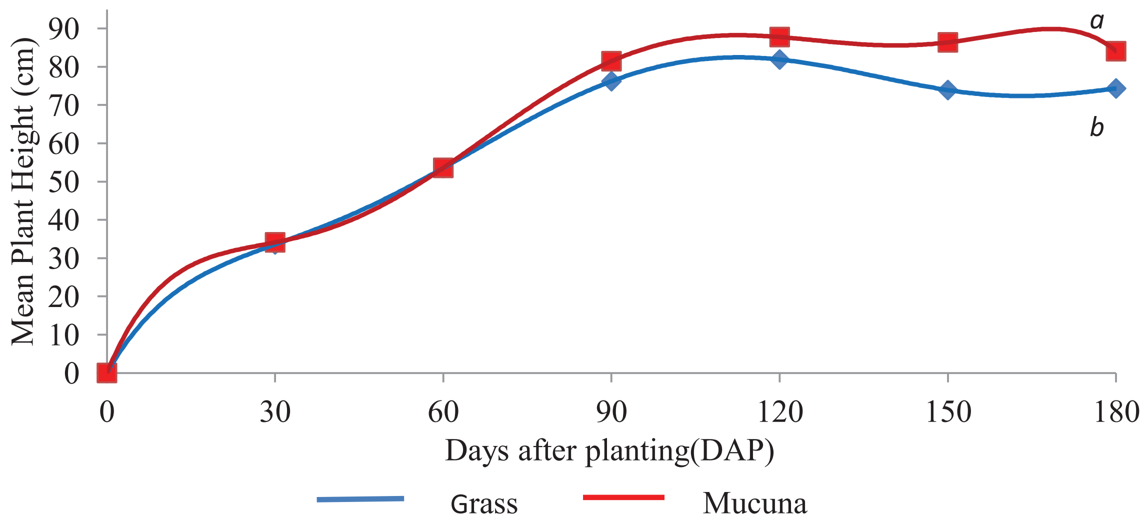


Figure 10. Mean plant height of taro grown under the two fallow systems

4.2.5 Association between taro plant height and corm yield

The association between taro plant height and corm yield (r=0.28) was only marginally significant (P=0.05) (Fig. 11). It is concluded that plant height is not a good predictor of taro corm yield. This can be attributed to the competitive advantage higher plants provide for greater sunlight interception and subsequently higher rate of photosynthesis.

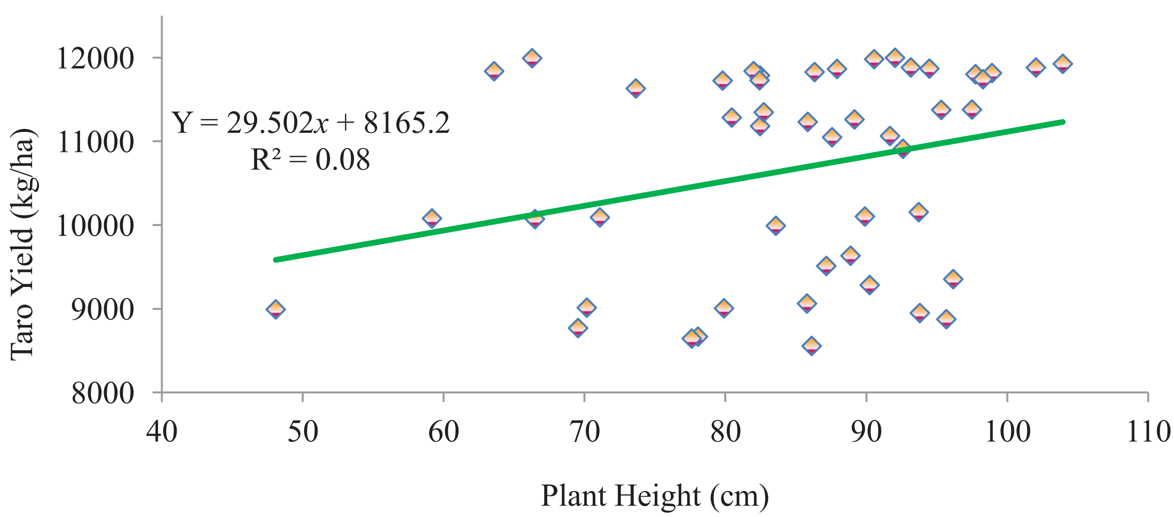


Figure 11. Relationship between taro plant height and yield

4.2.6 Taro leaf number

Mean number of leaves of taro grown under mucuna fallow system was significantly greater (P<0.05) than taro grown under grass fallow system at 120 DAP (Fig. 12). At other time periods, there were no significant differences.

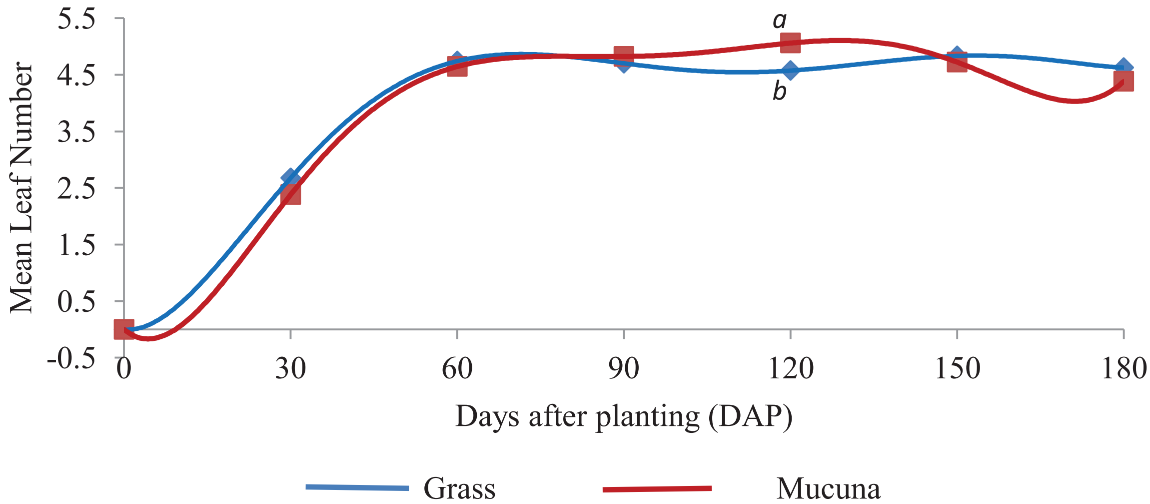


Figure 12. Mean number of taro leaves grown under the two fallow systems

4.2.7 Relationship between number of taro leaves and corm yield

The correlation between number of taro leaves and corm yield is shown in Figure 13. The positive association between number of taro leaves produced at 120 days after planting and corm yield (r = 0.52) was significant (P<0.05). This relationship can be attributed to the photosynthetic ability of the plant which is largely a function of number of leaves. Greater number of leaves also increase the effective leaf surface area. It can therefore be concluded that as the number of leaves increases, the total leaf area will also increase, increasing the degree of photosynthesis, thus resulting in higher corm yields.

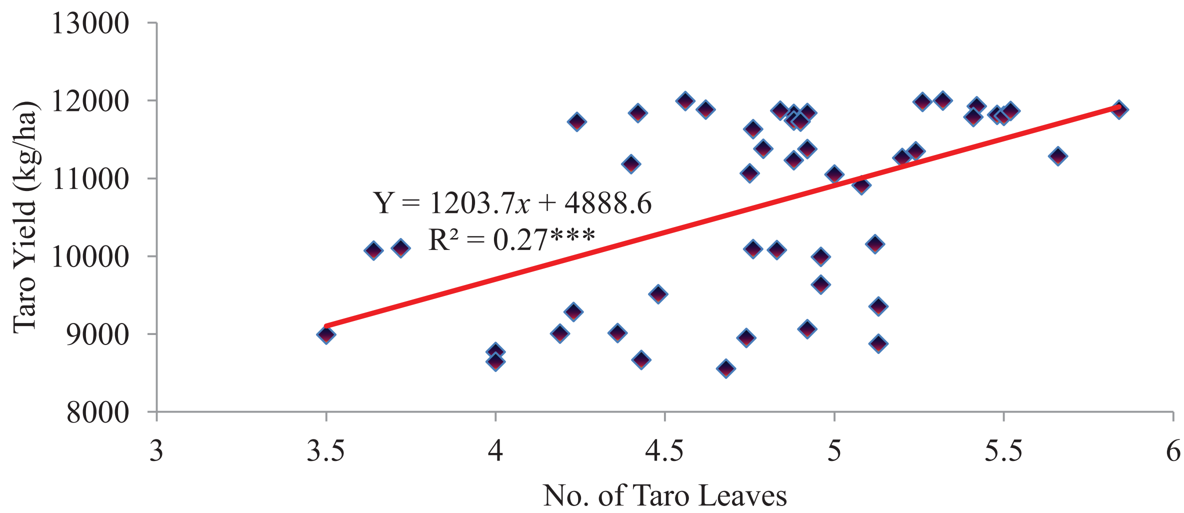


Figure 13. Relationship between taro leaf numbers and yield

4.2.8 Taro leaf length

Mean length of taro leaf grown under the two fallow systems are shown in Figure 14. Mean leaf length of taro grown under mucuna fallow system was significantly ($P<0.05$) greater than taro grown under grass fallow system at 180 DAP.

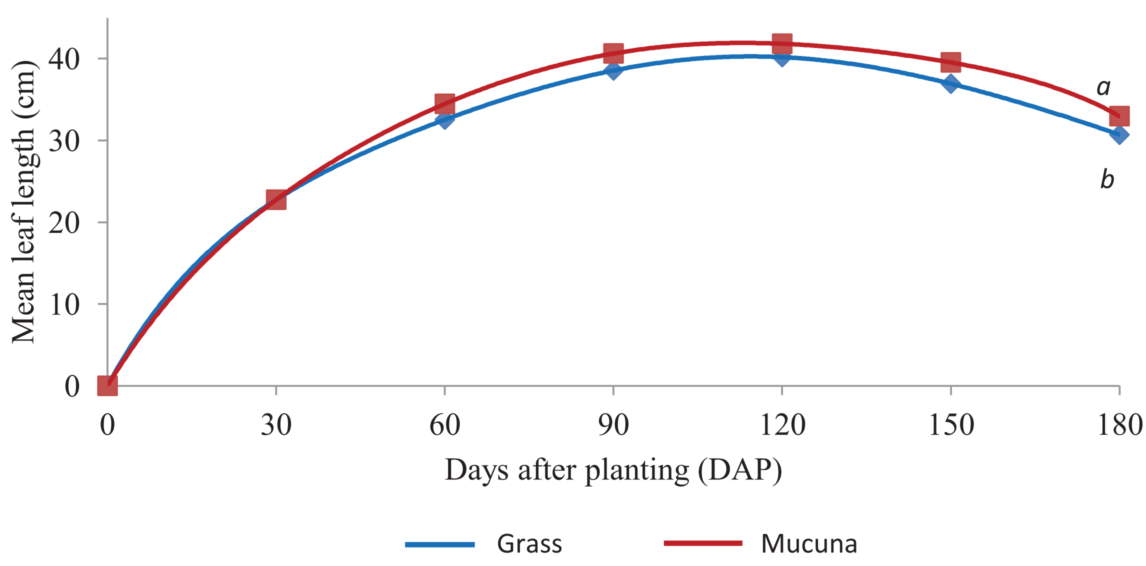


Figure 14. Mean length of taro leaf grown under the two fallow systems

4.2.9 Relationship between taro leaf length and corm yield

The relationship between taro leaf length and corm yield are shown in Figure 15. The positive association between length of taro leaves and corm yield (r = 0.32) is significant (P<0.02). It can be concluded that as the leaf length increases, the total leaf area will subsequently increase, thereby increasing the plant's capacity to photosynthesise, resulting in higher corm yields.

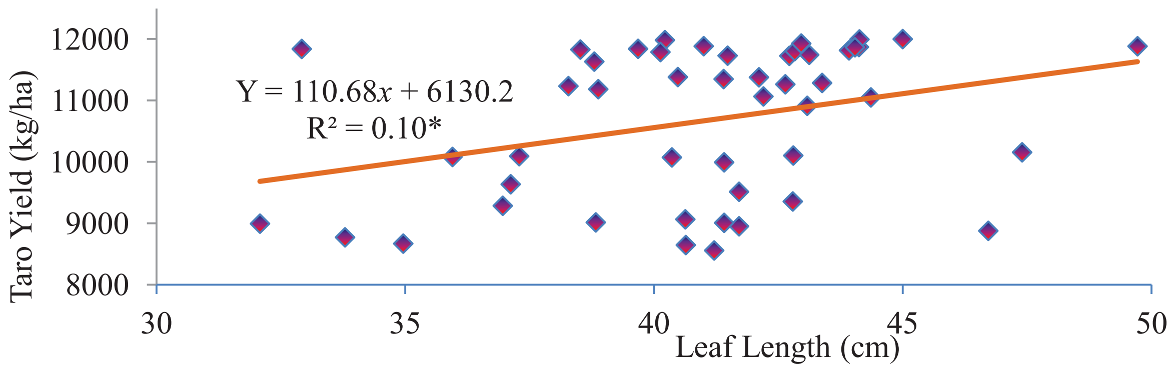


Figure 15. Relationship between taro leaf length and taro yield

4.2.10 Predicting taro corm yield using growth parameters

Multiple regression analysis revealed that there was an overall significant (P<0.05) multivariate relationship (R^2 = 65.8%; F = 23.64; Appendix 47) between the growth parameters of taro (plant height, leaf number, leaf area and leaf length) and the corm yield of taro as per the predictor linear model:

Taro yield = 1660 + 3.308 (leaf area in cm^2) + 5.6 (leaf length in cm) + 731 (leaf number) + 6.0 (plant height in cm).

However, only leaf area and leaf number components of the model have significant effects on the final taro corm yield. Hence, leaf length and plant height components were dropped. The resulting multiple linear regression model became:

Taro yield = 1938 + 3.278 (leaf area in cm) + 837 (leaf number). The model is significantly (R^2 = 67.8%; F = 48.8; Appendix 48; P<0.001) better than the first one.

4.2.11 Taro yield

Taro grown under mucuna fallow significantly out-yielded that grown under grass fallow system (Table 7). Overall, taro grown under mucuna fallow type had 33.5 % higher yield than taro grown under grass fallow type. Crop yields and N uptake following cover crops were reported to be usually greater with legume cover crops than with non-legumes or with no cover crop treatment mainly due to higher N supply by legumes (Clark *et al.,* 1994; Vaughn and Evanylo, 1998; Kuo and Jellum, 2002).

Although, the taro crop did not significantly respond to additional applications of lime and rock phosphate under mucuna, it did respond under grass fallow system. Sakala *et al*. (2003) stated that short term mucuna fallow increased maize yields significantly as compared to maize grown under natural fallow. In addition, Carsky *et al*. (1998) concluded that mucuna fallow improved the yield of succeeding crop and this was attributed to the fact that mulches from mucuna residues increase soil moisture content and has the potential to supply some essential nutrients to replenish soil fertility.

Table 7. Mean taro yield under mucuna and grass fallow types with selected soil amendments

Fallow Type	**Soil Amendment**		**Mean Yield (kg/ha)**
Mucuna	Rock Phosphate (885.7 kg/ha)		11442 *a*
	Rock Phosphate (442.9 kg/ha)		11415 *a*
	Lime (2.5 t/ha)		11806 *a*
	Lime (1.25 t/ha)		11925 *a*
	Rock Phosphate (442.9 kg/ha) + Lime (1.25 t/ha)		11858 *a*
	Control		11810 *a*
Grass	Rock Phosphate (885.7 kg/ha)		9710 *b*
	Rock Phosphate (442.9 kg/ha)		8928 c
	Lime (2.5 t/ha)		10302 *b*
	Lime (1.25 t/ha)		10097 *b*
	Rock Phosphate (442.9 kg/ha) + Lime (1.25 t/ha)		9872 *b*
	Control		8844 *c*
Least Significant Difference (5%)		Fallow type	523
		Soil Amendment	486
		Interactions	714

4.3 Weed Infestation under Mucuna and Grass Fallows

The two species of weeds observed under both the fallow types were crowsfoot (*Eleusine indica*) and tar weed (*Cuphea carthgenensis*). Crowsfoot infestation was higher (approximately 70 % of total weed count). According to Queensland Government Department of Agriculture, Fisheries & Forestry (2012) crowsfoot colonises thin open turf, particularly on worn areas with compacted soils and some populations are Glyphosate resistant. In Taveuni it was observed to be Paraquat resistant, thus making it difficult to control. Mucuna fallow system had significantly lower ($P<0.05$) weed count per quadrant, sampled 60 days after planting taro, compared with grass fallow system (Table 8). Lower weed numbers in taro production lead to savings on herbicide and labour requirements, thus reducing farmer's cost of production and increasing profit margin. A study by Coyne and Mubiru (2009) concluded that natural fallow had significantly more weed infestation than lablab fallow, but there were no significant differences between mucuna (*Mucuna pruriens)*, crotalaria (*Crotalaria juncea*) and canavalia (*Canavalia ensiformis*) fallow systems. In addition, Boateng (2005) stated that weeds were suppressed significantly under mucuna fallow as compared with grass fallow. The results of this study confirm the findings of Boateng (2005). Furthermore, Sakala *et al.* (2003) proved that mucuna fallow produced huge quantities of leaf biomass which protected the soil from direct penetration of sunlight, thus reducing weed infestation.

Table 8. Weed count per 1 m^2 quadrant under mucuna and grass fallow types

Fallow type	Mean no. of weeds
Grass	208 *a*
Mucuna	34 *b*
Least significant difference (5%)	113

4.4 Cost/benefit analysis of taro grown under the two fallow types

The comparative gross margin analysis of taro grown under mucuna and grass fallow is given in Table 9. Succeeding taro crop grown after 6 months of mucuna fallow type had 52 % higher gross margin (Table 9) compared to crops grown under grass fallow type. This was attributed to the fact that yields of succeeding taro crop grown after mucuna fallow system was significantly higher than taro grown after grass fallow system. Mucuna fallow system requires additional costs for establishment; however, weed infestation due to the thick ground cover was less in this fallow system, thus it reduced the duration and quantity of herbicide spraying.

Table 9. Cost/benefit analysis of taro grown under mucuna and grass fallow types based on 6 month fallow duration and succeeding taro crop yield

Farming Activities	**Unit costs**	**Mucuna fallow**		**Grass fallow**	
		Qty	**Costs FJD ($)**	**Qty**	**Costs FJD ($)**
Income					
Taro yield (t/ha)			11.81		8.84
Gross income ($)	$1,200/mt		$14,172		$10,613
Expenditure					
Mucuna establishment- Herbicide	$10/Litre	10	100		
Labour spraying	$2/knapsack	100	200		
Labour planting	$30/0.25 acre	4	120		
Taro establishment- Herbicide	$10/Litre	10	100	10	100
Labour	$2/Knapsack	100	200	100	200
Planting material- Suckers	$0.12/sucker	10,000	1200	10,000	1200
Planting- Contract	$0.10/sucker	10,000	1000	10,000	1000
Weed control- Labour	$2/knapsack	150	300	300	600
Herbicide	$12/litre	7.5	90	15	180
Harvesting- Contract	$60/1000 plants	10	600	10	$600
Total costs ($/ha)			$3910		$3880
Gross margin (FJD$/ha)			**$10,262**		**$6,733**

CHAPTER 5

5.0 SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

Soil fertility decline remains one of the most serious problems facing agriculture in the tropics. In many developing countries nutrient depletion already threatens food production and food shortages are again a problem. Methods for controlling soil degradation and improving productivity are well known but economic and political factors determining the acceptability of improved practices have limited their adoption.

In spite of criticisms, the ‘green revolution’ methods of greater fertiliser use with responsive crop varieties have mostly ensured that food production has kept pace with the rapid population growth of the past decades. Nevertheless, the economic problems determining the costs of importing, manufacturing and distributing fertilisers, key factors in countering soil fertility decline and ensuring yield improvement, have not been solved. Crop production cannot be sustained unless nutrient removals are balanced by replenishment, and soil erosion is controlled.

Currently, more than 95% of the human population increase is in the tropics, which puts existing agricultural systems under stress. In order to produce sufficient food and to curb land degradation, productive cropping systems need to be developed. The sustainability of cropping systems is largely affected by the judicious management of the soil chemical fertility. This has been recognised for many decades, but there is a need for hard data on soil changes and nutrient management strategies in order to improve our understanding of agricultural systems and to design sustainable cropping systems in the tropics.

Soil productivity decline, nutrient mining and sustainable land management in the Pacific has focused on low external input agriculture by subsistence farmers. With growing interest in reducing excessive synthetic chemical inputs in farming, the importance of cover crops as determinant of productivity has been recognised in many countries. Cover crops provide a lot of benefits for agricultural soil, such as supplying soil organic matter, preventing wind and water erosion, adding biologically fixed nitrogen, scavenging soil residual nutrients, suppressing weeds and breaking pest cycles. However, these benefits can be greatly improved by selecting the most suitable species and rotation. This has been the focus of this research considering the constrained economic climate under which an average farmer operates.

The comparative effects of mucuna (*Mucuna pruriens*) fallow and farmer's natural fallow (mostly grasses and creepers) was evaluated on continuously cropped taro soils. The mucuna fallow was introduced since natural fallow systems tend to take a longer time to restore soil productivity. The fallow cover crops were grown for durations of 6 and 12 months for evaluation of changes in soil properties. A separate fallow trial was established for duration of 6 months after which, a crop of taro was planted to investigate any fallow effects on the yield of taro.

Biomass production (dry matter basis) under mucuna fallow treatment significantly ($P<0.05$) out-yielded that of grass fallow treatment in both 6 and 12 month fallow durations. At both fallow durations mucuna fallow crop significantly accumulated ($P<0.05$) higher levels of plant N, P, K and Ca as compared to grass fallow crop. As the fallow duration increased, the dry matter production also increased in both the fallow systems.

Under the 6-month fallow duration, lime application to grass fallow resulted in significant increase ($P<0.05$) in soil pH (from 5.3 to 5.6); however, the same application to mucuna did not. Under the 12-month fallow duration, both the fallow types that were applied with lime resulted in significantly ($P<0.05$) higher soil pH. However, there were no significant differences ($P>0.05$) in pH between 6 and 12-month grass fallows applied with lime treatments but both the 6 and 12-month grass fallows treated with lime had significantly ($P<0.05$) higher soil pH than the control (grass fallow). In contrast, there were significant differences ($P<0.05$) between 6 and 12-month mucuna fallow treated with lime. Under the 12-month fallow duration, both the fallow types that were applied with lime resulted in significantly ($P<0.05$) higher soil pH.

Total soil organic carbon levels significantly increased ($P<0.05$) as the fallow duration increased from 6 to 12 months but there were no significant ($P>0.05$) differences amongst the two fallow types at both the durations and additional applications of lime and rock phosphate.

Changes in Olsen available soil P over time with different fallow types, fallow duration and application of lime and rock phosphate were not significant ($P>0.05$). There were significant differences ($P<0.05$) in total nitrogen levels between 6 and 12 month fallow duration across all the treatments but there were no significant differences ($P>0.05$) between the fallow types, lime and rock phosphate application. Total nitrogen levels significantly increased ($P<0.05$) with increase in fallow durations across both the fallow types.

Calcium levels significantly ($P<0.05$) increased with the application of lime under both the fallow durations and fallow types. Magnesium levels remained fairly constant across all the treatment combinations except under 6 month mucuna with no additional application of lime and rock phosphate where it was recorded to be lowest. Potassium levels significantly ($P<0.05$) increased with the increase in the length of the fallow duration across all treatments but there were no significant differences between any treatments within the 2 durations.

Soil bulk density significantly increased ($P<0.05$) with the length of the fallow duration across all treatment combinations but there were no significant difference amongst all the treatments at the same fallow duration.

Furthermore, significant associations ($P<0.05$) were found to exist between soil pH and earthworm population; bulk density and earthworm population; exchangeable calcium and soil pH; and, total organic carbon and earthworm population.

Taro grown under mucuna fallow significantly ($P<0.05$) out-yielded (11.8 t/ha) those grown under grass fallow systems (8.8 t/ha). Overall taro grown under mucuna fallow type had 33.5% higher yield than taro grown under grass fallow type. Significant differences ($P<0.05$) found in yield components of taro grown under different fallow types include taro leaf area, plant height, leaf number and leaf length. Significant associations ($P<0.05$) were found to exist between yield of taro and leaf area ($r = 0.75$), leaf number ($r = 0.52$) and leaf length ($r = 0.32$) while plant height ($r = 0.28$) only marginally correlated with yield.

The gross margin analysis of taro grown under mucuna and natural fallow systems revealed 52% higher returns from taro grown under mucuna fallow. This is mainly due to significantly greater taro yield obtained under mucuna fallow.

In addition, weed suppression in taro grown under mucuna was significantly greater ($P<0.05$) than that grown under natural fallow of grass.

5.2 Conclusion

From this study, it was evident that mucuna fallow offers benefits for sustainable crop production systems. Mucuna fallow significantly increased ($P<0.05$) taro yield, farmers' profit margin and reduced weed numbers as compared to traditional grass fallow. Mucuna fallow had significantly higher ($P<0.05$) biomass production and accumulated higher levels of N, P, K and Ca. Secondly, longer fallow duration is vital for rejuvenating heavily cultivated soil. As the fallow duration increased from 6 to 12 months, total soil organic carbon, nitrogen, potassium, bulk density and earthworm numbers increased significantly ($P<0.05$). Furthermore, application of lime over time can significantly improve soil pH and Ca levels. Taveuni soils have high acid extractable aluminium levels (2% or more) and low bulk density (less than 0.9 g/cm^3). Application of lime, mucuna fallow and longer fallow duration can sustainably overcome these problems. Application of rock phosphate had no significant ($P>0.05$) effect on taro yield and soil phosphorus levels during the research period. Rock phosphate should be finely ground and incorporated into the soil. The rock phosphate used in this experiment was coarse and was broadcast on the soil surface, thus solubility was low.

5.3 Recommendation for future researchers

Based on this study following recommendations can be made:

1. Mucuna fallow is recommended for rejuvenating excessively cultivated soils in Taveuni, Fiji. Further research should be conducted on comparing the effect of longer fallow durations (6, 12, 18 and 24 months) on changes in soil properties and taro yields. Soil

nutrients had been taken up by the mucuna fallow crop but long term trials can clearly measure the changes in soil properties. Quantifying the amount of nitrogen fixed by mucuna and its subsequent release to the crop is also an important research area.

2. Lime could be used to raise soil pH and Ca levels. Further research should be conducted on different application rates of lime, different types, availability and cost while comparing liming benefits on depleted soils. In this experiment it was observed lime remained on the top soil even after 4-5 months of its application.

3. Most of the soils in Taveuni, Fiji have low soil phosphorus (P) levels, thus trials with different forms and rates of P should be established. Current research should continue measuring the changes in P levels over time on the current trial site because it seems rock phosphate takes a longer period of time to release plant available P.

4. Earthworm counts increased with fallow duration but future research should study their biomass and species diversity rather than counts alone because these will give a true indication of earthworm-based biological activity in the soil. In addition, indications of soil health such as soil respiration rate, enzyme activity and mineralisable nitrogen will give a better indication of microbiological activities in the soil.

5. Future research on fallow crops should study the effect of fallow treatments on corm rots incidence as this may arise due to the fact that fallow crop maintains soil moisture and this may provide favourable environment for rot-causing pathogens.

6. A comparative study between mucuna and other short term annual legumes in the Pacific needs to be conducted for specific production systems.

REFERENCES

Aguilar, S.A. & Van Diest, A. 1998. How do plants roots acquire mineral nutrients? Chemical processes involved in the rhizosphere. *Advances in Agronomy,* 64:225-265.

All Fiji, 2011. Taveuni weather [Online], Available at: http://allfiji.com.au/taveuni/weather/ [Accessed June 12, 2011].

Angers, D. A., Bissonnette N, Legere A. & Samson N. 1993. Microbial and biochemical changes induced by rotation and tillage in a soil under barley production. *Canadian Journal of Soil Science,* 73:39-50.

Anthofer, J. & Kroschel, J. 2005. Above ground biomass, nutrients and persistence of an early and late maturing mucuna variety in the forest savannah zone of Ghana [Online], Available at: http://www.sciencedirect.com/science/article/pii/S0167880905001908 [Accessed June 12, 2011].

Ashgar, M. & Tira, A. 1985. Effect of plant residues on corn (*Zea mays* L.) growth. *Alafua Agricultural Bulletin,* 14 (3):13-18.

Berdah, J.T. 2005. Republic of Fiji Islands country environmental analysis [Online]. Available at: www.sprep.org/att/irc/ecopies/countries/fiji/15.pdf [Accessed Feb 13, 2012].

Bandy, D.E., Garrity, D.P. & Sanchez, P.A. 1993. The worldwide problem of slash-and-burn agriculture. *Agroforestry Today,* 5:2-6.

Baldwin, K.R. & Creamer, N.G. 2006. Cover crops for organic farms [Online]. Available at: http://www.cefs.ncsu.edu/resources/organicproductionguide/covercropsfinaljan2009.pdf [Accessed June 12, 2011].

Blackshaw R.E., Moyer J.R. & Huang H.C. 2005. Benefits of cover crops on soil health and crop management. *Recent Research Development in Soil Science* 1:15-35.

Blakemore, L.C., Searle, P.L. & Daly, B.K. 1987. Methods for chemical analysis of soils. New Zealand Soil Bureau Scientific Report 80. pp.103-122.

Boateng, S.A. 2005. *Mucuna pruriens* and its effects on some physical, chemical and biological properties of a forest Acrisol. *West African Journal of Applied Ecology,* 8(1). [Online] Available at: http://www.ajol.info/index/wajne/article/veiw/45789. [Accessed June 12, 2011].

Brady, C.N & Weil, R.R. 2008. The Nature and Properties of Soils, 16th ed., Pearson Education Inc., New Jersey.

Brown, G.G., Barois, I. & Lavelle, P. 2000. Regulation of soil organic matter dynamics and microbial activity in the drilosphere and the role of interactions with other edaphic functional domains. *European Journal of Soil Biology,* 37: 177-198.

Buckles, D. 1995. Velvet Bean: A “new” plant with history. *Economic Botany,* 49(1): 13-25.

Buckles, D., Bernard, T., & Gustaros. 1998. Cover crops in hillside agriculture-Farmer innovation in Mucuna [Online]. Available at: http://www.idrc.ca/openbooks/269-4/. [Accessed June 12, 2011].

Burkill, I.H. 1966. A dictionary of the economic products of the Malay Peninsula. Governments of Malaysia and Singapore, Kuala Lumpur, Malaysia.

Carsky, J.R., Tarawali, S.A., Becker, M., Chikoye, D., Tian, G., & Sanginga, N. 1998. Mucuna: a herbaceous cover legume with potential for multiple uses. International Institute of Tropical Agriculture, Ibadan, Nigeria. RCMD Research Monograph No. 25.

Ceballos, A.I.O., Juan, R.A.R, & Manuel, O.A. 2012. Velvet bean (Mucuna pruriens var. utilis) a cover crop as bio herbicide to preserve the environmental services of soil [Online]. Available at: http://cdn.intechopen.com/pdfs/25997/intech-velvet_bean [Accessed Feb 12, 2012].

Chien, S.H. & Menon, R.G. 1995. Factors affecting the agronomic effectiveness of rock phosphate for direct application [Online]. Available at: http://link.springer.com/article/10.1007%2FBF00748312#page-1 [Accessed Feb 12, 2012].

Chikowo, R., Mapfumo P., Nyamugafata, P. & Giller, K.E. 2004. Mineral N dynamics, leaching and nitrous oxide losses under maize following two-year improved fallows on a sandy loam soil in Zimbabwe. *Plant Soil,* 259:315-330.

Clark, A.J., Decker, A.M. & Meisinger, J.J. 1994. Seeding rate and kill date effects on hairy vetch-cereal rye cover crop mixtures for corn production. *Agronomy Journal,* 86:1065-1070.

Coyne, M.S. & Mubiru, N.D. 2009. Leguminous cover crops are more beneficial than natural fallows in minimally tilled Ugandan soils. *Agronomy Journal,* 101:644-652.

Dalal, R.C.1998. Soil microbial biomass-what the numbers really mean? *Australian Journal of Soil Science,* 38: 649-665.

Daly, B.K. & Wainiqolo, J.L. 1997. Methods of analysis for agricultural samples: soil, plant, animal feed and water. Fiji chemistry Laboratory Technical Report 03/93. pp. 122-123.

Dinesh, R., Suryanarayana, M.A., Ghosal, C.S. & Sheeja, T.E. 2004. Long-term influence of leguminous cover crop on the bio-chemical properties of a sandy clay loam Fluventic sulfaquent in a humid tropical region of India. *Soil and Tillage Research,* 77: 69-77.

Dinesh, R., Suryanarayana, M.A., Ghosal C.S., Sheeja, T.E., & Shiva, K.N. 2006. Long term effects of leguminous cover crops on bio chemical and biological properties in the organic and mineral layers of soils of a coconut plantation. *European Journal of Soil Biology,* 42: 147-157.

Doran, J.W., & Parkin, T.B. 1994. Defining and assessing soil quality. pp. 3-21. In: Doran, J.W. (Ed.), *Defining soil quality for a sustainable environment*. *SSSA Spec. Publ*. 35. SSSA, Madison, WI.

Doran, J.W., M. Sarrantonio, & Liebig, M.A. 1996. Soil health and sustainability. *Advances in Agronomy,* 56:1-54.

Doran, J.W., Coleman, D.C., Bezdicek, D.F, & Stewart, B.A. 1994. Defining soil quality for a sustainable environment. *SSSA Special Publication No*. 35, ASA, SSSA, Madison, WI.

Duke, J.A. 1981. Handbook of Legumes of World Economic Importance. Plenum Press, New York. USA.

Edwards, C. A., Bohlen, P. J., Linden, D. R. & Subler, S. 1995. Earthworms in agroecosystems. In Edwards, C. A. *et al.* (eds). Earthworm Ecology and Biogeography. Lewis, Boca Raton, Florida, pp.185-206.

Edwards, C. A. & Bohlen, P. J. 1996. Biology and Ecology of Earthworms, Chapman & Hall, London.

Estevez, B., N'Dayegamiye, A. & Coderre, D. 1996. The effect on earthworm abundance and selected soil properties after 14 years of solid cattle manure and N, P, K & Mg fertilizer application. *Canadian Journal of Soil Science,* 76:351-355.

Fageria, N.K., Baliger, V.C. & Clark, R.B. 2006. Physiology of crop production. The Haworth Press, New York.

Fageria, N.K., Baliger, V.C. & Jones, C.A. 1997. Growth and mineral nutrition of field crops. Marcel Dekker, New York.

Fageria, N.K., Baliger V.C. & Barbose F.M.P. 2007. Dry matter and grain yield, nutrient uptake and phosphorus use efficiency of lowland rice as influenced by phosphorus fertilization. *Communication in Soil Science and Plant Analysis,* 38:1289-1297.

FAO. 2008a. FAOSTAT. FAO Statistics Division [Online]. Available at: http://faostat.fao.org/site/535/DesktopDefault.aspx?PageID=535. [Accessed June 12, 2011].

FAO. 2012a. FAOSTAT. FAO Statistics Division [Online]. Available at: http://faostat.fao.org/site/339/Default.aspx. [Accessed Feb 20, 2012].

FAO. 2012b. Soil health [Online]. Available at: http://faostat.fao.org/arg/save-and-grow/en/3/index.html. [Accessed Feb 20, 2012].

Feller, C., Balesdent J., Nicolardot, B. & Cerri, C. 2001. Approaching soil organic matter pools through particle size fractionation-Examples of tropical soils. In: Lal, R., Kimble, K.M., and Follet, R.F. (Eds), *Assessment methods for soil carbon*. *Advances in Soil Science*, pp53-67.

Fenton, G. 2003. Planning on liming [Online]. Available at: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/167196/liming.pdf [Accessed Feb 20, 2012].

Fiji Government Online Portal. 2009 [Online]. Available at: http://www.fiji.gov.fj/index.php?option=com_content&view=article&id=645&Itemid=196 [Accessed Feb 20, 2012].

Fosu, M. 2002. Nitrogen accumulation and release by sunn hemp, calap, mucuna and devil beans in semi-arid Ghana. *Agricultural and Food Science Journal of Ghana,* 2:141-156.

Fosu M., Kuhne R. F. & Vlek P. L. G. (2004). Improving maize yield in the Guinea savannah zone of Ghana with leguminous cover crops and PK fertilization. *Agronomy Journal* **3**(2): 115–121.

Gerold, R. 1988. Cultivation of Marehea. In: Webber, J.J. The role of green manure for agriculture production in the tropics with special reference to *Crotalaria ochrolenca* (Marejea) [Online] Available at:

www.jarts.info/index.php/tropenlandwirt/article/download/1000/305 [Accessed November 22, 2013].

Goh, K.J. & Chin, S.B. 2007. Mucuna bracteata: A cover crop and living green manure [Online]. Available at: http://books.google.com.fj/books?id=NtbZxS2hxnAC&dq=N+FIXED+BY+MUCUNA&sitesec=reviews [Accessed June 12, 2011].

Gruhn, P., Francesco, G. & Montague, Y. 2000. Integrated Nutrient Management, soil Fertility and Sustainable Agriculture: Current Issues and Future Challenges [Online]. Available at: http://www.ifpri.org/sites/default/files/publications [Accessed June 12, 2011].

Hall, N.M., Kaya, B., Jan, D., Ute, S., Amadou, N. & Ramadjita, T. 2006. Effect of improved fallow on crop productivity, soil fertilty and climate-forcing gas emission in semi-arid conditions. *Biology & Fertility of Soils* 42:224-230.

Hamblin, A.P. 1980. Changes in aggregate stability and associated organic matter properties after direct drilling and ploughing on some Australian soils. *Australian Journal of Soil Science,* 18:27-36.

Hartemink, A.E. 2003. Soil fertility Decline in the Tropics-with case studies on plantations. Netherlands, pp 56-213.

Hillel, D. 1982. Introduction to soil physics. Academic Press, Me., San Diego, CA, USA.

Hinsinger, P. 1998. How do plants roots acquire mineral nutrients? Chemical processes involved in the rhizosphere. *Advances in Agronomy,* 64:225-265.

Huhta, V. & Raty, M. 2003. Earthworms and pH affect communities of nematodes and enchytraeids in forest soils [Online]. Available at: http://link.springer.com/article/10.1007/s00374-003-0614-5. [Accessed April 20, 2013].

International Fertilizer Industry Association (IFA). 2013. Direct application of phosphate rock [Online]. Available at: www.fertilizer.org/ifacontent/download/97688/2013 [Accessed December, 23, 2013].

Iordache, M. & Borza, I. 2010. Relation between chemical indices of soil and earthworm abundance under chemical fertilization. Plant Soil Environ. 56:401-407.

Iordache, M.I. & Borza, I. 2012. Earthworms responsible (*Oligochaeta lumbricidae)* to physical properties of soil under condition of organic fertilization. *Journal of Food, Agriculture & Environment,* 10(2): 4-7.

Jarvis, S.C. & Hatch, D.J. 1985. Rates of hydrogen efflux by nodulated legumes grown in flowering solution culture with continuous pH monitoring and adjustment. *Annals of Botany,* 55:41-51.

Jennifer, H., Heidi, L. & Jonathan, C. 1992. Earthworm preference: analyzing the effects of soil moisture, pH, and calcium levels on the distribution of *Lumbricus rubellus* [Online]. Available at: http://deepblue.lib.umich.edu/handle/2027.42/54362. [Accessed April 20, 2013].

Joschko, M., Diestel, H. & Larink, O. 1989. Assessment of earthworm burrowing efficiency in compacted soils with a combination of morphological and soil physical measurements, *Biology and Fertility of Soils,* 8:191-196.

Juo, A.S.R., & Lal, R.L. 1977. The effect of fallow and continuous cultivation on the chemical and physical properties of an Alfisol in Western Nigeria. *Plant and Soil,* 447:567-584.

Kumwenda, J.D.T., Waddingto, S., Snapp, S.S., Jones, R.B, & Blackie, M. J.1997. Soil fertility management in southern Africa: In: D. Byerlee and C.K. Eicher (Eds.), *Africa's emerging maize revolution.* Lynne Rienner Publishers, Boulder, Colorado.

Kuo, S., Sainju, U.M. & Jellum, E.J. 1997. Winter cover crop effects on soil organic carbon and carbohydrate. *Soil Science Society America Journal,* 61:145-152.

Kuo, S. & Jellum, E.J. 2002. Influence of winter cover crop and residue management on soil nitrogen availability and corn yield. *Agronomy Journal,* 94: 501-508.

Lal, R. 1997. Soil quality and sustainability. In: Lal, R., Blum, W.H., Valentin, C. & Stewart, B.A. Methods for assessment of soil degradation. CRC Press, Boca Raton, pp.17-30.

Lathwell, D. J. (1990). Legume green manures: Principles for management based on recent research. Soil Management CRSP Bulletin No. 00-01, Raleigh, North Carolina: Soil Management Collaborative Research Support Program, NCSU, pp. 30-31.

Latos, T.H. 2009. Cover crops and crop yields. Nova Science Publisher, Inc, New York, pp.59-100.

Leslie, D.M. 1997. An introduction to the soils of Fiji, Ministry of Agriculture, Fisheries and ALTA, Fiji. pp 17-50.

Leslie, D.M. 2012. A reference manual for utilising and managing the soil resources of Fiji. Secretariat of the Pacific Community, Nabua, Fiji.

Lu, Y.C., Watkins, B., Teasdale, J.R. & Abdul–Bhaki, A.A. 2000. Cover crops in sustainable food production. *Food Reviews International,* 16:121-157.

Maobe, S.N., Mburu, M.W.K., Akundabweni, L.S.M., Ndufa, J.K., Mureithi, J.G., Gachene, C.K.K., Makini, F.W. & Okello, J.J. 2010. Residual effect of *Macuna pruriens* green manure application rate on maize grain yield. *World Journal of Agricultural Sciences,* 6(6):720-727.

Marhan, S. & Scheu, S. 2005. Effects of sand and litter availability on organic matter decomposition in soil and casts of *Lumbricus terrestris L. Geoderma,* 128(1-2): 155-166.

Marschner, H. 1995. Mineral nutrition of higher plants. Academic Press, New York.

Marschner, H. & Romheld, V. 1983. In vivo measurement of root-induced pH changes at soil-root interface effect of plant species and nitrogen source. *ZPflanzenphysiol.* 111: 241-251.

Martini, N.L. 2004. Georgia velvet bean (*Mucuna Pruriens*) and sun hemp (*Crotalaria Juncea*): Biomass accumulation and nutrient content study [Online]. Available at: http://www.atheneum.libs.uga.edu/bitstream/.../martininicole_1_200405_ms.pdf [Accessed June 12, 2011].

McGregor, A. 2011. Pacific island taro market excess scoping study [Online]. Available at: http://www.archives.pireport.org/archive2011/1pril/market_access_study_taro_march_2011[p1].pdf [Accessed June 12, 2011].

Meelu, O.P., Singh, Y. & Singh, B. 1994. Green manuring for soil productivity improvement. *World Soil Resource Report,* Rome: FAO, 123pp.

Minten, B. & Ralison, E. 2003. Economic Analysis-Part II: Summary of analytical findings*,* Final report. FOFIFA/INSTAT, Cornell University, pp.27.

Ministry of Agriculture. 2009. Statement on soil fertility decline in Taveuni, *press release ministry of information* [Online]. Available at: http://www.fijisun.com.fj/mainpage/veiw.asp?id=33539 [Accessed June 12, 2011].

Ministry of Primary Industries. 2010. Taveuni extension annual report. MPI, Fiji.

Morrison, R.J., Ravindra, N., Regina, P. & Seru, V.B. 1986. Classification of some reference soils from Taveuni, Fiji, Institute of Natural Resources, USP.

Murphy, J. & Riley, J.P. 1962. A modified single solution method for determination of phosphate in natural waters. *Analytica Chimica Acta,* 27: 31-36.

Nelson, D.W. & Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. In: Methods of soil analysis (part 2), (Eds. Page A.L., Miller, R.H. & Keeney, D.R.) Agronomy Publication #9. American Society of Agronomy, Madison, Wisconsin. pp 539-577.

Ngome, A.F.E., Becker, M. & Mtei, K.M. 2011. Leguminous cover crops differentially affect maize yields in three contrasting soil types of Kakamega, Western Kenya. *Journal of Agriculture & Rural Development in the Tropics and Subtropics,* 112(1): 1-10.

Onwueme, I. 1999. Taro cultivation in Asia and the Pacific, FAO, Bangkok, Thailand.

Prasad, A. 2000. Sustainable land resources management for plant nutrition management in Fiji [Online]. Available at: http://www.fao.org/docrep/010/ag120e/AG120E20.htm [Accessed Feb 12, 2012].

Queensland Government Department of Agriculture, Fisheries & Forestry. 2012. Crowsfoot grass in lawns [Online]. Available at: http://www.daff.gov.au/26_21324.htm [Accessed Feb 12, 2012].

Raty, M. & Huhta, V. 2003. Earthworms and pH affect communities of nematodes and enchytraeids in forest soils [Online]. Available at: http://link.springer.com/article/10.1007/s00374-003-0614-5 [Accessed April 20, 2013].

Reddy, V. B., Meredith, W.F. and Brown, B.T. 1968. A note on the relationship between corm yield and certain leaf measurements in taro [Colocasia esculenta (L.) Schott]. *Tropical Agriculture*, 45:243-245.

Reganold, J.P., Elliot, L.F. & Unger, Y.L. 1987. Long term effects of organic and conventional farming on soil erosion. *Nature,* 330: 370-372.

Riley, J. 2001. The indicator explosion: local needs and international challenges. *Agriculture, Ecosystems, and Environment,* 87: 119-120.

Sainju, U.M., Schomberg, H.H., Singh, B.P., Whiteherd, W.F., Tillman, P.G. & Lachnicht-Weyers, S.L. 2007. Cover crop effect on soil carbon fractions under conservation tillage cotton. *Soil & Tillage Research,* 96:205-218.

Sainju, U.M., Singh, B.P., Whitehead, W.F., & Wang, S. 2006. Carbon supply and storage in tilled and non-tilled soils as influenced by cover crops and nitrogen fertilization. *Journal of Environmental Quality,* 35:1507-1517.

Sainju, U.M., Singh, B.P. & Whitehead, W.F. 2002. Long term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. *Soil & Tillage Research,* 63:167-179.

Sakala, W.D., Saka, A.R. & Kayira, D. 2003. The effect of mucuna-maize rotations and short term improved fallows on soil fertility and maize yields under smallholder farms in Malawi. *Malawi Journal of Agriculture Science,* 2(1):34-40.

Sanchez, P.A. & Swaminathan, M.S. 2005. Hunger in Africa: the link between unhealthy people and unhealthy soils. *The Lancet*, 365: 442-444.

Sanginga, N., Ibewiro, B., Houngnandan P., Vanlauwe, B., Okogum, J.A., Akobundu, I.O. & Versteeg, M. 1996. Evaluation of symbiotic properties and nitrogen contribution of mucuna to maize grown in the derived savanna of West Africa. *Plant and Soil,* 179(1): 119-129.

Sanginga, A., Houngnandan, P., Okogun, N., Vanlauwe, B., Merckx, R. & Van Cleemput, O. 2001. Assessment of soil factors limiting growth and establishment of velvetbean in farmers' fields in the derived savanna of the Benin Republic. *Biology and Fertility of Soils* 33:416-422.

Schutter, M.E. & Dick, R.P. 2002. Microbial community profiles and activities among aggregates of winter fallow and cover-cropped soil. *Soil Science Society of America Journal*, 66:142-153.

Scopel, E., Findeling, A. & Chavez, G.E. 2002. The impact of direct sowing mulch based cropping systems on soil erosion and C stocks in semi-arid zones of western Mexico. In: *Land use, Erosion, Carbon Sequestration International Meeting Proceedings,* Montpellier, France, 23-28 September.

Seguy, L., Bouzinac, S., Scopel, E. & Ribeiro, F. 2003. New concept for sustainable management of cultivated soils through direct seeding mulch based cropping systems: the CIRAD experience, partnership and networks. *II World congress on conservation agriculture.* Foz de Igacu, Brasil, CAAPAS.

Silatoga, S. 2012. Soil risks on Garden Island. *Fiji Times* [Online]. Available at: http://www.fijitimes.com/print.aspx?id=194018. [Accessed Feb 24, 2012].

Simmons, K.E., Kelling, K.A., Wolkowski, R.P. & Kelman, A. 1988. Effect of calcium source and application method on potato yield and cation composition. *Agronomy Journal, 80:13-21.*

Smaling, E.M.A. & Braun, A.R. 1996. Soil fertility research in Sub Saharan Africa: In: Mubiru, D.N. & Coyne, M.S. Legume cover crops are more beneficial than natural fallows in minimally tilled Ugandan soils. *Agronomy Journal,* 101:644-652.

Steinmaier, N. & A. Ngoliya. 2001. Potential of Pasture Legumes in Low-external-input and Sustainable Agriculture (LEISA) - Results from Green Manure Research in Luapula Province. *Zambia Experimental Agriculture,* 37:297-307.

Stocking, M.A. 2003. Tropical soils and food security: The next 50 years. *Soil Science,* 302, 1356-1359.

Sullivan, P. 2003. Overview of cover crops and green manure [Online]. Available at: http://attra.org/attra-pub/covercrop.html [Accessed June 12, 2011].

Sun Fiji Newsroom. 2009. Taveuni dalo farming a prospective business [Online]. Available at http://www.fijisun.com.fj/main_page/view.asp?id=31911[Accessed Feb 20, 2012].

Swift, M.J. & Sanchez, P.A. 1984. Biological management of tropical soil fertility for sustainable productivity. *Nature and Resources,* 20:1-10.

Tabatabai, M.A. 1996. Soil organic matter testing: An overview. In: Magdoff F.R., Tabatabai M.A., Hanlon E.A. (Eds.), S*oil organic matter analysis and Interpretation.* SSSA, Madison, pp.1-9.

Teasdale, J.R. 1996. Contribution of cover crops to weed management in sustainable agricultural system. *Journal of Production Agriculture,* 9:475-479.

Tei-Tei Taveuni. 2010. Teitei Taveuni [Online]. Available at: http://teiteitaveuni.com/home/8-tei- tei-taveuni-to-facelift-taveuni [Accessed June 12, 2011].

Tian, G., Kang, B.T. & Brussard, L. 1992. Effects of chemical composition on N, Ca, and Mg release during incubation of leaves from selected agro forestry and fallow plants. *Biogeochemistry,* 16:103-119.

Tian, G., Kolawole, G.O., Salako, F.K. & Kang, B.T. 1999. An improved cover crop-fallow system for sustainable management of low activity clay soils of the tropics. *Soil Science,* 164:671-682.

Utomo, M. 1995. Effect of rock phosphate on soil properties and apparent phosphorous recovery in acid soil of Sumatra, [Online]. Available at: http://link.springer.com/article/10.1007%2FBF00009588#page-2 [accessed November, 26, 2013].

Vaughn, J.D. & Evanylo, G.K. 1998. Corn response to cover crop species, spring desiccation time and residue management. *Agronomy Journal,* 90: 536-544.

Weeraratna, C.S. 1990. External inputs for sustainable agriculture [Online]. Available at: http://www.agriculturesnetwork.org/magazines/global/complementary-use-of-external-inputs/external-inputs-for-sustainable-agriculture [Accessed Feb 12, 2012].

Wikipedia. 2011. Taveuni [Online]. Available at: http://wiki.ask.com/Fiji [Accessed Feb 12, 2012].

Wikipedia. 2012. Taro [Online]. Available at: http://wikipedia.org/wiki/Taroi [Accessed Feb 12, 2012].

Williams, B.J. 2006. Aztec soil knowledge: Classes, management, and ecology. In: *Footprints in the soil: People and ideas in soil history,* Warkentin, B.P. (Ed.), Elsevier, Netherlands, pp. 16-42.

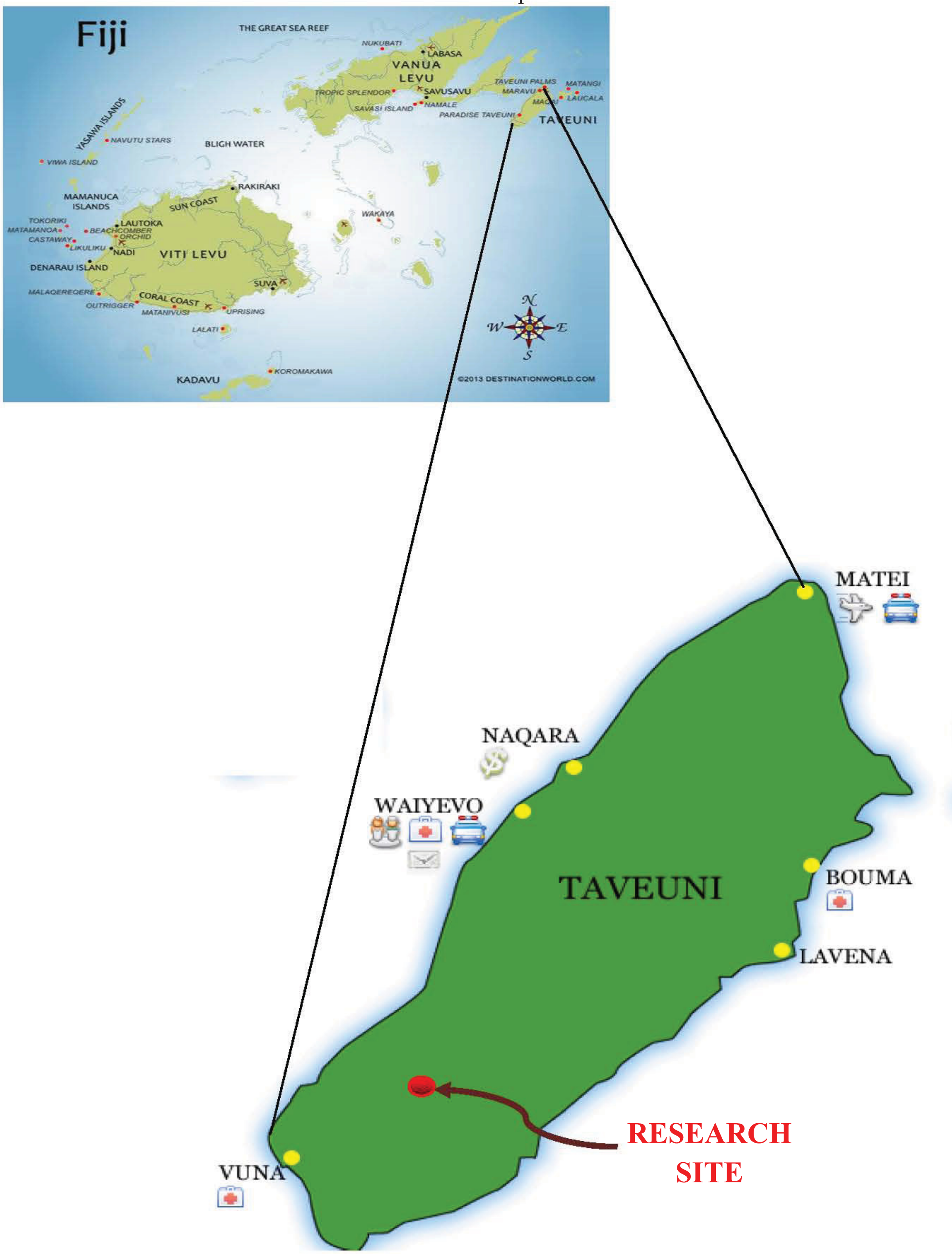
Woomer, P.L., Martin, A., Albrect, A., Resck, D.V.S. & Scharpenseel, H.W. 1994. The importance and management of soil organic matter in the tropics. In: Woomer, P.L., Swift J., (Eds.). *The biological management of tropical soil fertility.* Wiley-Sayce Production, Chichester, pp. 47-79.

Wyland, L.J., Jackson, L.E., Chancy, W.E., Klousky, K., Koike, S.T & Kumble, B. 1996. Winter cover crops in a vegetable cropping system: impacts on nitrate leaching, soil water, crop yield, pests and management costs. *Agriculture Ecosystems, & Environment,* 59:1-7.

Yates, S.R.; McConnell, L.L.; Hapeman, C.J.; Papiernik, S.K.; Gao, S. & Trabue, S.L. 2011. Managing agricultural emission to the atmosphere: state of the science, fate and mitigation, and identifying research gaps. *Journal of Environmental Quality*, 40:1347-1358.

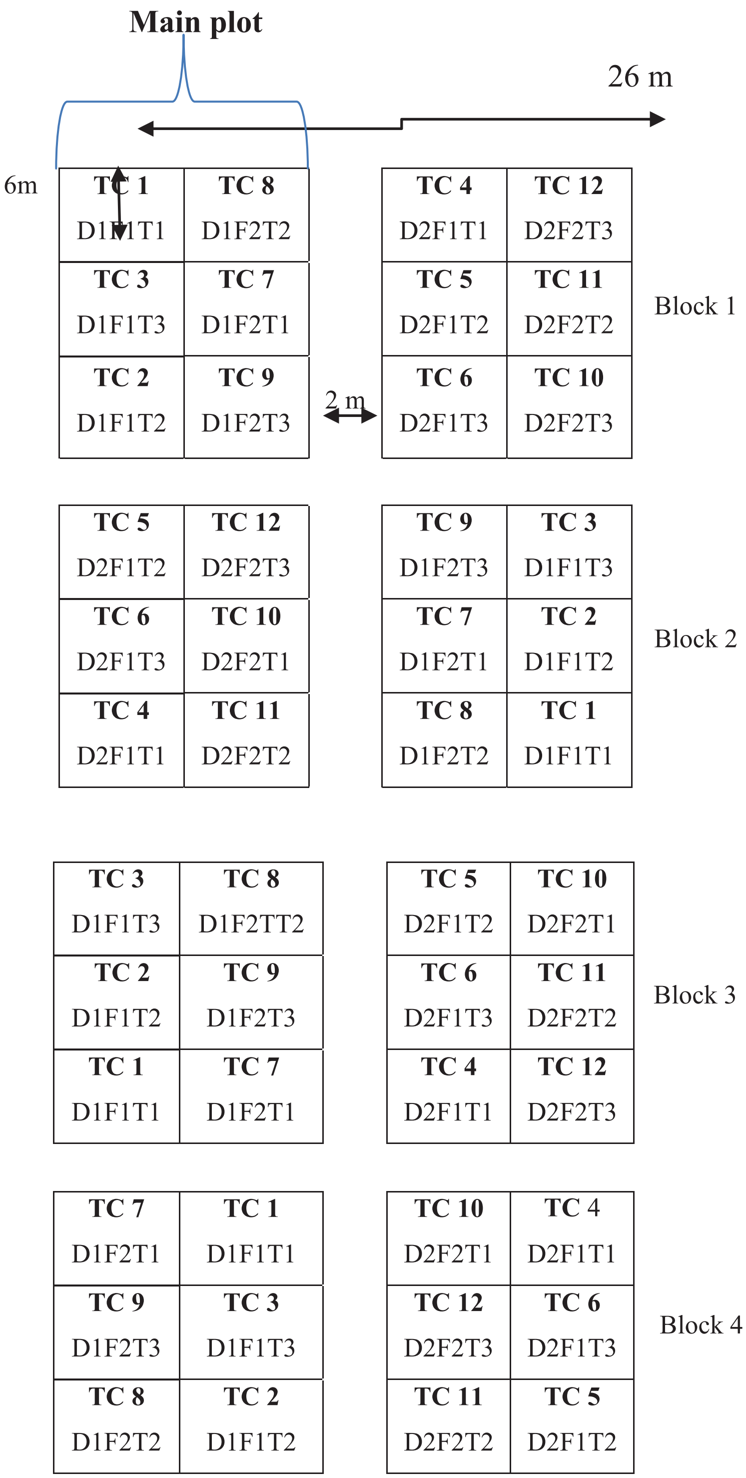
APPENDIX 1

Location map of research site



APPENDIX 2

Field layout for Experiment 1



LEGEND TO FACTORS AND LEVELS

D1 – 6 month fallow duration

D2 – 12 month fallow duration

F1 – Mucuna fallow

F2 – Grass fallow

T1 – Rock phosphate 885.7 kg/ha

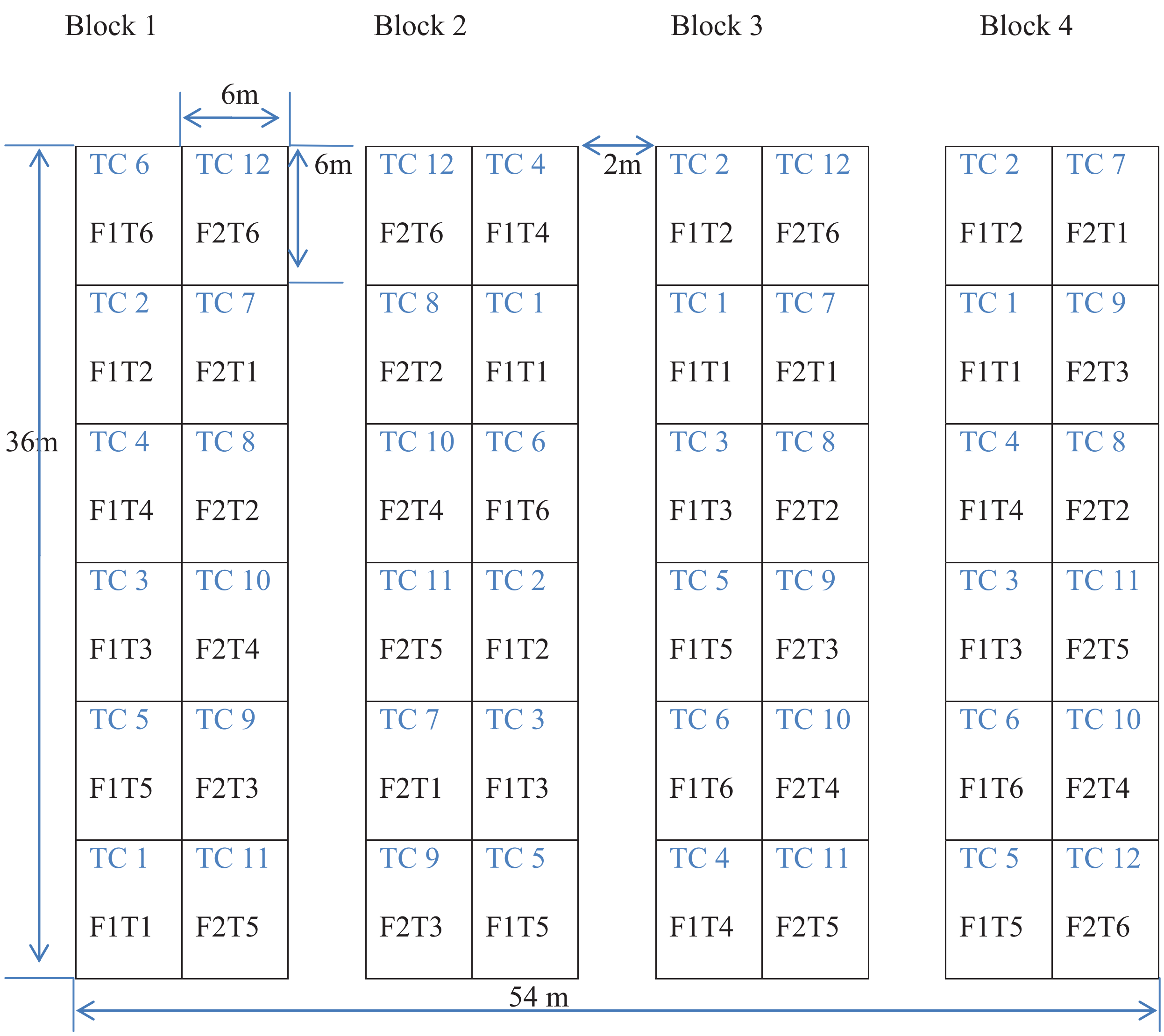
T2 – Lime 2.5 t/ha

T3 – Control

TC- Treatment combination

APPENDIX 3

Field layout for Experiment 2



The treatments have been randomized using Genstat. Each main plot had 36 plants of taro.

LEGEND TO FACTORS AND LEVELS

F1 – Mucuna fallow

F2 – Grass fallow

T1 – Rock phosphate 885.7 kg/ha

T2 – Rock phosphate 442.9 kg/ha

T3 – Lime 2.5 ton/ha

T4 – Lime 1.25 ton/ha

T5 – Rock phosphate 442.9 kg/ha & Lime 1.25 ton/ha

T6 – Control

TC- Treatment combination

APPENDIX 4

Analysis of variance for Mg

Variate: Mg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	26.498	8.833	8.47	
Block.*Units* stratum					
fallow_duration	1	2.641	2.641	2.53	0.121
fallow_type	1	0.715	0.715	0.69	0.413
soil_amendments	2	4.747	2.374	2.28	0.119
fallow_duration.fallow_type	1	0.018	0.018	0.02	0.895
fallow_duration.soil_amendments	2	0.709	0.354	0.34	0.714
fallow_type.soil_amendments	2	2.499	1.250	1.20	0.315
fallow_duration.fallow_type.soil_amendments	2	2.610	1.305	1.25	0.299
Residual	33	34.414	1.043		
Total	47	74.853			

Tables of means

Variate: Mg

Grand mean 2.87

fallow_duration	1	2
	2.63	3.10

fallow_type	1	2
	2.75	2.99

soil_amendments	1	2	3
	3.26	2.86	2.49

fallow_duration	fallow_type	1	2
1		2.49	2.78
2		3.00	3.21

fallow_duration	soil_amendments	1	2	3
1		3.04	2.76	2.10
2		3.48	2.95	2.88

fallow_type	soil_amendments	1	2	3
1		3.44	2.48	2.32
2		3.08	3.23	2.66

fallow_duration	fallow_type	soil_amendments	1	2	3
1	1		3.43	2.05	2.00
	2		2.65	3.48	2.20
2	1		3.45	2.92	2.63
	2		3.51	2.98	3.13

Least significant differences of means (5% level)

Table	fallow_duration	fallow_type	soil_amendments	fallow_duration fallow_type
rep.	24	24	16	12
d.f.	33	33	33	33
l.s.d.	0.600	0.600	0.735	0.848

Table	fallow_duration soil_amendments	fallow_type soil_amendments	fallow_duration fallow_type soil_amendments
rep.	8	8	4
d.f.	33	33	33
l.s.d.	1.039	1.039	1.469

APPENDIX 5

Analysis of variance for soil pH

Variate: ph

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.24500	0.41500	30.10	
Block.*Units* stratum					
fallow_duration	1	0.06750	0.06750	4.90	0.034
fallow_type	1	0.10083	0.10083	7.31	0.011
soil_amendments	2	0.16792	0.08396	6.09	0.006
fallow_duration.fallow_type	1	0.01333	0.01333	0.97	0.333
fallow_duration.soil_amendments	2	0.07875	0.03938	2.86	0.072
fallow_type.soil_amendments	2	0.04292	0.02146	1.56	0.226
fallow_duration.fallow_type.soil_amendments	2	0.00542	0.00271	0.20	0.823
Residual	33	0.45500	0.01379		
Total	47	2.17667			

Tables of means

Variate: ph

Grand mean 5.442

fallow_duration	1	2
	5.404	5.479

fallow_type	1	2
	5.396	5.488

soil_amendments	1	2	3
	5.394	5.525	5.406

fallow_duration	fallow_type	1	2
1		5.342	5.467
2		5.450	5.508

fallow_duration	soil_amendments	1	2	3
1		5.338	5.450	5.425
2		5.450	5.600	5.388

fallow_type	soil_amendments	1	2	3
1		5.363	5.438	5.388
2		5.425	5.613	5.425

fallow_duration	fallow_type	soil_amendments	1	2	3
1	1		5.300	5.350	5.375
	2		5.375	5.550	5.475
2	1		5.425	5.525	5.400
	2		5.475	5.675	5.375

Least significant differences of means (5% level)

Table	fallow_duration	fallow type	soil_amendments	fallow_duration fallow_type
rep.	24	24	16	12
d.f.	33	33	33	33
l.s.d.	0.0690	0.0690	0.0845	0.0975

Table	fallow_duration soil_amendments	fallow_type soil_amendments	fallow_duration fallow_type soil_amendments
rep.	8	8	4
d.f.	33	33	33
l.s.d.	0.1194	0.1194	0.1689

APPENDIX 6

Analysis of variance for K

Variate: K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.076606	0.025535	3.18	
Block.fallow_duration stratum					
fallow_duration	1	0.133352	0.133352	16.58	0.027
Residual	3	0.024123	0.008041	1.72	
Block.fallow_duration.fallow_type stratum					
fallow_type	1	0.000052	0.000052	0.01	0.919
fallow_duration.fallow_type	1	0.004219	0.004219	0.90	0.378
Residual	6	0.027979	0.004663	2.34	
Block.fallow_duration.fallow_type.soil_amendmends stratum					
soil_amendments	2	0.009017	0.004508	2.27	0.126
fallow_duration.soil_amendments	2	0.000817	0.000408	0.21	0.816
fallow_type.soil_amendments	2	0.001217	0.000608	0.31	0.739
fallow_duration.fallow_type.soil_amendments	2	0.003050	0.001525	0.77	0.476
Residual	24	0.047767	0.001990		
Total	47	0.328198			

Tables of means

Variate: K

Grand mean 0.2052

fallow_duration	1	2
	0.1525	0.2579

fallow_type	1	2
	0.2042	0.2062

soil_amendments	1	2	3
	0.2244	0.1931	0.1981

fallow_duration	fallow_type	1	2
1		0.1608	0.1442
2		0.2475	0.2683

fallow_duration	soil_amendments	1	2	3
1		0.1662	0.1412	0.1500
2		0.2825	0.2450	0.2462

fallow_type	soil_amendments	1	2	3
1		0.2262	0.1962	0.1900
2		0.2225	0.1900	0.2062

fallow_duration	fallow_type	soil_amendments	1	2	3
1	1		0.1825	0.1425	0.1575
	2		0.1500	0.1400	0.1425
2	1		0.2700	0.2500	0.2225
	2		0.2950	0.2400	0.2700

Least significant differences of means (5% level)

Table	fallow_duration	fallow_type	soil_amendments	fallow_duration fallow_type
rep.	24	24	16	12
l.s.d.	0.08238	0.04824	0.03255	0.07840
d.f.	3	6	24	6.41
Except when comparing means with the same level(s) of				
fallow_duration				0.06822
d.f.				6

Table	fallow_duration soil_amendments	fallow_type soil_amendments	fallow_duration fallow_type soil_amendments
rep.	8	8	4
l.s.d.	0.07601	0.05652	0.08828
d.f.	6.51	17.44	15.35

Block.fallow_duration.fallow_type.soil_amendmends
24 0.04461 21.7

APPENDIX 7

Analysis of variance for C

Variate: C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	23.261	7.754	12.55	
Block.fallow_duration stratum					
fallow_duration	1	111.021	111.021	179.63	<.001
Residual	3	1.854	0.618	0.19	
Block.fallow_duration.fallow_type stratum					
fallow_type	1	3.741	3.741	1.14	0.326
fallow_duration.fallow_type	1	0.241	0.241	0.07	0.795
Residual	6	19.648	3.275	2.55	
Block.fallow_duration.fallow_type.soil_amendments stratum					
soil_amendments	2	0.775	0.388	0.30	0.742
fallow_duration.soil_amendments	2	0.753	0.376	0.29	0.748
fallow_type.soil_amendments	2	1.980	0.990	0.77	0.473
fallow_duration.fallow_type.soil_amendments	2	1.078	0.539	0.42	0.662
Residual	24	30.767	1.282		
Total	47	195.119			

Tables of means

Variety: C

Grand mean 8.98

fallow_duration	1	2
	7.46	10.50

fallow_type	1	2
	9.26	8.70

soil_amendments	1	2	3
	9.08	9.06	8.80

fallow_duration	fallow_type	1	2
1		7.67	7.25
2		10.85	10.15

fallow_duration	soil_amendments	1	2	3
1		7.55	7.39	7.44
2		10.61	10.72	10.16

fallow_type	soil_amendments	1	2	3
1		9.64	9.26	8.87
2		8.52	8.85	8.72

fallow_duration	fallow_type	soil_amendments	1	2	3
1	1		8.20	7.32	7.47
	2		6.90	7.45	7.40
2	1		11.07	11.20	10.27
	2		10.15	10.25	10.05

Least significant differences of means (5% level)

Table	fallow_duration	fallow_type	soil_amendments	fallow_duration fallow_type
rep.	24	24	16	12
l.s.d.	0.722	1.278	0.826	1.316
d.f.	3	6	24	7.91
Except when comparing means with the same level(s) of				
fallow_duration				1.808
d.f.				6

Table	fallow_duration soil_amendments	fallow_type soil_amendments	fallow_duration fallow_type soil_amendments
rep.	8	8	4
l.s.d.	1.060	1.475	1.779
d.f.	25.23	16.54	27.03

APPENDIX 8

Analysis of variance for Ca

Variety: Ca

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	82.009	27.336	6.13	
Block.fallow_duration stratum					
fallow_duration	1	20.856	20.856	4.68	0.119
Residual	3	13.375	4.458	1.55	
Block.fallow_duration.fallow_type stratum					
fallow_type	1	10.138	10.138	3.53	0.109
fallow_duration.fallow_type	1	2.832	2.832	0.99	0.359
Residual	6	17.232	2.872	0.84	
Block.fallow_duration.fallow_type.soil_amendments stratum					
soil_amendments	2	24.497	12.249	3.57	0.044
fallow_duration. Soil_amendments	2	10.658	5.329	1.55	0.232
fallow_type. Soil_amendments	2	0.108	0.054	0.02	0.984
fallow_duration.fallow_type.soil_amendments	2	0.615	0.308	0.09	0.915
Residual	24	82.433	3.435		
Total	47	264.754			

Tables of means

Variety: Ca

Grand mean 5.53

fallow_duration	1	2
	4.88	6.19

fallow_type	1	2
	5.07	5.99

soil_amendments	1	2	3
	5.68	6.33	4.60

fallow_duration	fallow_type	1	2
1		4.66	5.09
2		5.49	6.90

fallow_duration	soil_amendments	1	2	3
1		4.51	5.55	4.56
2		6.85	7.10	4.63

fallow_type	soil_amendments	1	2	3
1		5.29	5.82	4.12
2		6.08	6.83	5.07

fallow_duration	fallow_type	soil_amendments	1	2	3
1	1		4.47	5.33	4.18
	2		4.55	5.77	4.95
2	1		6.10	6.31	4.06
	2		7.60	7.89	5.19

Least significant differences of means (5% level)

Table	fallow_duration	fallow_typesoil_amendments	fallow_duration fallow_type	
rep.	24	24	16	12
l.s.d.	1.940	1.197	1.352	1.864
d.f.	3	6	24	6.72

Table	fallow_duration soil_amendments	fallow_typefallow_duration soil_amendments	fallow_type soil_amendments
rep.	8	8	4
l.s.d.	2.072	1.844	2.714
d.f.	14.93	28.40	27.98
			2.705

APPENDIX 9

Analysis of variance for N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.203550	0.067850	7.79	
Block.fallow_duration stratum					
fallow_duration	1	0.806008	0.806008	92.50	0.002
Residual	3	0.026142	0.008714	0.36	
Block.fallow_duration.fallow_type stratum					
fallow_type	1	0.015408	0.015408	0.64	0.454
fallow_duration.fallow_type	1	0.000033	0.000033	0.00	0.971
Residual	6	0.144125	0.024021	3.22	
Block.fallow_duration.fallow_type.soil_amendments stratum					
soil_amendments	2	0.009079	0.004540	0.61	0.552
fallow_duration. Soil_amendments	2	0.003879	0.001940	0.26	0.773
fallow_type. Soil_amendments	2	0.007879	0.003940	0.53	0.596
fallow_duration.fallow_type.soil_amendments	2	0.019679	0.009840	1.32	0.286
Residual	24	0.179083	0.007462		
Total	47	1.414867			

Tables of means
Variety: N

Grand mean 0.747

fallow_duration	1	2
	0.617	0.876

fallow_type	1	2
	0.765	0.729

soil_amendments	1	2	3
	0.765	0.732	0.743

fallow_duration	fallow_type	1	2
1		0.634	0.600
2		0.895	0.857

fallow_duration	soil_amendments	1	2	3
1		0.624	0.612	0.615
2		0.906	0.851	0.871

fallow_type	soil_amendments	1	2	3
1		0.796	0.754	0.744
2		0.734	0.710	0.742

fallow_duration	fallow_type	soil_amendments	1	2	3
1	1		0.677	0.607	0.617
	2		0.570	0.617	0.612
2	1		0.915	0.900	0.870
	2		0.897	0.802	0.872

Least significant differences of means (5% level)

Table	fallow_duration	fallow_type	soil_amendments	fallow_duration fallow_type
rep.	24	24	16	12
l.s.d.	0.0858	0.1095	0.0630	0.1185
d.f.	3	6	24	8.82
Except when comparing means with the same level(s) of				
fallow_duration				0.1548
d.f.				6

Table	fallow_duration soil_amendments	fallow_type soil_amendments	fallow_duration fallow_type soil_amendments
rep.	8	8	4
l.s.d.	0.0940	0.1219	0.1488
d.f.	16.15	14.38	24.69
Except when comparing means with the same level(s) of			
fallow_duration	0.0891		0.1724
d.f.	24		14.38
fallow_type		0.0891	
d.f.		24	
fallow_duration.fallow_type			0.1261
d.f.			24
fallow_duration. Soil_amendments			0.1724
d.f.			14.38

APPENDIX 10

Analysis of variance for P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	19.212	6.404	1.35	
Block.fallow_duration stratum					
fallow_duration	1	1.172	1.172	0.25	0.653
Residual	3	14.212	4.737	1.21	
Block.fallow_duration.fallow_type stratum					
fallow_type	1	3.910	3.910	0.99	0.357
fallow_duration.fallow_type					
	1	3.910	3.910	0.99	0.357
Residual	6	23.581	3.930	1.01	
Block.fallow_duration.fallow_type.soil_amendments stratum					
soil_amendments	2	0.601	0.301	0.08	0.926
fallow_duration.soil_amendments					
	2	0.926	0.463	0.12	0.888
fallow_type.soil_amendments					
	2	14.208	7.104	1.83	0.182
fallow_duration.fallow_type.soil_amendments					
	2	1.033	0.516	0.13	0.876
Residual	24	93.112	3.880		
Total	47	175.878			

Tables of means

Variate: P

Grand mean 4.16

fallow_duration	1	2
	4.31	4.00

fallow_type	1	2
	4.44	3.87

soil_amendments	1	2	3
	4.26	4.21	4.00

fallow_durationfallow_type	1	2
1	4.88	3.74
2	4.00	4.00

fallow_duration	soil_amendments	1	2	3
1		4.39	4.55	4.00
2		4.12	3.87	4.00

fallow_type	soil_amendments	1	2	3
1		3.77	4.82	4.72
2		4.74	3.60	3.27

fallow_duration	fallow_type	soil_amendments	1	2	3
1	1		4.05	5.65	4.95
	2		4.72	3.45	3.05
2	1		3.50	4.00	4.50
	2		4.75	3.75	3.50

Least significant differences of means (5% level)

Table	fallow_duration	fallow_type	soil_amendments	fallow_duration fallow_type
rep.	24	24	16	12
l.s.d.	2.000	1.400	1.437	1.984
d.f.	3	6	24	7.47

Table	fallow_duration soil_amendmends	fallow_type soil_amendments	fallow_duration fallow_type soil_amendments
rep.	8	8	4
l.s.d.	2.167	2.026	2.903
d.f.	15.63	26.88	29.12

APPENDIX 11

Analysis of variance for bulk density

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.015383	0.005128	1.76	
Block.fallow_duration stratum					
fallow_duration	1	1.968300	1.968300	677.43	<.001
Residual	3	0.008717	0.002906	0.68	
Block.fallow_duration.fallow_type stratum					
fallow_type	1	0.006075	0.006075	1.43	0.277
fallow_duration.fallow_type	1	0.001408	0.001408	0.33	0.586
Residual	6	0.025550	0.004258	0.80	
Block.fallow_duration.fallow_type.soil_amendments stratum					
soil_amendments	2	0.006017	0.003008	0.57	0.574
fallow_duration. Soil_amendments	2	0.000350	0.000175	0.03	0.968
fallow_type. Soil_amendments	2	0.003350	0.001675	0.32	0.732
fallow_duration.fallow_type.soil_amendments	2	0.025017	0.012508	2.36	0.116
Residual	24	0.127000	0.005292		
Total	47	2.187167			

Tables of means

Variety: bulk_density

Grand mean 0.806

fallow_duration	1	2
	0.603	1.008

fallow_type	1	2
	0.795	0.817

soil_amendments	1	2	3
	0.795	0.821	0.801

fallow_duration	fallow_type	1	2

1	0.598	0.609
2	0.992	1.025

fallow_duration	soil_amendments 1	2	3
1	0.590	0.617	0.602
2	1.000	1.025	1.000

fallow_type	soil_amendments 1	2	3
1	0.795	0.807	0.781
2	0.795	0.835	0.821

fallow_duration	fallow_type	soil_amendments 1	2	3
1	1	0.565	0.615	0.612
	2	0.615	0.620	0.593
2	1	1.025	1.000	0.950
	2	0.975	1.050	1.050

Least significant differences of means (5% level)

Table	fallow_duration	fallow_type	soil_amendments	fallow_duration fallow_type
rep.	24	24	16	12
l.s.d.	0.0495	0.0461	0.0531	0.0555
d.f.	3	6	24	8.79
Except when comparing means with the same level(s) of fallow_duration				0.0652
d.f.				6

Table	fallow_duration soil_amendments	fallow_type soil_amendments	fallow_duration fallow_type soil_amendments
rep.	8	8	4
l.s.d.	0.0691	0.0720	0.0989
d.f.	24.32	28.65	32.75

APPENDIX 12a

Analysis of variance for earthworm count

Variate: earthworm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	3052.5	1017.5	2.94	
Block.fallow_duration stratum					
fallow_duration	1	2187.0	2187.0	6.31	0.087
Residual	3	1039.2	346.4	1.27	
Block.fallow_duration.fallow_type stratum					
fallow_type	1	243.0	243.0	0.89	0.381
fallow_duration.fallow_type	1	48.0	48.0	0.18	0.689
Residual	6	1635.0	272.5	1.35	
Block.fallow_duration.fallow_type.soil_amendmends stratum					
soil_amendments	2	378.2	189.1	0.94	0.406
fallow_duration.soil_amendments	2	446.0	223.0	1.11	0.347
fallow_type.soil_amendments	2	600.0	300.0	1.49	0.246
fallow_duration.fallow_type.soil_amendments	2	369.5	184.8	0.92	0.414
Residual	24	4842.3	201.8		
Total	47	14840.7			

Tables of means

Variate: earthworm

Grand mean 24.3

fallow_duration	1	2
	17.6	31.1

fallow_type	1	2
	22.1	26.6

soil_amendments	1	2	3
	20.9	27.8	24.4

fallow_duration	fallow_type	1	2
1		16.3	18.8
2		27.8	34.3

fallow_duration	soil_amendments	1	2	3
1		18.4	19.5	14.9
2		23.4	36.0	33.9

fallow_type	soil_amendments	1	2	3
1		23.6	23.0	19.6
2		18.1	32.5	29.1

fallow_duration	fallow_type	soil_amendments	1	2	3
1	1		19.2	19.5	10.2
	2		17.5	19.5	19.5
2	1		28.0	26.5	29.0
	2		18.8	45.5	38.8

Least significant differences of means (5% level)

Table	fallow_duration	fallow_type	soil_amendments	fallow_duration fallow_type
rep.	24	24	16	12
l.s.d.	17.10	11.66	10.36	16.84
d.f.	3	6	24	7.31
Except when comparing means with the same level(s) of				
fallow_duration				16.49
d.f.				6

Table	fallow_duration soil_amendments	fallow_type soil_amendments	fallow_duration fallow_type soil_amendments
rep.	8	8	4
l.s.d.	17.22	15.50	22.43
d.f.	12.02	23.85	25.57
Except when comparing means with the same level(s) of			
fallow_duration	14.66		21.91
d.f.	24		23.85
fallow_type		14.66	
d.f.		24	
fallow_duration.fallow_type			20.73
d.f.			24
fallow_duration.soil_amendments			21.91
d.f.			23.85

APPENDIX 12b

Analysis of variance for transformed (log 10) earthworm count

Variate: EW

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.29154	0.43051	10.97	
Block.fallow_duration stratum					
fallow_duration	1	0.67847	0.67847	17.29	0.025
Residual	3	0.11775	0.03925	0.57	
Block.fallow_duration.fallow_type stratum					
fallow_type	1	0.04625	0.04625	0.67	0.444
fallow_duration.fallow_type	1	0.05141	0.05141	0.75	0.421
Residual	6	0.41333	0.06889	0.76	
Block.fallow_duration.fallow_type.soil_amendmends stratum					
soil_amendments	2	0.01079	0.00539	0.06	0.943
fallow_duration.soil_amendments	2	0.38896	0.19448	2.14	0.140
fallow_type.soil_amendments	2	0.37296	0.18648	2.05	0.151
fallow_duration.fallow_type.soil_amendments	2	0.10050	0.05025	0.55	0.583
Residual	24	2.18260	0.09094		
Total	47	5.65456			

Tables of means

Variate: T_ew

Grand mean 1.275

fallow_duration	1	2
	1.156	1.394

fallow_type	1	2
	1.244	1.306

soil_amendments	1	2	3
	1.272	1.294	1.258

fallow_duration	fallow_type	1	2
1		1.092	1.220
2		1.395	1.392

fallow_duration	soil_amendments	1	2	3
1		1.241	1.211	1.015
2		1.303	1.377	1.500

fallow_type	soil_amendments	1	2	3
1		1.316	1.312	1.103
2		1.229	1.276	1.412

fallow_duration	fallow_type	soil_amendments	1	2	3
1	1		1.275	1.238	0.764
	2		1.208	1.184	1.266
2	1		1.358	1.386	1.442
	2		1.249	1.368	1.558

Least significant differences of means (5% level)

Table	fallow_duration	fallow_type	soil_amendments	fallow_duration fallow_type
rep.	24	24	16	12
l.s.d.	0.1820	0.1854	0.2201	0.2149
d.f.	3	6	24	8.96
Except when comparing means with the same level(s) of				
fallow_duration				0.2622
d.f.				6

Table	fallow_duration soil_amendments	fallow_type soil_amendments	fallow_duration fallow_type soil_amendments
rep.	8	8	4
l.s.d.	0.2791	0.2957	0.4036
d.f.	25.85	28.99	32.66

APPENDIX 13

Correlations between bulk density and earthworm count

	BD	EW
BD		
EW	0.7405	

Number of observations: 10

Two-sided test of correlations different from zero
probabilities

	BD	EW
BD		
EW	0.0143	

APPENDIX 14

Correlations between pH and earthworm count

Earthworm		
pH_Water	0.6292	
	Earthworm	pH_Water

Number of observations: 11

Two-sided test of correlations different from zero
probabilities

Earthworm		
pH_Water	0.0381	
	Earthworm	pH_Water

APPENDIX 15

Correlations between pH and Ca

Ca		
pH	0.7566	
	Ca	pH

Number of observations: 12

Two-sided test of correlations different from zero
probabilities

Ca		
pH	0.0044	
	Ca	pH

APPENDIX 16

Two-sample t-test for 6 and 12 month total organic carbon

Variates: %12_monthsTotal_OC_%, %6_monthsTotal_OC_%.

Test for equality of sample variances

Test statistic F = 1.42 on 5 and 5 d.f.

Probability (under null hypothesis of equal variances) = 0.71

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
%12_monthsTotal_OC_%		6	10.498	0.2511	0.5011
0.2046					
%6_monthsTotal_OC_%	6	7.457	0.1769	0.4206	0.1717

Difference of means: 3.042
Standard error of difference: 0.267

95% confidence interval for difference in means: (2.447, 3.637)

Test of null hypothesis that mean of %12_monthsTotal_OC_% is equal to mean of %6_monthsTotal_OC_%

Test statistic t = 11.39 on 10 d.f.

Probability < 0.001

APPENDIX 17

Analysis of variance for taro yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	3	6343593.	2114531.	1.09	
block.fallow_type stratum					
fallow_type	1	72553730.	72553730.	37.40	0.009
Residual	3	5819159.	1939720.	1.09	
block.fallow_type.soil_amendments stratum					
soil_amendments	5	10298310.	2059662.	1.15	0.355
fallow_type. Soil_amendments	5	10510975.	2102195.	1.18	0.344
Residual	30	53603054.	1786768.		
Total	47	159128821.			

Tables of means

Grand mean 10480.

fallow_type	1	2
	11710.	9251.

soil_amendments	1	2	3	4	5	6
	10576.	10172.	11054.	11012.	9740.	10328.

fallow_type	soil_amendments	1	2	3	4	5
1		11442.	11415.	11807.	11926.	11859.
2		9711.	8929.	10302.	10098.	7622.

fallow_type	soil_amendments	6
1		11811.
2		8845.

Least significant differences of means (5% level)

Table	fallow_typesoil_amendments		fallow_type soil_amendments
rep.	24	8	4
l.s.d.	1279.5	1365.0	1943.5
d.f.	3	30	30.20
Except when comparing means with the same level(s) of			
fallow_type			1930.3
d.f.	30		

APPENDIX 18

t-test between grass and mucuna effect on taro leaf length at 120 DAP

One-sample t-test

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Grass-Mucuna	6	-1.757	0.8472	0.9204	0.3758

95% confidence interval for mean: (-2.723, -0.7907)

Test of null hypothesis that mean of Grass-Mucuna is equal to 0

Test statistic t = -4.67 on 5 d.f.

Probability = 0.005

***** Two-sample T-test (paired) *****
Calculated using one-sample t-test with the null hypothesis that the mean of Mucuna - Grass is equal to 0

One-sample t-test

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Mucuna-Grass	6	1.757	0.8472	0.9204	0.3758

95% confidence interval for mean: (0.7907, 2.723)

Test of null hypothesis that mean of Mucuna-Grass is equal to 0

Test statistic t = 4.67 on 5 d.f.

Probability = 0.005

APPENDIX 19

t-test between grass and mucuna effect on taro leaf area at 120 DAP

One-sample t-test

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Grass-Mucuna	6	-206.4	13843	117.7	48.03

95% confidence interval for mean: (-329.9, -82.98)

Test of null hypothesis that mean of Grass-Mucuna is equal to 0

Test statistic t = -4.30 on 5 d.f.

Probability = 0.008

APPENDIX 20

Analysis of variance for weed count

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	3	74695.	24898.	1.39	
block.fallow_type stratum					
fallow_type	1	365054.	365054.	20.45	0.020
Residual	3	53551.	17850.	9.29	
block.fallow_type.soil_amendments stratum					
soil_amendments	5	2481.	496.	0.26	0.932
fallow_type. Soil_amendments					
	5	12497.	2499.	1.30	0.290
Residual	30	57635.	1921.		
Total	47	565913.			

Tables of means

Grand mean 121.1

fallow_type	1	2
	208.3	33.9

soil_amendments	1	2	3	4	5	6
	112.9	123.1	119.5	112.6	133.1	125.5

fallow_type	soil_amendments	1	2	3	4	5
1		194.8	207.0	211.0	170.0	241.3
2		31.0	39.2	28.0	55.2	25.0

fallow_type	soil_amendments	6
1		226.0
2		25.0

Least significant differences of means (5% level)

Table fallow_typesoil_amendments

			fallow_type soil_amendments
rep.	24	8	4
l.s.d.	122.74	44.76	113.45
d.f.	3	30	6.90
Except when comparing means with the same level(s) of			
fallow_type			63.30
d.f.			30

APPENDIX 21

Correlation between organic carbon and earthworm count

	%_OC	
Earthworm_No	0.6529	
	%_OC	Earthworm_No

Number of observations: 12

Two-sided test of correlations different from zero
probabilities

	%_OC	
Earthworm_No	0.0213	
	%_OC	Earthworm_No

APPENDIX 22

Analysis of variance for 12 month cover crop dry matter

Variety: DM

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	1080.042	1080.042	270.27	<.001
Residual	22	87.917	3.996		
Total	23	1167.958			

Tables of means

Variety: DM

Grand mean 24.79

Fallow	1	2
	31.50	18.08

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	0.577

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	0.816

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	1.693

APPENDIX 23

Analysis of variance for 12 month cover crop Mg level

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	0.1734000	0.1734000	261.29	<.001
Residual	22	0.0146000	0.0006636		
Total	23	0.1880000			

Tables of means

Variety: Mg

Grand mean 0.3700

Fallow	1	2
	0.2850	0.4550

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	0.00744

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	0.01052

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	0.02181

APPENDIX 24

Analysis of variance for 12 month cover crop K level

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	1.76042	1.76042	35.89	<.001
Residual	22	1.07917	0.04905		
Total	23	2.83958			

Tables of means

Variety: K

Grand mean 1.746

Fallow	1	2
	1.475	2.017

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	0.0639

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	0.0904

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	0.1875

APPENDIX 25

Analysis of variance for 12 month cover crop N level

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	1.92667	1.92667	67.64	<.001
Residual	22	0.62667	0.02848		
Total	23	2.55333			

Tables of means

Variety: N

Grand mean 2.367

Fallow	1	2
	2.650	2.083

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	0.0487

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	0.0689

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	0.1429

APPENDIX 26

Analysis of variance for 12 month cover crop Ca level

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	0.66667	0.66667	22.28	<.001
Residual	22	0.65833	0.02992		
Total	23	1.32500			

Tables of means

Variety: Ca

Grand mean 0.875

Fallow	1	2
	1.042	0.708

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	0.0499

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	0.0706

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	0.1465

APPENDIX 27

Analysis of variance for 12 month cover crop P level

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	0.0682667	0.0682667	105.27	<.001
Residual	22	0.0142667	0.0006485		
Total	23	0.0825333			

Tables of means

Variety: P

Grand mean 0.2683

Fallow	1	2
	0.2150	0.3217

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	0.00735

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	0.01040

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	0.02156

APPENDIX 28

Two-sample t-test between grass and mucuna effect on taro leaf number at 120 DAP

Variates: Grass, Mucuna.

Test for equality of sample variances

Test statistic F = 1.26 on 5 and 5 d.f.

Probability (under null hypothesis of equal variances) = 0.81

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Grass	6	4.574	0.01511	0.1229	0.05019
Mucuna	6	5.061	0.01898	0.1378	0.05625

Difference of means: -0.4867
Standard error of difference: 0.0754

95% confidence interval for difference in means: (-0.6546, -0.3187)

Test of null hypothesis that mean of Grass is equal to mean of Mucuna

Test statistic t = -6.46 on 10 d.f.

Probability < 0.001

APPENDIX 29

t-test between grass and mucuna effect on taro plant height at 120 DAP

One-sample t-test

Variate: Y[1].

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Grass-Mucuna	7	-4.840	24.71	4.971	1.879

95% confidence interval for mean: (-9.437, -0.2424)

Test of null hypothesis that mean of Grass-Mucuna is equal to 0

Test statistic t = -2.58 on 6 d.f.

Probability = 0.042

APPENDIX 30

Analysis of variance for C/N ratio

Variate: CN

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.7096	0.2365	1.24	
Block.fallow_duration stratum					
fallow_duration	1	0.0245	0.0245	0.13	0.744
Residual	3	0.5723	0.1908	1.09	
Block.fallow_duration.fallow_type stratum					
fallow_type	1	0.1305	0.1305	0.74	0.421
fallow_duration.fallow_type	1	0.1114	0.1114	0.64	0.456
Residual	6	1.0520	0.1753	0.24	
Block.fallow_duration.fallow_type.soil_amendments stratum					
soil_amendments	2	2.0301	1.0151	1.39	0.269
fallow_duration.soil_amendments	2	2.4265	1.2132	1.66	0.211
fallow_type.soil_amendments	2	0.4935	0.2467	0.34	0.717
fallow_duration.fallow_type.soil_amendments	2	0.4946	0.2473	0.34	0.716
Residual	24	17.5438	0.7310		
Total	47	25.5888			

Tables of means

Variate: CN

Grand mean 12.06

fallow_duration	1	2
	12.08	12.04

fallow_type	1	2
	12.11	12.01

soil_amendments	1	2	3
	11.94	12.35	11.89

fallow_duration	fallow_type	1	2
1		12.09	12.08
2		12.14	11.94

fallow_duration	soil_amendments	1	2	3
1		12.10	12.06	12.09
2		11.78	12.65	11.70

fallow_type	soil_amendments	1	2	3
1		12.11	12.27	11.97
2		11.77	12.43	11.82

fallow_duration	fallow_type	soil_amendments	1	2	3
1	1		12.10	12.06	12.11
	2		12.11	12.06	12.08
2	1		12.11	12.49	11.82
	2		11.44	12.81	11.57

Least significant differences of means (5% level)

Table	fallow_duration	fallow_type	soil_amendments	fallow_duration fallow_type
rep.	24	24	16	12
l.s.d.	0.401	0.296	0.624	0.405
d.f.	3	6	24	7.77
Except when comparing means with the same level(s) of				
fallow_duration				0.418
d.f.				6

Table	fallow_duration soil_amendments	fallow_type soil_amendments	fallow_duration fallow_type soil_amendments
rep.	8	8	4
l.s.d.	0.761	0.756	1.071
d.f.	26.99	28.46	28.98

APPENDIX 31

Analysis of variance for 12 month cover crop N uptake

Variate: N_kg_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	1270060.	1270060.	278.72	<.001
Residual	22	100248.	4557.		
Total	23	1370308.			

Tables of means

Variate: N_kg_ha

Grand mean 606.

Fallow	1	2
	836.	376.

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	19.5

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	27.6

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	57.2

APPENDIX 32

Analysis of variance for 12 month cover crop P uptake

Variate: P_kg_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	558.74	558.74	8.40	0.008
Residual	22	1462.76	66.49		
Total	23	2021.50			

Tables of means

Variate: P_kg_ha

Grand mean 62.9

Fallow	1	2
	67.7	58.1

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	2.35

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	3.33

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	6.90

APPENDIX 33

Analysis of variance for 12 month cover crop K uptake

Variate: K_kg_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	59402.	59402.	14.25	0.001
Residual	22	91678.	4167.		
Total	23	151080.			

Tables of means

Variate: K_kg_ha

Grand mean 416.

Fallow	1	2
	465.	366.

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	18.6

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	26.4

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	54.7

APPENDIX 34

Analysis of variance for 12 month cover crop Ca uptake

Variate: Ca_kg_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	233051.	233051.	113.57	<.001
Residual	22	45146.	2052.		
Total	23	278197.			

Tables of means

Variate: Ca_kg_ha

Grand mean 228.0

Fallow	1	2
	326.6	129.5

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	13.08

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	18.49

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	38.35

APPENDIX 35

Analysis of variance for 12 month cover crop Mg uptake

Variate: Mg_kg_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	338.25	338.25	3.81	0.064
Residual	22	1954.37	88.83		
Total	23	2292.62			

Tables of means

Variate: Mg_kg_ha

Grand mean 85.9

Fallow	1	2
	89.7	82.2

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	2.72

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	3.85

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	7.98

APPENDIX 36

Analysis of variance for 6 month cover crop dry biomass

Variate: DM

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	216.6004	216.6004	295.50	<.001
Residual	22	16.1258	0.7330		
Total	23	232.7263			

Tables of means

Variate: DM

Grand mean 8.91

Fallow	1	2
	11.92	5.91

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	0.247

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	0.350

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	0.725

APPENDIX 37

Analysis of variance for 6 month cover crop N uptake

Variate: N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	0.0925042	0.0925042	113.11	<.001
Residual	22	0.0179917	0.0008178		
Total	23	0.1104958			

Tables of means

Variate: N

Grand mean 0.2171

Fallow	1	2
	0.2792	0.1550

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	0.00826

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	0.01167

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	0.02421

APPENDIX 38

Analysis of variance for 6 month cover crop P uptake

Variate: %6_M_P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	0.0160167	0.0160167	21.77	<.001
Residual	22	0.0161833	0.0007356		
Total	23	0.0322000			

Tables of means

Variate: %6_M_P

Grand mean 0.1700

Fallow	1	2
	0.1958	0.1442

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	0.00783

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	0.01107

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	0.02296

APPENDIX 39

Analysis of variance for 6 month cover crop K uptake

Variate: K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	0.60484	0.60484	18.99	<.001
Residual	22	0.70086	0.03186		
Total	23	1.30570			

Tables of means

Variate: K

Grand mean 1.517

Fallow	1	2
	1.358	1.676

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	0.0515

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	0.0729

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	0.1511

APPENDIX 40

Analysis of variance for 6 month cover crop Ca uptake

Variate: Ca

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	0.069337	0.069337	62.11	<.001
Residual	22	0.024558	0.001116		
Total	23	0.093896			

Tables of means

Variate: Ca

Grand mean 0.4271

Fallow	1	2
	0.3733	0.4808

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	0.00964

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	0.01364

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	0.02829

APPENDIX 41

Analysis of variance for 6 month cover crop Mg uptake

Variate: Mg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	0.121837	0.121837	52.02	<.001
Residual	22	0.051525	0.002342		
Total	23	0.173363			

Tables of means

Variate: Mg

Grand mean 0.2638

Fallow	1	2
	0.1925	0.3350

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	0.01397

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	0.01976

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	0.04097

APPENDIX 42

Analysis of variance for 6 month cover crop N uptake

Variate: N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	61598.5	61598.5	477.89	<.001
Residual	22	2835.7	128.9		
Total	23	64434.2			

Tables of means

Variate: N

Grand mean 94.3

Fallow	1	2
	145.0	43.7

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	3.28

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	4.63

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	9.61

APPENDIX 43

Analysis of variance for 6 month cover crop P uptake

Analysis of variance

Variate: P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	1325.07	1325.07	103.33	<.001
Residual	22	282.11	12.82		
Total	23	1607.18			

Tables of means

Variate: P

Grand mean 15.95

Fallow	1	2
	23.38	8.52

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	1.034

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	1.462

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	3.032

APPENDIX 44

Analysis of variance for 6 month cover crop K uptake

Variate: K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	24010.3	24010.3	79.34	<.001
Residual	22	6657.4	302.6		
Total	23	30667.7			

Tables of means

Variate: K

Grand mean 130.4

Fallow	1	2
	162.0	98.8

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	5.02

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	7.10

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	14.73

APPENDIX 45

Analysis of variance for 6 month cover crop Ca uptake

Variate: Ca

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	1564.13	1564.13	63.21	<.001
Residual	22	544.37	24.74		
Total	23	2108.50			

Tables of means

Variate: Ca

Grand mean 36.5

Fallow	1	2
	44.6	28.5

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	1.44

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	2.03

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	4.21

APPENDIX 46

Analysis of variance for 6 month cover crop Mg uptake

Variate: Mg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fallow	1	64.16	64.16	4.39	0.048
Residual	22	321.34	14.61		
Total	23	385.49			

Tables of means

Variate: Mg

Grand mean 21.39

Fallow	1	2
	23.03	19.76

Standard errors of means

Table	Fallow
rep.	12
d.f.	22
e.s.e.	1.103

Standard errors of differences of means

Table	Fallow
rep.	12
d.f.	22
s.e.d.	1.560

Least significant differences of means (5% level)

Table	Fallow
rep.	12
d.f.	22
l.s.d.	3.236

APPENDIX 47

Regression analysis of taro leaf area, leaf length, leaf number and plant height against corm yield

Response variate: Yield
Fitted terms: Constant, Leaf_Area, Leaf_Length, Leaf_No, Plant_height

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	4	47738487.	11934622.	23.64	<.001
Residual	43	21708709.	504854.		
Total	47	69447196.	1477600.		

Percentage variance accounted for 65.8
Standard error of observations is estimated to be 711.

Estimates of parameters

Parameter	estimate	s.e.	t(43)	t pr.
Constant	1660.	1323.	1.25	0.216
Leaf_Area	3.308	0.438	7.56	<.001
Leaf_Length	5.6	41.7	0.14	0.893
Leaf_No	731.	264.	2.77	0.008
Plant_height	6.0	13.1	0.46	0.649

Correlations between parameter estimates

Parameter	ref	correlations				
Constant	1	1.000				
Leaf_Area	2	-0.268	1.000			
Leaf_Length	3	-0.587	-0.084	1.000		
Leaf_No	4	-0.231	-0.238	-0.229	1.000	
Plant_height	5	0.135	0.154	-0.531	-0.379	1.000
		1	2	3	4	5

APPENDIX 48

Regression analysis of taro leaf area and leaf number against taro corm yield

Response variate: Yield
Fitted terms: Constant, Leaf_Area, Leaf_No

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	47531207.	23765603.	48.80	<.001
Residual	45	21915989.	487022.		
Total	47	69447196.	1477600.		

Percentage variance accounted for 67.0
Standard error of observations is estimated to be 698.

Message: the following units have high leverage.

Unit	Response	Leverage
21	10072.	0.144
23	8992.	0.158
39	11882.	0.160

Estimates of parameters

Parameter	estimate	s.e.	t(45)	t pr.
Constant	1938.	1017.	1.91	0.063
Leaf_Area	3.278	0.425	7.72	<.001
Leaf_No	837.	201.	4.17	<.001

Correlations between parameter estimates

Parameter	ref	correlations		
Constant	1	1.000		
Leaf_Area	2	-0.376	1.000	
Leaf_No	3	-0.806	-0.237	1.000
		1	2	3

APPENDIX 49

Raw data for harvested taro corms from each research plot

Plot	block	fallow type	soil amendment	taro yield (kg)
1	1	1	1	11726.25
2	1	1	2	11816.25
3	1	1	3	11828.75
4	1	1	4	11870.00
5	1	1	5	11803.00
6	1	1	6	11742.50
7	1	2	1	9634.37
8	1	2	2	9063.12
9	1	2	3	9991.87
10	1	2	4	8950.00
11	1	2	5	9354.37
12	1	2	6	9511.87
13	2	1	1	11380.63
14	2	1	2	11233.13
15	2	1	3	11883.75
16	2	1	4	11999.30
17	2	1	5	11926.88
18	2	1	6	11982.50
19	2	2	1	10911.87
20	2	2	2	8875.62
21	2	2	3	11065.00
22	2	2	4	10155.00
23	2	2	5	11049.37

Plot	block	fallow type	soil amendment	taro yield (kg/ha)
24	2	2	6	8555.62
25	3	1	1	11285.00
26	3	1	2	11348.13
27	3	1	3	11882.50
28	3	1	4	11993.75
29	3	1	5	11866.25
30	3	1	6	11788.13
31	3	2	1	9013.12
32	3	2	2	8770.00
33	3	2	3	10079.38
34	3	2	4	11183.12
35	3	2	5	10091.87
36	3	2	6	8667.50
37	4	1	1	11376.88
38	4	1	2	11262.50
39	4	1	3	11632.50
40	4	1	4	11840.36
41	4	1	5	11838.75
42	4	1	6	11729.38
43	4	2	1	9283.75
44	4	2	2	9005.62
45	4	2	3	10071.88
46	4	2	4	10102.50
47	4	2	5	8992.50
48	4	2	6	8644.37

APPENDIX 50

Raw data for selected soil properties from soil properties experiment

Block	fallow duration	fallow type	soil amendments	Ph	N	K	Mg	Ca	P	C	BD	earthworm
1	1	1	1	5.1	0.57	0.29	3.00	3.6	3.50	6.90	0.54	14
1	1	1	2	5.3	0.52	0.06	0.50	5.8	4.60	6.30	0.62	15
1	1	1	3	5.2	0.52	0.14	1.80	2.6	6.90	6.30	0.60	6
1	1	2	1	5.3	0.49	0.08	1.10	2.4	2.00	6.00	0.68	27
1	1	2	2	5.3	0.53	0.10	1.10	2.1	3.90	6.40	0.52	14
1	1	2	3	5.2	0.56	0.07	0.80	2.3	2.70	6.70	0.47	22
1	2	1	1	5.4	0.83	0.30	4.35	6.25	4.00	10.00	1.00	61
1	2	1	2	5.4	0.77	0.23	2.59	5.22	3.00	9.30	1.00	33
1	2	1	3	5.2	0.77	0.21	1.64	4.57	3.00	9.40	1.00	25
1	2	2	1	5.2	0.8	0.28	3.44	5.89	4.00	9.70	0.90	15
1	2	2	2	5.7	0.85	0.25	3.39	11.35	6.00	10.30	1.10	70
1	2	2	3	5.1	0.69	0.23	1.95	3.9	3.00	8.40	1.10	47
2	1	2	1	5.2	0.61	0.08	1.80	4.8	5.90	7.40	0.56	21
2	1	2	2	5.3	0.79	0.09	4.50	6.3	2.20	9.60	0.58	39

Block	fallow duration	fallow type	soil amendments	Ph	N	K	Mg	Ca	P	C	BD	earthworm
2	1	2	3	5.3	0.62	0.06	2.20	4.7	1.40	7.60	0.63	24
2	1	1	1	5	0.52	0.08	0.60	1.4	5.30	6.30	0.55	22
2	1	1	2	5.2	0.60	0.08	1.70	3.7	8.00	7.20	0.71	24
2	1	1	3	5.2	0.58	0.10	1.20	2.4	3.20	7.00	0.62	27
2	2	2	1	5.4	0.88	0.24	1.92	7.37	5.00	10.70	1.10	30
2	2	2	2	5.4	0.70	0.23	1.64	3.38	4.00	8.40	1.10	94
2	2	2	3	5.2	0.74	0.22	1.81	3.53	4.00	9.00	1.00	56
2	2	1	1	5.4	1.01	0.27	3.14	5.56	6.00	12.20	1.00	23
2	2	1	2	5.5	1.05	0.30	3.00	4.14	5.00	12.70	1.00	39
2	2	1	3	5.3	0.91	0.24	2.70	0.8	10.00	11.10	0.90	19
3	1	1	1	5.5	0.68	0.14	3.90	4.7	6.80	8.20	0.68	17
3	1	1	2	5.4	0.71	0.17	2.60	6.3	3.90	8.60	0.54	8
3	1	1	3	5.5	0.56	0.08	1.90	4.9	2.70	6.80	0.63	7
3	1	2	1	5.4	0.66	0.22	4.50	6	5.50	8.00	0.65	10
3	1	2	2	5.8	0.57	0.16	4.50	5.4	3.10	6.80	0.79	5
3	1	2	3	5.6	0.65	0.20	2.10	6.6	2.60	7.80	0.59	10
3	2	1	1	5.5	0.76	0.22	1.98	4.25	2.00	9.30	1.10	16

Block	fallow duration	fallow type	soil amendments	Ph	N	K	Mg	Ca	P	C	BD	earthworm
3	2	1	2	5.7	0.80	0.21	3.23	9.18	2.00	10.90	1.00	13
3	2	1	3	5.6	0.90	0.21	2.68	5.1	3.00	9.70	0.90	44
3	2	2	1	5.5	0.84	0.26	4.22	7.95	3.00	10.20	1.00	17
3	2	2	2	5.7	0.76	0.23	2.79	5.04	2.00	11.40	1.00	3
3	2	2	3	5.5	0.94	0.26	4.61	7.44	3.00	9.20	1.10	31
4	1	1	1	5.6	0.94	0.22	6.20	8.2	0.60	11.40	0.49	24
4	1	1	2	5.5	0.60	0.26	3.40	5.5	6.10	7.20	0.59	31
4	1	1	3	5.6	0.81	0.31	3.10	6.8	7.00	9.80	0.60	1
4	1	2	1	5.6	0.52	0.22	3.20	5	5.50	6.20	0.57	12
4	1	2	2	5.8	0.58	0.21	3.80	9.3	4.60	7.00	0.59	20
4	1	2	3	5.8	0.62	0.24	3.70	6.2	5.50	7.50	0.68	22
4	2	1	1	5.4	1.06	0.29	4.34	8.33	2.00	12.80	1.00	12
4	2	1	2	5.5	0.98	0.26	2.84	6.71	6.00	11.90	1.00	21
4	2	1	3	5.5	0.90	0.23	3.51	5.78	2.00	10.90	1.00	28
4	2	2	1	5.8	1.07	0.40	4.46	9.2	7.00	10.00	0.90	13
4	2	2	2	5.9	0.90	0.25	4.10	11.8	3.00	10.90	1.00	15
4	2	2	3	5.7	1.12	0.37	4.13	5.9	4.00	13.60	1.00	21