An Assessment of Intercropping and Fertilization in Cassava - (Manihot esculenta) Based Systems in the Kolli Hills, South India

by

Tina Harms

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science in Soil Science

Department of Renewable Resources
University of Alberta

Abstract

There is much interest in reducing risk, increasing yield and maintaining soil fertility and biodiversity in agriculture. The effects of intercropping cassava (*M. esculenta crantz)* with beans (*Phaseolus spp*), millet (*E. coracana*) or a bean-millet mixture with the use of various soil amendment treatments; manure, manure and synthetic fertilizer, synthetic fertilizer or mulch under a rainfed cropping system were investigated over a two year period in Kolli Hills, South India. Physical and chemical properties of soil, bean protein content, cassava leaf nutrients and starch content, and marginal rates of return were assessed. Results varied greatly across sites and seasons. Intercropping with millets significantly reduced crop yields in Mathyriolovo and Oleyur; mean yields in year one and two were higher when synthetic fertilizer and a combination of fertilizer and manure were applied; during year two, the greatest yield increase resulted from mulching. Intercropping with millets had both negative and positive impacts on soil: lowering available N, and exchangeable Mn, while showing increases in available P in various sites. When bean with millets were intercropped with cassava, there were significant increases in soil exchangeable Na, available P, EC, Cu and exchangeable K in comparison to other treatments. Manure resulted in a significant increase in soil pH, and a decrease in Zn; the addition of synthetic fertilizer resulted in an increase in soil EC in various sites. Results of principal component analysis (PCA) showed that soil Zn, clay content, CEC, Cu, pH and available K accounted for the greatest amount of variation in samples and the resultant soil quality index (SQI) for cassava production in the Kolli Hills. Economic analysis highlighted the great variation between site and seasons; fertilizer and manure plus fertilizer intercropped with millets or bean and millets having the highest marginal rate of return in year one, while sole cropping of cassava under a mulch treatment provided a positive return in year two. Based on soil properties, crop qualities and economics cassava based cropping systems may be improved by various intercropping systems and soil amendments; however, the great variation in

soil, climate, availability of inputs and the needs of the smallholder farmer need to be considered prior to forming overall management recommendations.

Acknowledgements

This thesis research would not have been possible without help from a number of individuals and organizations.

Thank you to DR. Miles Dyck. He generously gave me his time, guidance and support throughout this project, helping me grow as a scientist and as an individual. I am honored to have worked with him.

IDRC project staff at the University of Alberta: Dr. Nat Kav, Dr. Brent Swallow, Dr. Henry An, Dr. Ellen Godard, Dr. Mike Deyholes and John Pattison

MSSRF: Main staff in Chennai, field staff in Kolli Hills in particular Dr. Nambi, Dr. Olivier King, Siddick Abubacker and Nita Salena.

Dr. Balasubraminian Ecosave Labs, Salem Tamilnadu

UPASI: Dr. Robert Premkumar, Soil and leaf testing lab

Participatory farmers and day labourers

CIDA

IDRC

Thank you to my colleagues, Amanuel, Pam, Heilong, Sheryl, and Sunny for their help, advice.

My parents have always been there with love, support, encouragement, guidance and interest in what I choose to do. Thank you. Finally thank you Zaho.

Table of Contents

List of Tables

List of Figures

1.0 Intensification of smallholder cassava agroecosystems with intercropping, and soil amendments in Kolli Hills South India on soil and crop quality: A Review

1.1 Introduction

Agriculture is a means to sustain human life; it is also the source of income and a basis of culture for many of the world's people. To create sustainable agroecosystems we need to look beyond the basics of crop production and consider the ecological and environmental as well as the sociological impacts of agricultural systems (Altieri et al., 2012).

Agriculture is not static and is strongly influenced by population, global market forces, science, technology, and climate variability (Altieri et al., 2012). Within modern agriculture there is a focus on the use of monocultures, machines, improved crop varieties, and agrochemicals which has resulted in a decreased amount of biodiversity (Bedoussac and Justes 2011; Altieri et al., 2012). This system of agriculture has also led to increased risk and vulnerability of smallholder farmers and food insecurity on a more global scale. To diversify our agroecosystems and encourage healthy soils, standard practices should include the growth of native varieties and multiple species (Alteiri et al., 2012; Bedoussac and Justes 2011). To address the changing climate and increased vulnerability of monocropping systems, current agricultural practices should be integrative, focusing on efficient crop rotations, intercropping, organic manure and chemical fertilization to provide the greatest yields, conserving soil fertility and biodiversity, and providing food security (Kumar et al., 2008; Altieri et al., 2012; Lithourgidis et al., 2011).

Continuous cultivation of cassava in the Kolli Hills, Namakkal district of Tamilnadu, has resulted in reduced soil quality, reduced crop yields and reduced biodiversity. The farmer's preference for cassava *(m. esculenta),* being a cash crop, has resulted in less land being planted to traditional food crops such as millet and beans. To address these issues, a review of production in the Kolli Hills, intercropping, soil amendments, soil quality, and smallholder intensification was undertaken.

1.2 Kolli Hills, Tamil Nadu

The Kolli Hills (Kollimalai in Tamil) are a mountainous region in the Eastern Ghats on the Eastern border of the Namakkal District in Tamil Nadu, south India. They are located at longitude 78°20' to 78°30' E and latitude 11°10' to 11°30' N (Figure 1-1). They spread over an area of 28 293 hectares. The Kolli Hills are very diverse with 44% of the land preserved as a national forest, the majority of this forested land is along the steep slopes, while 52% of the flatter region is agricultural or agro-forestry based (Gruere et al., 2009; Jayakumar et al., 2009).

There are approximately 54 tribal communities in the Eastern Ghats (Panda et al., 2011; Jayakumar et al., 2009). The 2011 census found that there were 42,200 people living in the Kolli Hills, the majority of which belong to the Malayali, one of the Scheduled Tribes of India (Census of India 2011; MSSRF 2002, Gruere et al., 2009). The average family size is 4.4 and 36.9% of households income comes directly from crop production, another 22.1% of the income coming from farm wage earnings (Baseline APM study 2013).

The majority of households are poor, with an average farm size of 0.78 hectares; 0.70 hectares of un-irrigated dry, upland fields with the remaining 0.08 hectares in lowland, wet areas (Baseline APM study 2013). Rain-fed agriculture is predominant in the area with only 15 % under irrigation (paddy rice (*Oryza sativa)*). Pineapple (*Ananas comosus*) and banana *(Musa sp.)* are the major horticultural crops grown, while cassava (tapioca) *(M. esculenta),* acid lime (*Citrus aurantifolia*), mango (*Mangifera indica*), coffee (*Coffea arabica*), cardamom (*Elettaria cardamomum*), coriander (*Coriandrum sativum*), jackfruit (*Artocarpus heterophyllus)*, orange (*Citrus sp*.) and guava (*Psidium sp*.) are cultivated on a large scale. Ginger (*Zingiber officinale*), turmeric (*Curcuma longa*), pepper (*Piper nigrum*) and mustard (*Brassica juncea*) are grown in a few specific areas. Ragi, small millets, and pulses are also grown (Panda et al., 2011; Jayakumar et al., 2009).

There is one main road to the Kolli Hills, which leads to the city of Semmedu, and was built in the mid 1990's (Finins 2007). With the road came cassava cultivation; the area traditionally planted millets and other subsistence crops (Finins 2007; Maloles et al., 2011). Cassava production led to a decline in other crop production and the amount of crop genetic diversity, especially in minor millets began to decrease (Maloles et al., 2011; FAO 2002; MSSRF 2002). In 2006, it is estimated that 75% of dry land areas are seeded with Cassava (Gruere et al., 2009).

1.2.1 Climatic conditions

The hills range from 1000 to 1300 metres above sea level (masl) and have a moderate climate with daytime temperatures reaching 20 to 30 degrees °C as the maximum and 10 to 20 degrees Celsius as the minimum. The average annual precipitation is 1440 mm (Gruere et al., 2009; Maloles et al., 2011) and varies greatly from year to year, between 800 – 1800 mm (Figure 1-2). Rainfall is usually heaviest during the monsoon (August to December), however, there is a great amount of variation within that period as well (Figure 1-3). The majority of agriculture in the Kolli Hills is rainfed and therefore the great variation in rainfall that affects crop yields from year-to-year.

1.2.2 Soil Characterization

The Kolli Hills region consists of highly weathered laterite soils, also referred to as Kaolisols or Acrisols by the FAO. The clay fractions of these soils are dominated by 1:1 clays and aluminum and iron oxides. The bedrock of the Kolli Hills is composed of granite gneiss of ancient origin, plateau type with mineral deposits. The area contains acid charnokite with minor bands of pyroxene, magnetite and quartzite. The hills are highly undulating with seasonal and semi-permanent streams throughout that flow in all directions and drain into the Ayyar River and Varattar Nadi (King 2005).

The soils are deep to very deep, non-calcareous and developed from weathered gneiss (Jayakumar et al., 2009). There is high bauxite content in some areas. Soil texture varies with the hilltops characterized by rocky terrain with various sized stones and boulders. The soil has a sandy loam texture and the bases of the hillsides are characterized by alluvial clay loam texture (King 2005). The soils are excessively drained and have moderate permeability.

1.3 Cassava Production

Globally cassava (*Manihot esculenta* Cranz, family Euphoribiaceae) has a growing area of 18.5 million ha. Cassava is one of the world's major staple crops and can grow under a great variety of soil and climatic regions while still able to produce a high number of calories for a comparatively low production cost (Herrera Campo et al., 2011; Amanullah et al., 2007; Polthanee et al., 2007; Howeler 1990; Kanto et al., 2012; Islami et al., 2011; Chaisri et al., 2013). Cassava is a perennial crop and originated in Northeastern and Central Brazil. During the 17th century, cassava was introduced in India.

Originally, a food crop, cassava has become a major industrial crop in recent years (Suresh et al., 2011; Srinivas 2009; Srinivas 2007). In India, there are over 800 small-scale food and industrial uses for the cassava starch, such as: pharmaceutical purposes, textiles as well as sago pellets, which can be used as the equivalent of noodles for various food preparations such as porridge, crackers and gruel, chips, flour, and wafers (Srinivas 2009; Gruere et al., 2009; Srinivas 2007). The major use of cassava in Tamil Nadu is for the production of adhesives, corrugated cardboard and textiles, and there is a projected increase in demand for these products and therefore continued pressure for the production of cassava (Srinivas 2007). Due to the great diversity in uses, cassava has become an important commercial crop in the agricultural economy of Tamil Nadu (Srinivas 2007).

There is a strong reliance on agriculture in India and it depends heavily on monsoon rains for its rain fed systems (Muthumanickam et al., 2012). Higher moisture is related to increases in yield for cassava (Herrera Campo et al., 2011) since water stress in cassava will increase the above ground biomass growth instead of tuber growth (Fukai and Trenbath 1993). There are several factors that can lead to losses in cassava yields: 1) pests, including whiteflies, disease, cassava mosaic virus (CMV); and 2) loss of soil fertility (Cadavid et al., 1998, Herrera Campo et al., 2011, Howeler 1991). The major causes of loss in cassava production systems need to be addressed to meet cassava demand. The great demand for cassava had led to continuous cropping in many parts of Thailand and India (Howeler 1991; Sittibusaya et al., 1988; Kanto et al., 2012). Studies conducted in Thailand showed that 20 to 25 years of continuous cropping of cassava led to reductions of 60 to 70% in yields (Howeler 1991; Sittibusaya et al., 1988). One major factor that has led to reductions in yields and soil fertility in the cassava production system is the lack of nutrient replenishment either with inorganic or organic fertilizers (Islami et al., 2011; Polthanee et al., 2007; Howeler et al., 1991). Continuous cassava production usually results in declines in soil fertility since it is widely spaced, slow to cover the soil in the first 90 to 120 days of growth, and planting is done at the onset of the monsoon, leading to heavy rains and high soil losses (Polthanee et al., 2007; Islami et al., 2011; Chaisri et al., 2013; Kanto et al., 2012; Howeler 1991). Cassava production also leads to soil fertility reduction since the aboveground portions of cassava (stems) are used for replanting (i.e., not reincorporated back into the soil; Polthanee et al., 2007; Howeler 1991) and the tubers are removed and sold. Cassava monocropping was shown to decrease soil organic matter (SOM) after 4 years and also resulted in decreased available soil phosphorus (P) levels (Islami et al., 2011). Cassava extracts more potassium (K) than any other comparable crop, while also extracting a large amount of nitrogen (N) and P. Howeler (1991) showed that exhaustion of soil K seems to be the most important factor in tuber yield loss. Therefore, to maintain cassava production and to create sustainable soil fertility, management changes that address the loss of soil nutrients required by cassava need to occur (Cadavid et al., 1998).

1.4 Intercropping

Intercropping and multiple cropping is a management strategy that could help to increase agricultural intensification and meet increasing global food demand while addressing soil quality issues (Midmore 1993). Intercropping, mixed cropping and polyculture refer to the growth of two or more crops at the same time within the same space (Altieri and Nicholls 2003; Zuo and Zhang 20011; Lithourgisdis et al., 2011; Bedoussac and Justes 2011) and is widely practiced in China, Southeast Asia, Africa, Latin America and India. As Altieri et al., (2012) have pointed out, intercropping is commonly used in tropical parts of the world by smallholder farmers and as much as 15 to 20 percent of the world's food supply comes from these systems, providing reduced risk in agriculture and increased food security.

Within an intercropping system, there is most often one main crop and one or more added crops, which are usually from different plant families and have a large portion of their growing period together, although they need not be planted or harvested at the same time (Willey 1979; Lithourgisdis et al., 2011). Natural systems are often composed of mixed species and therefore intercropping would most closely resemble this system (Bedoussac and Justes 2011). Intercropping is especially useful in low N systems because the N produced by the legume can often be used as a source of N for the component crops (Bedoussac and Justes 2011). Choices as to which intercrop to be used should be based on resource needs, light and water availability and the spatial requirement of each component crop (Midmore 1993). The timing of planting, the density and the spatial arrangement of the component crops must also be considered in intercropping systems; systems are most effective when the component crops have different growth durations and different maximum growth resource and nutrient uptake times (Islami et al., 2011; Fukai and Trenbath 1993; Midmore 1993).

A summary of various studies and the resulting benefits found from intercropping. A greater amount of soil conservation, due to reduced soil erosion, occurred because of greater ground cover in intercropping systems (Anil et al., 1998; Amanullah et al., 2007; Fukai and Trenbath 1993; Sharma et al., 2011). Better weed control and lower weed competition from greater land area use was found in intercropping systems (Banik et al., 2006; Lithourgisdis et al., 2011). With greater bio diversity, pest and disease pressure was reduced according to several authors (Altieri and Nicholls 2003; Fukai and Trenbath 1993). Several authors also found that there was improved lodging resistance in intercropping systems (Anil et al., 1998; Lithourgisdis et al., 2011). Intercropping with legumes led to an increased amount of available N to their component, non-legume crops (Ram et al., 2012; Islami et al., 2011; Sharma et al., 2011; Polthanee et al., 2007). Finally, significantly improved yields and an overall greater efficiency of land use from having intercrops were found (Lithourgisdis et al., 2011; Zuo and Zhang 2008; Islami et al., 2011; Altieri 1999).

Disadvantages in intercropping systems include increased competition for light, water and nutrients, and allelopathic effects (Lithourgisdis et al., 2011; Zuo and Zhang 2011; Islami et al., 2011; Altieri 1999). Additional difficulties encountered in intercrop research are experimental results are often site-specific and vary by season this can also occur in monocrops, but higher levels of competition between crops at different growth stages increases variability (Fukai and Trenbath 1993; Islami et al., 2011).

Cassava is an ideal crop for intercropping since its row spacing is wide and it is slow in its initial growth, the initial 100 days of cassava development is slow and its nutrient, light and water requirements are minimal (Suja et al., 2010 Amanullah et al., 2006; Polthanee et al., 2007). In humid and sub-humid tropics, intercropping cassava is widely practiced to reduce soil erosion, nutrient leaching, soil fertility depletion, and to control weeds (Amanullah et al., 2007; Islami et al., 2011; Howeler 1991).

Approximately one third of the cassava grown worldwide is intercropped (Amanullah et al., 2007; Suja et al., 2010). Intercropping cassava with cowpea found non-significant decreases in cassava yields (Amanullah et al., 2007). Sharma et al., (2011) found increases or non-significant decreases to cassava when it was intercropped with a legume. When intercropped with maize, cassava yields decreased significantly, this may be attributed to greater competition for the same resources (Amanullah et al., 2007). Cassava intercropping in the Kolli Hills may be effective in providing food security, increasing bio diversity and improving soil conservation.

1.5 Soil Amendments

Agroecosystems require nutrient management strategies that will maintain yields and soil quality (Ogunwole et al., 2010). Organic and inorganic fertilizers are used to increase yields and improve soil fertility in agricultural systems (Ram et al., 2012; Cadavid et al., 1998; Yadav et a. 1994; Patra et al., 1997; Ram and Kumar 1997; Ram et al., 2006). Responses to fertilizers for monocultures have led to recommendations for fertilizer application to achieve higher yields and maintain soil fertility (Leihner 1983). Fertilizer responses in intercropping systems may respond differently than monocrops and application rates for these systems still require more study (Leihner 1983). However, many studies have shown that there are great benefits to intercropping systems of organic and inorganic soil fertility amendments.

1.5.1 Organic Inputs

Organic manures are useful for maintenance of soil quality and focus on the concept of recycling nutrients as opposed to applying nutrients regularly (Sharma et al., 2011). Organic amendments, such as composts and manures, generally provide plants with lower N levels due to its slower releases and provide a more uniform foliar N concentration, which avoids the high flux of N, which may help to achieve optimum crop nutritional levels that deter pest attack (Altieri and Nicholls 2003).

As table1-2 demonstrates, there are many benefits to the application of organic inputs. Organic manures can increase the activity and the overall biomass of the soil microbial community within intercropping systems (Kumar et al., 2008; Drinkwater et al., 1995; Bulluck et al., 2002; Goulding 2000). Soil physical properties including structure, aggregate stability, bulk density, porosity and water holding capacity as well as infiltration can be improved in intercropping systems with the application of organic fertilizers (Kumar et al., 2008; Amanullah et al., 2007; Bulluck et al., 2002; Saha et al., 2008; Doran 1995). Studies have also shown that organic amendments in intercropping systems will improve soil fertility and available nutrients, including nitrogen to crops (Bulluck et al., 2002; Saha et al., 2008; Singh et al., 2007; Cadavid et al., 1998). Finally, many studies have concluded that organic fertility amendments improve overall soil quality (Drinkwater et al., 1995; Saha et al., 2008; Singh et al., 2007; Datta et al., 2010).

Application of plant mulch with minimum tillage has been shown to reduce soil erosion, maintain soil structure, conserve soil water, reduce soil temperature, and maintain soil fertility via nutrient cycling (Cadavid et al., 1998). Mulching improved crop growth, root yield and dry matter content without fertilization (Cadavid et al., 1998). Mulching significantly reduced soil temperatures and increased soil organic carbon, K, P, calcium (Ca) and magnesium (Mg) (Cadavid et al., 1998).

There are many benefits to the use of organic fertilizers in intercropping systems. However, Goulding (2000) has pointed out that there are negative effects as well as positive impacts with the use of organic manures including higher levels of N leaching loss with cattle manure. In addition, Datta el al. in 2010 demonstrated that yields in organic systems were lower than yields in synthetic fertilizer systems.

1.5.2 Chemical Inputs

Synthetic fertilizers provide great yield improvements; they contributed to the Green Revolution in India and around the world (Agoramoorthy 2008). Pathak et al., 2010 showed that there were major increases in yields from 1970 to the late 1990's. Moderate applications of N, P and K have been shown to sustain productivity for longer periods (Cadavid et al., 1998). Fertilizer application increased soil organic matter in a study done by Saha et al., 2008. With continual use of synthetic fertilizers, there could be a reduction in soil health and a reduction in crop productivity (Ram et al., 2012). Critics of the Green Revolution in India have claimed that the introduction of inorganic fertilizers has led to negative implications for yields, the environment and the social status of farmers (Agoramoorthy 2008). Yields have plateaued or are decreasing even with high fertilizer application and environmental impacts such as salinity, contamination of water sources and loss of soil organic matter in occurring (Bouman et al., 2007).

Therefore, the combined use of organic and inorganic fertilizers can provide many crop and environmental benefits. Ram et al., 2012 showed that organic with inorganic fertility amendments led to improved crop productivity and soil health. Combined organic/inorganic input management practices that incorporate crop residues into soils enhanced macro-aggregate stability, bulk density, soil porosity and soil fertility status of the soil (Ogunwole et al., 2010; Datta et al., 2010; Chen et al., 2011; Miao et al., 2011). The use of both inorganic and organic soil amendments could improve yields, and soil health (Yadav et al., 1994; Patra et al., 1997; Ram and Kumar 1997; Ram et al., 2006; Ram et al., 2012).

1.6 Soil Quality

Intensification of agriculture, including intercropping, even with the application of organic and inorganic fertilizers, affects sustainability and soil quality (Saha et al., 2008; Midmore 1993). Soil is not a renewable resource, there has been widespread soil degradation in the past which has led to acidification, salinization and under extreme circumstances desertification (Chen et al., 2011). In areas where these extreme effects have not been seen, improper soil management results in lower soil fertility, decreased ability for water infiltration and water holding capacity which ultimately lowered yields.

Reducing soil degradation, producing food, feed, and supporting animal and plant health are measures to assess soil quality (Schoenholtz et al., 2000; Ogunwole et al., 2010; Karlen et al., 1997; Doran et al., 2004). Soil quality can be defined as the ability that the soil has, in managed or natural ecosystems, to achieve a particular goal (Karlen et al., 1997). Various definitions constitute what attributes are a part of good soil; these are often based on the needs of the end user. The capacity of soils to be productive in any agricultural system depends on many factors not solely to supply sufficient plant nutrients. The physical, biological and chemical characteristics of a soil including its microbial communities, organic matter content, pH, texture, cation exchange capacity (CEC),electrical conductivity (EC), moisture content, and water-retention capacity among others all influence fertility and ecosystem functioning. Soil is an essential part of our food and fibre system as well as the quality of the environment and ecosystem functioning. The health of soil can change over time due to both human and natural effects (Doran et al., 2004).

1.6.1 Physical Soil Properties and Soil Quality

Physical soil properties affecting soil quality include texture and bulk density. Texture is the proportion of sand, silt and clay within the soil. Soils with higher clay content are often considered more fertile than sandy soils although often more difficult to till and may be more susceptible to compaction. Sandy soils are often easier to till but can be less fertile, and have lower water retention capacities. Soil texture will also influence the soil's ability to retain and transport water and nutrients (Doran and Parkin 1994). Soil aggregation is also an important indicator of soil physical quality, maintaining soil structural stability, and thereby soil water movement and retention (Ogunwole et al., 2010). Soil porosity measures the spaces between soil aggregates and contributes to the percentage of air and water in the soil. It functions to retain soil water and it is important for root growth (Doran and Parkin 1994). Plant available water holding capacity, the water content at field capacity minus the water content at permanent wilting point, plays an important part of the amount of water available to plants. Higher water holding capacity can also reduce the amount the soil is able to erode (Doran and Parkin 1994; Brady and Wiel 2007).

Bulk density is a measure of the compactness of a soil, when the bulk density of soil increases to a critical level it becomes more difficult for roots to penetrate the soil, thereby impeding root growth. Erosion and the loss of organic matter can lead to an increase in bulk density, which can lead to lower yields and higher production costs (Brady and Wiel 2007).

1.6.2 Chemical Soil Properties and Soil Quality

Chemical soil properties include soil organic matter content (SOM), cation exchange capacity (CEC), soil macro and micronutrient levels, pH, and electrical conductivity (EC) (Saha et al., 2008) among others. SOM is often considered one of the most important indicators of soil quality (Saha et al., 2008; Craswell and Lefroy 2001; Abawi and Widmer 2000). Many of the biological, physical and chemical properties of soil are functions of SOM (Abawi and Widmer 2000). SOM has many functions and these can vary in different soil types and under different climatic conditions (Craswell and Lefroy 2001). SOM can serve as a reserve for N and other micro and macronutrients; as well, it can buffer and regulate the release of these nutrients (Ogunwole et al., 2010; Craswell and Lefroy 2001). SOM is a source of energy for soil organisms, influences soil structure, water holding capacity, cation exchange capacity and the formation of stable aggregates (Ogunwole et al., 2010; Craswell and Lefroy 2001; Sharma et al., 2013).

CEC is the ability of the soil to hold onto cations at its surface, clay particles and organic matter (OM) with negative charges on their surfaces have a high CEC. CEC is therefore linked to SOM and is a good indication of how readily nutrients will be bound or released from the soil to be available for plant uptake (Brady and Wiel 2007). The major nutrients required for plant growth include N, P, and K. K is important in a plants ability to regulate water uptake and can help crops to become more tolerant to dry spells in a rain fed system (Sharma et al., 2011). K is also important in cassava systems since it is important for tuber formation (Howeler 1991). N and P are important for above ground growth of the plant (Howeler 1991).

The availability of micro and macronutrient is affected by the soil's pH. Measuring soil pH can also demonstrate, over a short period, if trends emerge in terms of changes in soil acidification, salinization, electrical conductivity and exchangeable Na content (Doran and Parkin 1996; Sharma et al., 2011). Changes in pH can cause root to decrease, increase root disease and affect biological activity (Doran and Parkin 1996; Sharma et al., 2011).

1.7 Intensification of Smallholder Agro ecosystems

With worldwide yields plateauing or declining, populations increasing and a limit on available arable land, methods need to be developed to meet the global needs of agriculture production (Killham 2011; Singh et al., 2007; Kumar et al., 2008; Altieri et al., 2012; Lithourgidis et al., 2011). The soil is an integral part of agro ecosystems and needs to be maintained if we are to achieve sustainability (Killham 2011). Methods that include intercropping, multiple cropping and the use of inorganic and organic fertilizer need to be considered to develop a system that would create more efficient and sustainable agro ecosystems (Chen et al., 2011; Altieri et al., 2012).

Countries like China, India, Brazil, Mexico, Indonesia, Vietnam, Pakistan and Sri Lanka face great challenges when it comes to agriculture since their populations are growing rapidly while soil fertility is decreasing (Chen et al., 2011). Integrated soil management (ISM) as defined by Killham (2011), is a method of sustaining production by managing the water, nutirents and crops in a soil. ISM can also include the ability to increase cropping, while improving water, nutrient and soil efficiency and enhancing overall soil structure (Killham 2011). The focus of integrated soil management is the assessing the overall system in terms of the soil, while sustainable agriculture would look more broadly at all aspects (soil, insects, plants, etc.) of an agricultural system. Management practices of soil should be aimed at providing adequate crop nutrition, reducing pest and disease pressure, maintaining the soil and avoiding negative environmental impacts (Saha et al., 2008; Midmore 1993). ISM is an important aspect to achieve a sustainable level of agricultural production (Duegd et al., 1998).

Chen et al., (2011) state that countries that benefited most from the Green Revolution (1960-1980) are countries that now need to develop an integrated soil-crop system of management (ISSM), this would include India and China. Many farmers in these areas have an average farm size of less than one hectare; therefore, the labour needed to implement a more intensive system of agriculture technique may be available (Chen et al., 2011).). ISSM, which takes into consideration soil and crops to manage fertility, has the ability to lower costs and the potential environmental impacts of overuse of fertilizers. Another model of integrated management comes from Khan et al., (2011) the push-pull technology, which is a conservation approach for weed, insect and soil management. This method of integrated control was designed for cereal–livestock-based farming systems (Khan et al., 2011).

However is there is a lack of significant research in many aspects of integrated crop management. The push –pull technology of Khan et al., (2011) and the ISSM of Chen et al., (2011) and the ISM models of Killham 2011 are new methods to try to increase yields in areas of the world where food security is an important issue. Further research needs to go into developing a method that assesses the production system, the soil quality, the crop quality as well as economics and this may result in a model of agriculture intensification that could help contribute to meeting the needs of global agricultural demand.

1.8 Conclusion

A review of production in the Kolli Hills indicates that monocropping cassava production is on the rise (Gruere et al., 2009). As cassava production increases there is less land used for food production and this increases the risks for the smallholder farmers in the Kolli Hills. The literature has shown worldwide approximately one third of the cassava is intercropped (Amanullah et al., 2007; Suja et al., 2010). Intercropping is a management strategy that could help to increase agricultural intensification and meet food demand, decrease risk and improve soil quality in the Kolli Hills (Midmore 1993).

Soil quality is an integral part of agricultural intensification and therefore a review of chemical and physical soil properties showed how important SOM is for many chemical functions. In addition, the use of organic amendments can help to increase SOM and preserve and improve soil quality, synthetic fertilizers are also important in providing nutrients needed by cropping systems. Finally, a review of smallholder intensification showed that a focus not just on yield, but also on soil quality, weed control and sustainability is necessary for sustainable agricultural intensification.

1.9 Objectives

Continuous cultivation of cassava in the Kolli Hills, in the Namakkal district of Tamilnadu, has resulted in reduced soil quality, reduced crop yields and reduced biodiversity. The farmer's preference for cassava *(m. esculenta),* being a cash crop, has resulted in less land being planted with traditional food crops such as millet and beans. To address these issues a review of cassava production in the Kolli Hills, intercropping, soil amendments, soil quality, and smallholder intensification was undertaken.

This study aimed to investigate whether local intensification (achieved through intercropping and fertilizer treatments) of the cassava cropping system could improve overall yields, soil quality, and crop biodiversity with the overall goal of increasing food security in these communities. Specifically the objectives of the thesis were to:

1. Assess yields, crop quality and economics of intercropping rotations and fertilizer amendments on cassava based systems in the Kolli Hills.

2. Assess intercropping and fertilizer practices on soil physical and chemical properties with the creation of a soil quality index.

This study hopes to promote bio diversity and effective and sustainable cropping systems. This study may act as a demonstration to local farmers and increase the use of intercropping in the Kolli Hills. This study may also lead to further studies of intercropping in this area. Finally, the results of this study hope to demonstrate that intercropping and fertilizing will help to increase diversity, both above and belowground as well as ensure food security for smallholder farmers in the Kolli Hills.

1.10 Figures and Tables

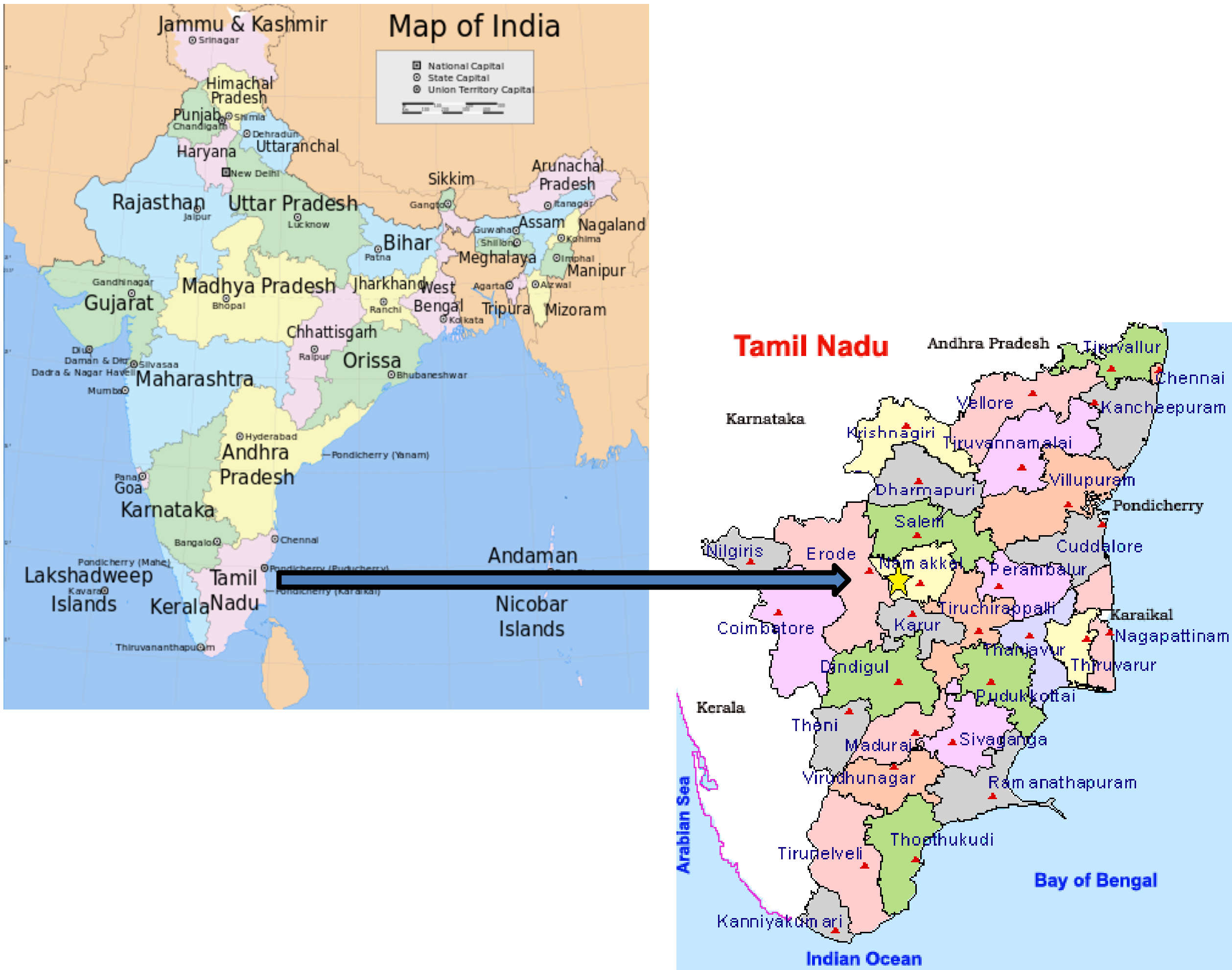

Figure 1-1: Study area, Kolli Hills highlighted with a star, in the Namakkal district in the state of Tamil Nadu, south India (Source:http://commons.wikimedia.org/wiki/File:India_states_and_union_territories_map.svg#filelinks, http://kidedu.org/domains/kidedu.org/images/c/c6/Tamil nadu.gif)

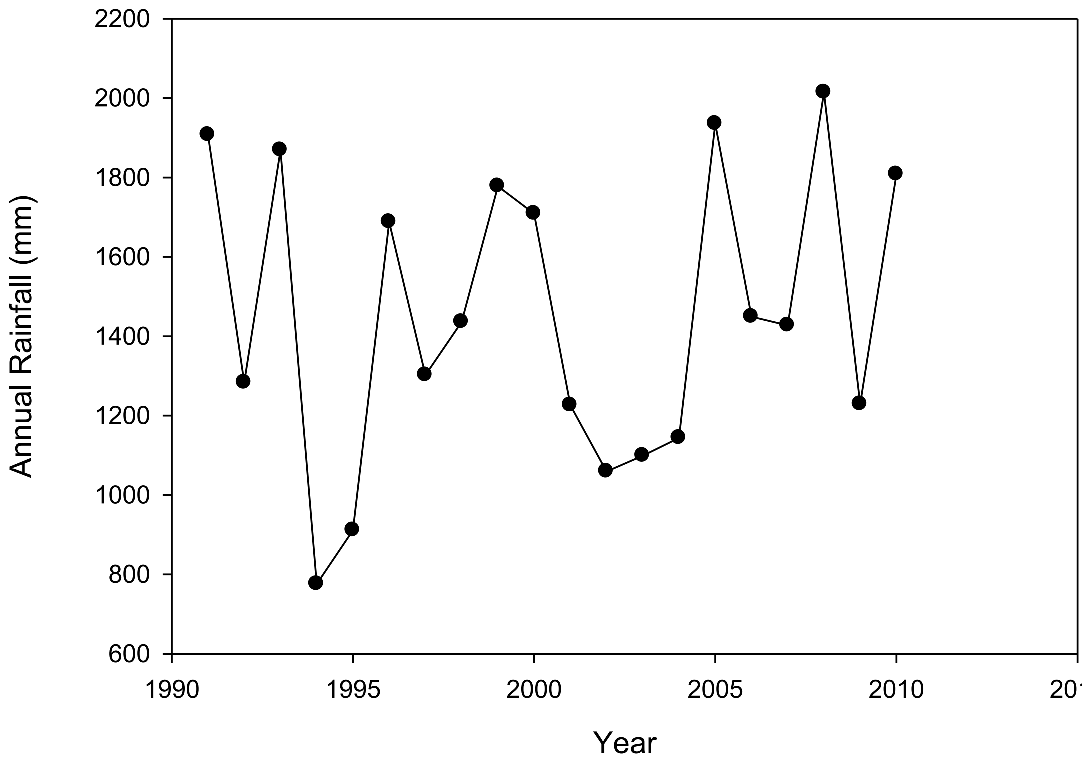

Figure 1-2: Mean annual precipitation (mm) from 1990 to 2010 in Kolli Hills, South India

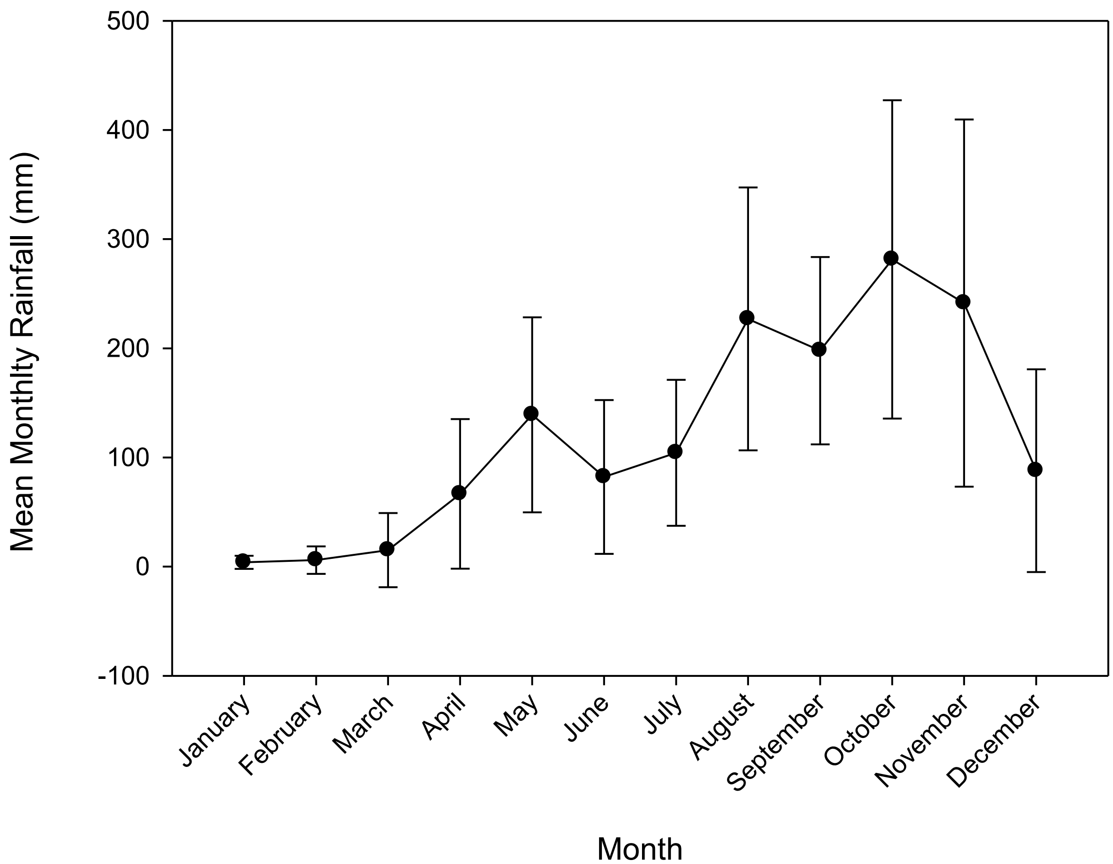

Figure 1-3: Mean Monthly precipitation (mm) from 1991 to 2010 in Kolli Hills, South India (n=20 bars=standard deviation)

1.11 Literature Cited

Abawi, G. S., & Widmer, T. L. (2000). Impact of soil health management practices on soilborne pathogens, nematodes and root diseases of vegetable crops. *Applied Soil Ecology, 15*(1), 37-47. doi:10.1016/S0929-1393(00)00070-6

Agoramoorthy, G. (2008). Can India meet the increasing food demand by 2020? *Futures, 40*(5), 503-506. doi:10.1016/j.futures.2007.10.008

Altieri, M. (1999). The ecological role of biodiversity in agroecosystems. *Agriculture Ecosystems & Environment, 74*(1-3), 19-31. doi:10.1016/S0167-8809(99)00028-6

Altieri, M. A., & Nicholls, C. I. (2003). Soil fertility management and insect pests: Harmonizing soil and plant health in agroecosystems. *Soil and Tillage Research, 72*(2), 203-211. doi:10.1016/S0167-1987(03)00089-8

Altieri, M. A., Funes-Monzote, F. R., & Petersen, P. (2012). Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty. *Agronomy for Sustainable Development, 32*(1), 1-13. doi:10.1007/s13593-011-0065-6

Anil L, Park J, Phipps RH, Miller FA. (1998). Temperate intercropping of cereals for forage: A review of the potential for growth and utilization with particular reference to the UK. Grass Forage Sci 53:301-317.

Amanullah, M. M., Kailasam, C., Safiullah, A. M., Selvam, S., & Sivakumar, K. (2007). Crop simulation growth model in cassava. *Research Journal of Agriculture and Biological Sciences, 3*(4), 255-259.

Amanullah, M. M., Sathyamoorthi, K., Vaiyapuri, K., Alagesan, A., & Pazhanivelan, S. (2007). Influence of organic manures on the nutrient uptake and soil fertility of cassava (manihot esculenta crantz.) intercropping systems. *International Journal of Agricultural Research, 2*(2), 136-144.

Amanullah, M. M., Sathyamoorthi, K., Vaiyapuri, K., & Pazhanivelan, S. (2007). Yield and economics of cassava (manihot esculenta crantz.) as influenced by intercropping and organic manures. *International Journal of Plant Sciences (Muzaffarnagar), 2*(1), 18-22.

Banik P, Midya A, Sarkar BK, Ghose SS (2006) Wheat and chickpea intercropping systems in an additive series experiment: Advantages and weed smothering. Eur J Agron 24:325-332.

Baseline APM Survey (2013). M.S. Swaminathan Foundation and the University of Alberta. Alleviating Poverty and Malnutrition in Agrobiodiversity Hotspots: Baseline Report.

Bedoussac, L., & Justes, E. (2011). A comparison of commonly used indices for evaluating species interactions and intercrop efficiency: Application to durum wheat-winter pea intercrops. *Field Crops Research,124*(1), 25-36. doi:10.1016/j.fcr.2011.05.025

Brady, Nyle and Ray Weil. 2008. The Nature and Properties of Soils. 14th ed. Prentice Hall, Upper Saddle River, NJ. 975 p. ISBN 13-978-0-13-227938-3.

Bulluck, L., Brosius, M., Evanylo, G., & Ristaino, J. (2002). Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. *Applied Soil Ecology,19*(2), 147-160. doi:10.1016/S0929-1393(01)00187-1

Cadavid, L., El-Sharkawy, M., Acosta, A., & Sanchez, T. (1998). Long-term effects of mulch, fertilization and tillage on cassava grown in sandy soils in northern Colombia. *Field Crops Research, 57*(1), 45-56. doi:10.1016/S0378-4290(97)00114-7

Census of India. (2011). Population Enumeration Data (Final Population) Tamilnadu. Retrieved November 25, 2011, from http://www.censusindia.gov.in/2011census/population_enumeration.aspx

Chaisri, S., Panitnok, K., Sarobol, E., Thongpae, S., Chaisri, P., Ngamprasitthi, S., . . . Boonsri, N. (2013). Effects of chicken manure and chemical fertilizer management on yield of cassava grown on map bon, coarse-loamy variant soil. *Communications in Soil Science and Plant Analysis, 44*(1-4), 347-355. doi:10.1080/00103624.2013.742004

Chen, X., Cui, Z., Vitousek, P. M., Cassman, K. G., Matson, P. A., Bai, J., . . . Zhang, F. (2011). Integrated soil-crop system management for food security. *Proceedings of the National Academy of Sciences of the United States of America, 108*(16), 6399-6404. doi:10.1073/pnas.1101419108

Craswell, E., & Lefroy, R. (2001). The role and function of organic matter in tropical soils. *Nutrient Cycling in Agroecosystems, 61*(1-2), 7-18. doi:10.1023/A:1013656024633

Datta, S. P., Rattan, R. K., & Chandra, S. (2010). Labile soil organic carbon, soil fertility, and crop productivity as influenced by manure and mineral fertilizers in the tropics. *Journal of Plant Nutrition and Soil Science,173*(5), 715-726. doi:10.1002/jpln.200900010

Deugd, M., Röling, N., & Smaling, E. M. A. (1998). A new praxeology for integrated nutrient management, facilitating innovation with and by farmers. *Agriculture, Ecosystems & Environment, 71*(1–3), 269-283. doi:10.1016/S0167-8809(98)00146-7

Doran, J.W., Sarrantonio, M., Janke, R., 1994. Strategies to promote soil quality and soil health. In: Pankhurst, et al., (Eds.),Soil Biota: Management in Sustainable Farming Systems. CSIRO, Vic., Australia, pp. 230–237.

Doran JW, Parkin TB (1994) Defining and assessing soil quality. In: Doran JW, Coleman DC, Bezdicek DF, Stewart BA (Eds.) Defining soil quality for a sustainable environment. SSSA Spec. Publ. 35. ASA, Madison, WI, pp 3–21

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

Drinkwater, L. E., Letourneau, D. K., Workneh, F., Vanbruggen, A. H. C., & Shennan, C. (1995). Fundamental differences between conventional and organic tomato agroecosystems in California. *Ecological Applications, 5*(4), 1098-1112. doi:10.2307/2269357

Finnis, E. (2007). The political ecology of dietary transitions: Changing production and consumption patterns in the Kolli Hills, India. *Agriculture and Human Values, 24*(3), 343-353. doi:10.1007/s10460-007-9070-4

Fukai, S., & Trenbath, B. (1993). Processes determining intercrop productivity and yields of component crops. *Field Crops Research, 34*(3-4), 247-271. doi:10.1016/0378-4290(93)90117-6

Goulding, K., Poulton, P., Webster, C., & Howe, M. (2000). Nitrate leaching from the broadbalk wheat experiment, Rothamsted, UK, as influenced by fertilizer and manure inputs and the weather. *Soil use and Management, 16*(4), 244-250.

Gruere, G., Nagarajan, L., & King, E. D. I. O. (2009). The role of collective action in the marketing of underutilized plant species: Lessons from a case study on minor millets in south India. *Food Policy, 34*(1), 39-45. doi:10.1016/j.foodpol.2008.10.006

Herrera Campo, B. V., Hyman, G., & Bellotti, A. (2011). Threats to cassava production: Known and potential geographic distribution of four key biotic constraints. *Food Security, 3*(3), 329-345. doi:10.1007/s12571-011-0141-4

Howeler, R., & Cadavaid, L. (1990). Short-and long-term fertility trials in Colombia to determine the nutrient-requirements of cassava. *Fertilizer Research, 26*(1-3), 61-80. doi:10.1007/BF01048744

Howeler, R.H. (1991). Long-term effect of cassava cultivation on soil productivity. Field Crops Res., 26: 1-18.

Islami, T., Guritno, B., & Utomo, W. H. (2011). Performance of cassava (manihot esculenta crantz) based cropping systems and associated soil quality changes in the degraded tropical uplands of east java, Indonesia. *Journal of Tropical Agriculture, 49*(1/2), 31-39.

IUSS Working Group WRB, 2006. World Reference Base for Soil Resources 2006: a Framework for International Classification, Correlation and Communication, 2ndedition. Food and Agriculture Organization of the United Nations, Rome

Jayakumar, S., Ramachandran, A., Bhaskaran, G., & Heo, J. (2009). Forest dynamics in the Eastern Ghats of Tamil Nadu, India. *Environmental Management, 43*(2), 326-345. doi:10.1007/s00267-008-9219-y

Kanto, U., Jutamanee, K., Osotsapar, Y., & Jattupornpong, S. (2012). Effect of swine manure extract on leaf nitrogen concentration, chlorophyll content, total potassium in plant parts and starch content in fresh tuber yield of cassava. *Journal of Plant Nutrition, 35*(5), 688-703. doi:10.1080/01904167.2012.653074

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F., Schuman, G.E., 1997. Soil quality: a concept, definition, and framework for evaluation. Soil Sci. Soc. Am. J. 61, 4–10.

Khan, Z., Midega, C., Pittchar, J., Pickett, J., & Bruce, T. (2011). Push-pull technology: A conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa UK government's foresight food and farming futures project RID B-8523-2009. *International Journal of Agricultural Sustainability, 9*(1), 162-170. doi:10.3763/ijas.2010.0558

King, E.D.I.O., 2005. Sacred Forests of Kolli Hills, Tamil Nadu, India: A Study on Botany, Ecology and Community Interactions. Ph.D. Thesis, M.S. Swaminathan Research Foundation, Chennai, India

Kumar, A., Angadi, S. S., & Ravikumar, R. L. (2008). Influence of legumes on yield, quality and economics of pop sorghum under inter and mixed cropping system. *Plant Archives, 8*(1), 351-353.

Leihner, D. (1983). *Management and evaluation of intercropping systems with cassava.*

Lithourgidis, A. S., Dordas, C. A., Damalas, C. A., & Vlachostergios, D. N. (2011). Annual intercrops: An alternative pathway for sustainable agriculture. *Australian Journal of Crop Science, 5*(4), 396-410.

Maloles, J. R., Berg, K., Subramanyam Ragupathy, Nirmala, B. C., Althaf, K. A., Palanisamy, V. C., & Newmaster, S. G. (2011). The fine scale ethnotaxa classification of millets in southern India. *Journal of Ethnobiology, 31*(2), 262-287. doi:10.2993/0278-0771-31.2.262

Miao, Y., Stewart, B. A., & Zhang, F. (2011). Long-term experiments for sustainable nutrient management in china. A review. *Agronomy for Sustainable Development, 31*(2), 397-414. doi:10.1051/agro/2010034

Midmore, D. (1993). Agronomic modification of resource use and intercrop productivity. *Field Crops Research, 34*(3-4), 357-380. doi:10.1016/0378-4290(93)90122-4

MSSRF, 2002. Rural and Tribal Women in Agro-Biodiversity Conservation. Food and Agriculture Organization (FAO) RAP Publication 2002/08. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.

Muthumanickam, D., Kannan, P., Kumaraperumal, R., Natarajan, S., Sivasamy, R., & Poongodi, C. (2011). Drought assessment and monitoring through remote sensing and GIS in western tracts of Tamil Nadu, India. *International Journal of Remote Sensing, 32*(18), 5157-5176. doi:10.1080/01431161.2010.494642

Ogunwole, J. O., Iwuafor, E. N. O., Eche, N. M., & Diels, J. (2010). Effect of organic and inorganic soil amendments on soil physical and chemical properties in a west Africa savanna agroecosystem. *Tropical and Subtropical Agroecosystems, 12*(2), 247-255.

Panda, R. K., Arora, C. P., Gore, K. P., Jakhar, P., & Dash, B. K. (2011). Managing terraced lowland and medium sloping land for sustainable agriculture: A study from the eastern ghat region of India. *Irrigation and Drainage, 60*(5), 694-702. doi:10.1002/ird.643

Pathak, H., Mohanty, S., Jain, N., & Bhatia, A. (2010). Nitrogen, phosphorus, and potassium budgets in Indian agriculture. *Nutrient Cycling in Agroecosystems, 86*(3), 287-299. doi:10.1007/s10705-009-9292-5

Patra DD, Anwar M, Chand S. 1997. Residue recycling for restoring soil fertility and productivity of Japanese mint (Mentha arvensis) mustard (Brassica juncea) cropping system. International Plant Nutrition Colloquium; 1997 Sep 13–19; Tokyo, Japan. In: Ando T, Fujita K, Mae T, Matsumoto H, Mori S, Sekiya J, editors. Plant nutrition for sustainable food production and environment. Tokyo (Japan):Kluwer Academic. p. 587–588.

Polthanee, A., Wanapat, S., Wanapat, M., Wachirapokorn, C. (2007). Cassava-Legumes inter-cropping: A potential food-feed system for dairy farmers. Thailand Report: Use of Cassava as Animal Feed http://www.mekarn.org/procKK/polt.htm.

Ram M, Kumar S. 1997. Yield improvement in the regenerated and transplanted mint, Mentha arvensis by recycling the organic wastes and manures. Biores Technol. 59:141–149.

Ram D, Ram M, Singh R. 2006. Optimization of water and nitrogen application to menthol mint (Mentha arvensis L.) through sugarcane trash mulch in a sandy loam soil of semi-arid subtropical climate. Biores Technol. 97:886–893.

Ram, M., Singh, M., Prajapati, A. K., Ram, D., & Rawat, G. (2012). Towards sustainable production of peppermint (mentha piperita L.) through integrated use of vermicompost and cowpea green manuring with synthetic nitrogen fertilization. *Archives of Agronomy and Soil Science, 58*(3), 293-301. doi:10.1080/03650340.2010.514266

Saha, S., Mina, B. L., Gopinath, K. A., Kundu, S., & Gupta, H. S. (2008). Organic amendments affect biochemical properties of a subtemperate soil of the Indian Himalayas. *Nutrient Cycling in Agroecosystems, 80*(3), 233-242. doi:10.1007/s10705-007-9139-x

Schoenholtz, S. H., Miegroet, H. V., & Burger, J. A. (2000). A review of chemical and physical properties as indicators of forest soil quality: Challenges and opportunities. *Forest Ecology and Management, 138*(1–3), 335-356. doi:10.1016/S0378-1127(00)00423-0

Sharma, K. L., Grace, J. K., Mishra, P. K., Venkateswarlu, B., Nagdeve, M. B., Gabhane, V. V., . . . Ramachandran, K. (2011). Effect of soil and nutrient-management treatments on soil quality indices under cotton-based production system in rainfed semi-arid tropical vertisol. *Communications in Soil Science and Plant Analysis, 42*(11), 1298-1315. doi:10.1080/00103624.2011.571735

Sharma, K. L., Grace, J. K., Raj, M., Mittal, S. B., Singh, J., Sharma, S. K., . . . Rani, K. U. (2013). Improvement and assessment of soil quality under long-term conservation agricultural practices in hot, arid tropical aridisol. *Communications in Soil Science and Plant Analysis, 44*(6), 1033-1055. doi:10.1080/00103624.2012.750338

Singh, K. P., Suman, A., Singh, P. N., & Srivastava, T. K. (2007). Improving quality of sugarcane-growing soils by organic amendments under subtropical climatic conditions of India. *Biology and Fertility of Soils, 44*(2), 367-376. doi:10.1007/s00374-007-0216-8

Sittibusaya, C., Narkaviroj, C., Tunmaphirom, D. (1988). Cassava soils research in Thailand. In. R.H. Howeler and K. Kawano (Eds). Cassava Breeding and Agronomy Research in Asia. Proc. Regional Workshop, Held in Rayong, Thailand. Oct. 26-28, 1987. Pp. 145-156.

Srinivas, T. (2007). Industrial demand for cassava starch in India. *Starch-Starke, 59*(10), 477-481. doi:10.1002/star.200700657

Srinivas, T. (2009). Impact of research investment on cassava production technologies in India. *Australian Journal of Agricultural and Resource Economics, 53*(3), 367-383. doi:10.1111/j.1467-8489.2009.00453.x

Suja, G., John, K. S., Sreekumar, J., & Srinivas, T. (2010). Short-duration cassava genotypes for crop diversification in the humid tropics: Growth dynamics, biomass, yield and quality. *Journal of the Science of Food and Agriculture, 90*(2), 188-198. doi:10.1002/jsfa.3781

Suresh, R., Saravanakumar, M., & Suganyadevi, P. (2011). Anthocyanins from Indian cassava (Manihot esculenta Crantz) and its antioxidant properties. Int. J. Pharm. Sci. Res, 2, 1819-1828.

Willey, R. W. (1979). Intercropping - its importance and research needs. 1. competition and yield advantages. *Field Crop Abstracts, 32*(1), 1-10.

Yadav RL, Prasad SR, Singh R, Srivastava VK. 1994. Recycling sugarcane trash to conserve soil organic carbon for sustaining yield of successive ratoon crops in sugarcane. Boires Technol. 49:231–235.

Zuo, Y., & Zhang, F. (2011). Soil and crop management strategies to prevent iron deficiency in crops. *Plant and Soil, 339*(1-2), 83-95. doi:10.1007/s11104-010-0566-0

2.0 Assessments of Intercropping and Fertilizer amendments to soil on yields, crop quality and economics in cassava based systems in the Kolli Hills

2.1 Introduction

Intercropping is a management strategy that increases agricultural intensification and biodiversity (Midmore 1993). The growth of two or more crops in the same space at the same time is referred to as intercropping, mixed cropping or polyculture (Altieri and Nicholls 2003; Zou and Zhang 2008; Lithourgisdis et al., 2011; Bedoussac and Justes 2011). As much as 15 to 20 % of the world's food supply comes from intercropping systems commonly used in tropical parts of the world by smallholder farmers and intercropping systems are seen as a way to increase food security in developing countries (Altieri et al., 2012).

Biodiversity often improves ecosystem functions that are important for water and soil conservation as well as resilience (Altieri et al., 2012; Liebig et al., 2001). Biodiversity in agricultural systems can increase yields, decrease risk and increase sustainability for smallholder farmers (Chen et al., 2011; Altieri et al., 2012; Liebig et al., 2001). Other potential benefits of intercropping include a greater amount of soil conservation, due to reduced soil erosion and better ground cover in intercropping systems (Anil et al., 1998; Amanullah et al., 2007; Fukai and Trenbath 1993; Sharma et al., 2011). Increased weed control and lower weed competition from greater land area use was found in intercropping systems (Banik et al., 2006; Lithourgisdis et al., 2011). Intercropping is especially useful in low N systems because of the high level of complementary N use by the component crops (Bedoussac and Justes 2011; Ram et al., 2012; Islami et al., 2011; Sharma et al., 2011; Polthanee et al., 2007).

Main crops and component crops need to be carefully selected based on nutrient need, solar radiation requirements, water needs and harvestability (Willey 1979; Lithourgisdis et al., 2011; Islami et al., 2011; Fukai and Trenbath 1993; Midmore 1993). Disadvantages in intercropping systems are most often seen in the component plants competition for light, water, nutrients and allelopathic effects (Lithourgisdis et al., 2011; Zuo and Zhang 2008; Islami et al., 2011; Altieri 1999). Additional difficulties in intercrop research arise because experimental results are often site-specific and vary by season. This can also occur in monocrops, but in intercropping systems, there are higher levels of competition at one growth stage or another and several crops to assess (Fukai and Trenbath 1993; Islami et al., 2011).

Globally, cassava (*Manihot esculenta* Cranz, family Euphoribiaceae) has a growing area of 18.5 million ha. Cassava is one of the world's major staple crops it can grow under a great variety of soil and climatic regions while still able to produce a high number of calories for a comparatively low production cost (Campo et al., 2011; Amanullah et al., 2007; Polthanee et al., 2007; Howeler 1991; Kanto et al., 2013; Islami et al., 2011; Chaisri et al., 2013). Approximately one third of the cassava grown worldwide is intercropped (Amanullah et al., 2007; Suga et al., 2009). Cassava is an ideal crop for intercropping since its row spacing is wide and it is slow in its initial growth, the initial 100 days of the crop's development are slow and its nutrient, light and water requirements minimal (Suga et al., 2009; Amanullah et al., 2006; Polthanee et al., 2007).

Cassava is able to produce high levels of starch under many soil and climatic conditions; it is very versatile and can be planted or harvested in a flexible manner (Vieira et al., 2010). The main constituent of cassava roots is starch (Reis et al., 2002). Changes in temperature and rainfall are more likely to cause changes in cassava starch than age of the plant (Reis et al., 2002; Suja et al., 2009). Cassava requires large amounts of K for storage root formation and N for leaf production (Howeler, 1991, Howeler, 2002 and Carsky and Toukourou, 2005). Starch is influenced by developmental stage and growth season. Planting in the rainy season will result in larger starch grain size than in the dry season (Reis et al., 2002). Quality is measured in cassava by measuring the crop's starch content. In the industrial context, price premiums are paid for high quality tubers. One method of quality assessment in cassava is to measure the tuber starch content.

Finger millets, native to the Kolli Hills region, are ideal candidates for intercropping with cassava, a cash crop; because they are, an important subsistence crop that can be stored safely for years and they contain methionine, an important amino acid that is lacking in the diets of many people (Guere et al., 2009). According to Guere et al., in 2009, minor millets in the Kolli Hills can be defined as underutilized plants with economic potential that make them appropriate as a focus for market development. They are also locally abundant and globally rare (Guere et al., 2009). In the Kolli Hills of Tamil Nadu, genetically diverse pools of minor millet varieties are cultivated for consumption (Guere et al., 2009). Finger millets have a high phosphate requirement that needs to be provided both at seeding and as a top dressing 21 days after sowing (Bhatt et al., , 2012).

Legumes within an intercropping system can provide available nitrogen to component crops (Ram et al., 2012; Islami et al., 2011). Therefore, crops like black beans are ideal component crops and are generally ready for harvest 50 days after sowing. Yield limitations in common beans are often experienced under rainfed systems where there is a moisture deficit, however this yield limitation can also be attributed to pests, soil-borne pathogens and soil fertility (Islami et al., 2011). Conditions greatly influence the yield of common bean (Ram et al., 2012).

Organic and inorganic fertilizers are often used to increase yields and improve soil fertility in agricultural systems (Ram et al., 2012; Cadavid et al., 1998; Yadav et a. 1994; Patra et al., 1997; Ram and Kumar 1997; Ram et al., 2006). Responses to fertilizers in monocultures have led to recommendations for fertilizer application to achieve higher yields and maintain soil fertility (Leihner 1983). Fertilizer responses in intercropping systems are likely different than monocrops and application rates for these systems still require more study (Leihner 1983). However, many studies have shown that there are great benefits to intercropping systems with the addition of organic and inorganic soil fertility amendments (Kumar et al., 2008; Amanullah et al., 2007; Bulluck et al., 2002; Saha et al., 2008; Doran 1995).

In many parts of the world, agricultural investments including organic and inorganic fertilizers, especially in rainfed systems are risky (Ngigi et al., 2005). Many farmers are risk averse when it comes to investing and adopting new technologies. Uncertainty and risk as well as labour shortages are often the largest factors for farmers not wanting to adopt a new technology (Ngigi et al., 2005; Pypers et al., 2011). Recommendations for intercropping or using soil fertility amendments need to consider the expense of the recommendation.

Economic analysis of farming practices need to be considered prior to recommending these practices to farmers. While increases in yields are important, there may be costs associated with improving yields and these costs need to consider how the recommendations and their associated risk may affect the profits of the farmers (Dillon and Hardaker, 1993; Asumadu et al., 2004; Makinde, et al., 2006; Pypers et al., 2011). Marginal Rates of Return are a basic method to compare the various treatments and determine if they would meet a general acceptable minimum rate of return as a way to assess whether to recommend new cropping systems to farmers (Perrin et al., 1988; Makinde, et al., 2006; Pypers et al., 2011). Marginal analysis is a method to determine whether it is worthwhile for a farmer to invest in a new practice by determining what return from each extra unit invested equals the cost of the extra unit (Perrin et al., 1988).

2.2 Study objectives

This study aims to increase the efficiency and improve the sustainability of cassava production with the use of intercropping and fertilizer amendments and in particular:

1. Determining the yield impacts of various intercropping and fertilizer additions to the current cassava production system in the Kolli Hills.
2. Compare the crop quality of cassava and the component intercrops with the various intercrops and fertilizer amendments.
3. Explore the economic impacts of various intercropping and fertilizer amendments.

2.3 Materials and methods

2.3.1 Site description

The study was conducted in the Kolli Hills, a mountainous region in the Eastern Ghats, on the Eastern border of the Namakkal District in Tamil Nadu, south India (78°20’ to 78°30’ E longitude; 11°10’ to 11°30’ N latitude area = 28 293 hectares (Gruere et al., 2009; Jayakumar et al., 2009). There are 14 villages and 247 hamlets in this district (Baseline APM survey 2013). Year one sites were located in the hamlets of Perikovilo, Asakadu and Soldaipatti; year two sites were located in the hamlets of Oleyur, Aalavadi, and Mathryilovo. All the sites were located within 4 kilometers of each other. All sites have been continuously planted to cassava for at least the past 5 years. All the sites have not had any additional nutrients added during this period and all are rainfed.

The average annual precipitation is 1440 millimeters, ranging from as little as 800 millimeters to as much as 1800 millimeters per annum (Gruere et al., 2009; Maloles et al., 2011). Rainfall is usually heaviest during the monsoon, August to December however; there is a great amount of variation within that period as well. The sites are located in a hilly region and therefore even at a close distance from each other rainfall is highly variable over short distances.

2.3.2 Soil Characterization

The Kolli Hills region consists of highly weathered laterite soils, also referred to as Kaolisols or Acrisols by the FAO. The bedrock of the Kolli Hills is composed of gneiss of ancient origin. Minerals within the gneiss bedrock include acid charnokite with minor bands of pyroxene and magnetite quartzite. The hills are highly undulating with seasonal and semi-permanent streams throughout that flow in all directions and drain into the Ayyar River and Varattar Nadi (King 2005).

The soils are deep to very deep, non-calcareous and developed from weathered gneiss (Jayakumar et al., 2009). There is high bauxite content in some areas. Soil texture varies with the hilltops characterized by rocky terrain with various sized stones and boulders. The soil is a sandy loam and the bases of the hillsides are characterized by alluvial clay loam texture (King 2005). The soils are excessively drained and have moderate permeability. The sites consist mainly of red, sandy clay loams with relatively low CEC's. All sites were located at elevations of over 1000 meters above seas level (masl) with relatively flat topography. Soil samples were taken of all sites prior to the study and results can be seen in Chapter 3 in tables (3-2 and 3-3).

2.3.3 Experimental plot design

The study was laid out in a split plot design with the soil fertility amendments as the main plot treatments and the intercrops as the sub plot treatments. The plots were 5 m x 5 m during year one and 5.6 m x 5.6 m during year two. All sites were soil sampled prior to planting and then ploughed 3 times to a depth of 30 cm. All planting, weeding, plot maintenance and harvesting was done by hand and as per normal farmer practice. At harvest yields were measured in kg/plot and results were then converted to kg/ha.

Year one consisted of four main plot treatments:

1) Control, no added fertilizer or manure;
2) farmyard manure (See table 3-1 for nutrient content) applied at a rate of 5 tonnes/ha;
3) fertilizer, N in the form of urea applied at a rate of 100 kg N/ha, triple superphosate at a rate of 50 kg P/ha, and potash applied at a rate of 100 kg K/ha;

4) farmyard manure plus fertilizer at the same rates as the farmyard manure and fertilizer;

The second year sites had the same main plot fertility treatments with the addition of a mulch treatment that consisted of rice paddy straw applied once at a rate of 6 kg/ha completely covering the soil at the time of application.

The sub plot treatments were the same for year one and year two:

1) Cassava alone spaced at 1 m x 1 m during year one and 0.80 m x 0.80 m during year two;
2) cassava intercropped with rows of finger millet (GPU 48) planted 10 cm apart and at a distance of 0.5 m from the cassava during year one and 0.40 m during year two;
3) cassava intercropped with local black bean planted 30 cm apart with a distance of 0.5 m from the cassava during year one and 0.4 m during year two;
4) cassava with finger millet and black bean intercrop that consisted of one row of cassava, one row of bean, one row of cassava, one row of finger millet;

During year one, the experimental plots at Asakadu and Perikovilo had 2 replications for a total of 32 subplots, while Soldaipatti had 4 replications and therefore 64 subplots. In year two, Mathryilovo had 3 replications for a total of 60 subplots and Aalavadi and Oleyur each had 4 replications for a total of 80 subplots. Years will be differentiated throughout the rest of the chapter due to the great variability in precipitation and temperature between the two seasons and the impact that this non-measured component could have on yield and soil properties.

2.3.4 Planting, Crop Maintenance and Harvesting Data

Plots were planted and then harvested according to plant maturity and local practices. Cassava plants were taken from cuttings and planted by hand; intercrop species were planted concurrently with cassava and then bean plants were harvested approximately 70-80 days after planting, while millet was harvested approximately 120 days after planting. Cassava plants were harvested by uprooting whole plants from centre rows, harvesting occurring 9 months to 16 months after the planting date, dependent on the occurrence of rainfall which was approximately 13 months after planting in year one and 11 months after planting in year 2. Rainfall prior to harvesting is necessary to help increase the ease of harvesting and allow the tubers to take up more water, increasing their final weight. Yields were then calculated on a per hectare basis.

2.3.5 Crop Quality

Throughout the season, notes were taken on disease using a 1 to 5 rating system developed by Howeler in 1999. Insect stress and any additional abiotic or biotic factors affecting the plots were also noted. Weeding was conducted as per standard local practice, three times per cassava season. Leaf samples from cassava were taken when the cassava was at its 4th major leaf stage, the stage with the highest nitrogen uptake by the leaves. These leaves where then sent to the UPASI labs for analysis of percent total nitrogen, phosphorus and potassium. Millet and bean (100 gram) samples were taken from each plot and sent to the UPASI labs to undergo Ash collection to assess the N, P and K in the beans, and millet biomass. N content was then used as a part of a conversion to determine the protein content of the crops (Jones 1941).

To calculate the starch content of cassava, an indirect measure using a hydrostatic balance, a rhiemen balance, was used; it is based on water displacement thus specific gravity, to measure starch content of the tubers. A 5 kilogram (kg) sample of cassava was taken from each plot and washed. The tubers had root hairs removed and then cut into large sections that were then place in the balance and weighed with the rhiemen balance, which would then give starch content (Grossmann and Freitas, 1950).

2.3.6 Economic Analysis

Marginal Rates of Return were used as a basic method to compare the various treatments and determine if they would meet a general acceptable minimum rate of return as a way to assess whether the intercropping or soil fertility methods should be recommended to local farmers (Perrin et al., 1998).

To determine the marginal rate of return requires several steps. Determination of the “net benefits”, which are based on a partial budget, would consider all the benefits and then subtract the costs for each different recommendation. An adjusted yield would be used to represent a fraction (in this case 0.9) of the average yield obtained under an experimental condition, which may vary from a producer’s results. The adjusted yield would be used and then the total gross field benefit for each recommendation would be calculated based on local prices for all component crops. The costs that vary for each recommendation will then be added or subtracted from the control amount (the amount prior to the addition of any recommendation).

The net benefits, which were determined for each recommendation, were then used to calculate the marginal rate of return between recommendations. The difference between the net benefit of the control and a recommendation was then calculated and presented as a percent. For a farmer to implement the practice there should be a marginal rate of return that would provide at least the return of the investment plus a gain. A minimum acceptable rate of return is often determined, this can be determined with consultation with farmers. In 1998, Perrin, et al., noted that a rate between 50% and 100% was required in order for farmers to risk new practices. In general, more difficult and complicated recommendations (e.g., new equipment, new seeding practice), require higher rates of return in order for the farmer to be willing to implement them. This study assumed that a marginal rate of return over 50% would be the minimum acceptable rate of return based on recommendations by Perrin 1998.

2.3.7 Sample Analysis Data analysis

When assessing the impacts of several different treatments on several variables, as is common in agronomic studies, one of the major challenges is selecting appropriate statistical methods. In addition, within field studies there are always other random impacts that may influence the variable of interest and therefore a linear mixed model was used to analyze all yield and crop quality data. All analysis of treatment differences was conducted via an analysis of variance (ANOVA), correlations and regressions were done in the mixed procedure with SAS software (Mixed Procedure SAS Institute 2008).The use of a split plot design influences the precision that the results of the statistical analysis will determine for both main and sub plot treatments. There is greater precision in results pertaining to the intercropping in this study, as they were the sub plot treatment. Soil, rainfall, and many other abiotic factors that affect crop growth can vary greatly between sites; therefore, after testing for normality, homogeneity of variance, the data was assessed in each site individually.

2.4 Results

There was great variation in results from year to year and site to site, therefore each year and each site were analyzed separately to determine if there were any significant treatment impacts on yields, cassava leaf nutrients, starch content and legume protein content. Pearson's correlation and linear regression analysis examined the relationship between the cassava leaf nutrients, cassava starch content and yield. Economic analysis assessed the viability of each of the treatment recommendations as a consideration for smallholder farmer adoption.

2.4.1 Cassava Yields

Across the sites in year one and year two there was a great variation in the cassava yields under all the intercropping and fertility treatments. Year one yields were higher than year two yields across all intercrop and fertilizer treatments (Tables 2-1 and 2-2). Year one data showed that there were no significant differences in treatments for cassava yields at Asakadu or Soldaipatti and yield data was not taken from Perikovilo due to harvest labour availability (Table 2-1). During year two, site wise there were no statistically significant ($P<0.05$) differences in treatment means in Aalavadi, however, both Mathyriolovo and Oleyur had significant intercrop treatment differences (Table 2-2). In Mathyriolovo, cassava yield in the control treatment was significantly greater than all the intercrop treatments; the cassava yield in the cassava-legume inter-crop was significantly lower than the control, but significantly higher than the cassava-finger millet and the cassava-finger millet plus legume treatment (Table 2-2). In Oleyur, the cassava yields in the control were significantly higher than the cassava-finger millet, which was significantly lower than the cassava-finger millet plus legume and the cassava-legume treatment (Table 2-2).

2.4.2 Intercrop Yields

Across the sites in year one and year two there was a great variation in the yields of both the legume and the millet intercrops under all the intercropping and fertility treatments. Year one yields were consistently higher than year two yields across all intercrop and fertilizer treatments (Tables 2-3 and 2-4). Year one data showed that there were no significant differences in treatments for millet or legume yields at Asakadu or Perikovilo, intercrop yield data was not collected in Soldaipatti due to harvest labour availability (Table 2-3). Year two data also showed that there were no significant differences in treatments for millet or legume (Table 2-4).

2.4.3 Crop Components and Quality

Across the sites in year two there was great variation in the starch content between sites, there were no statistically significant differences of the treatments on the starch content of the cassava (Table 2-5). Mean cassava tuber starch content did vary greatly from site to site, with starch content in Aalavadi ranging from 22.2 to 23.6, while Mathyriolovo had a starch content in the range of 25.6 to

27.33, and Oleyur had a starch content range from 20.78 to 23.68 (Table 2-5). Legume protein content also showed no significant differences from treatment effects during year two (Table 2-6). Mean legume protein content did vary greatly from site to site, with protein content in Aalavadi ranging from 15.56 to 18.44, while Mathyriolovo had mean protein content in the range of 18.5 to 22.69, and Oleyur had mean legume protein content ranging from 13.72 to 18.84 (Table 2-6). 5^{th} leaf cassava % total N, P and K had no statically significant impacts from treatment effects, except in Oleyur where a significant difference was noted in % total K between the control and finger millet intercrops, results again varied from site to site (Table 2-7 to 2-9).

2.4.4 Correlation and Regression Analysis

Across the sites in year two there were significant correlations (p-value <0.01) between the total cassava tuber weight, and the cassava tuber starch content, the site, the cassava leaf total % N, the leaf total % P, and the leaf total %K (Table 2-10). There was also a significant correlation (p-value <0.01) between cassava tuber starch content and the cassava leaf total % N, the leaf total % K (Table 2-10). A significant correlation (p-value <0.01) between the Site and the cassava leaf total % N, the leaf total % P, and the leaf total %K (Table 2-10) was also found. Finally, a correlation at a p-value of <0.01 exists between cassava leaf total % P and cassava leaf total % K (Table 2-10).

The relative regression relationships between cassava leaf total % N, total % P, and Total % K and cassava tuber starch content and yields of cassava (total tuber weight in kg/plot). Cassava leaf total % N has a slight negative relationship with cassava starch content as well as cassava yields across sites (Table 2-10). Cassava leaf total % P has no apparent relationship with cassava starch content and a slight positive relationship with cassava yields across sites (Table 2-10). Finally, cassava leaf total % K has a slight positive relationship with cassava starch content and a slight positive relationship with cassava yields across sites (Table 2-10).

2.4.5 Economic Analysis

Figures 2-1 and 2-2 show the Marginal Rates of Return from year one and year two respectively, results from the two seasons varying greatly. Year one results demonstrated that with the fertilizer addition treatment, the greatest marginal rate of return could be seen from intercropping treatments of finger millet and finger millet with a legume, and monocrop cassava. Control fertility treatment, intercropping with finger millet and finger millet and legume also produced a high marginal rate of return in comparison to no change to monocropped cassava. A combination of farmyard manure and fertilizer as a fertility treatment resulted in increased marginal rates of return in comparison to the traditional cassava monocrop for the finger millet and finger millet and legume intercropping as well as just the sole addition of the fertility treatment. The addition of farmyard manure resulted in small increases in the marginal rates of return when intercropping with finger millet and finger millet and legume, while there was a negative marginal rate of return without using an intercrop. Across all four fertility treatments, the marginal rate of return for intercropping with legumes was negative or less than 100 % in comparison to the control (Figure 2-1).

Year two results were dramatically different from year one results with only the mulching treatment, and no intercrop resulting in a positive marginal rate of return. All other fertility and intercropping treatments produced a negative marginal rate of return when compared with the traditional cassava monocrop (Figure 2-2).

2.5 Discussion

2.5.1 Cassava and Intercrop Yields

Yields of the fresh cassava tubers as well as intercrop legume and finger millet within the various intercropping and fertilizer treatments varied greatly from site to site and year to year (Table 2-1 to 2-4). First year (2012) yields in cassava, legume and finger millet were higher overall across all sites in contrast to the second year (2013) trials. This may be attributed to the great variation in climatic conditions, annually there is great variation in precipitation from 800mm to 1800mm (Gruere et al., 2007; Maloles et al., 2011). During the study period precipitation data was not collected; overall however, in year two the entire province of Tamil Nadu went through a drought period suggesting that overall year two may have had less precipitation. Soil nutrient content is highly variable both spatially and temporally. The variation in the site-wise soil properties prior to treatment could help to explain the variation in results seen in yields, and perhaps, an overall lack of nutrients or the inability of the nutrients to be available to crops was affecting all sites prior to treatments. Intercropping has been found to have several disadvantages as component crops compete for light, water, nutrients or cause allelopathic effects (Lithourgisdis et al., 2011; Zuo and Zhang 2008; Islami et al., 2011; Altieri 1999). Additional difficulties researchers have encountered include experimental results that are site-specific and vary by season, which also happens in monocropping systems, however with intercrops you have higher levels of competition at one growth stage or another and several crops to assess (Fukai and Trenbath 1993; Islami et al., 2011).

Mean fresh cassava yields in the first year sites were impacted by fertilizer and fertilizer and farmyard manure treatments, control and intercropping treatments (Table 2-1). Fertilizer, farmyard manure and farmyard manure plus fertilizer treatments also saw increased yields of component finger millet, legume and finger millet plus legume in comparison to the control (Table 2-3). Nutrient replenishment, inorganic and organic, has been shown to increase yields in many different cropping systems (Islami et al., 2011; Polthanee et al., 2007; Howeler et al., 1991; Ram et al., 2012; Cadavid et al., 1998; Yadav et a. 1994; Patra et al., 1997; Ram and Kumar 1997; Ram et al., 2006). The impacts of intercropping on crop yields was not statistically significant during year one, however the millet treatment over all reduced cassava yields across the fertilizer treatments, while there was often only slight decrease when finger millet plus legume was intercropped with cassava. The addition, legumes often slightly increased or had a negligible impact on cassava yields. Similarly, Amanuallah et al., found in 2006 that intercropping cassava with cowpea resulted in a non-significant decrease in cassava yields. Sharma et al., 2011 also found increases or non-significant decreases to cassava when it was intercropped with a legume.

Second season results showed no differences between fertilizer treatments across all sites, but a slightly higher yield in the mulch treatment for the cassava monocrop was observed (Table 2-2). Intercropping yields showed a clearer trend of having increased yields when fertilizer or farmyard manure and fertilizer was applied (Table 2-4). Cadavid et al., 1998 also found increased yields with the use of a mulching treatment as mulch has been shown to reduce soil erosion, maintain soil structure, conserve soil water, reduce soil temperature, and maintain soil fertility via nutrient cycling. Finally cassava yields with only farmyard manure applied were lower than all fertilizer and control treatments across intercrop treatments (Tables 2-2). Intercrop yields of legume, finger millet and finger millet plus legume were less under farmyard manure and mulch in contrast to fertilizer, fertilizer and farmyard manure and the control. Datta el al. in 2009 demonstrated that yields in organic systems were lower than yields in synthetic fertilizer systems. This could be attributed to a higher C:N ratio in manure that would result in net N immobilization. Site wise there were no statistically significant differences in treatment means in Aalavadi; however, both Mathyriolovo and Oleyur had significant intercrop treatment differences (Table 2-2). In Mathyriolovo, the control yielded highest and the legume had a yield significantly higher than any of the finger millet treatments (Table 2-2). In Oleyur the control, legume and finger millet and legume also yielded significantly higher than the finger millet treatment (Table 2-4). Finger millet treatments yielded lower across sites and fertilizer treatments and demonstrated that there may have been some competition for light, water, or nutrients.

2.5.2 Cassava and Legume Crop Quality

Assessing the impacts of the various intercropping and fertilizer treatments resulted in no significant differences to the cassava tuber starch content (Table 2-5). The greatest difference in mean cassava tuber starch content was site, with starch content in Aalavadi ranging from 22.2 to 23.6, while Mathyriolovo had a starch content in the range of 25.6 to 27.33, and Oleyur had a starch content range from 20.78 to 23.68 (Table 2-5). The variation in the soil properties between sites prior to treatment could help to explain the variation in results seen in overall starch content, and perhaps, an overall lack of nutrients or the inability of the nutrients to be available to the crop was affecting all sites prior to treatments. Although cassava is able to produce high levels of starch under many soil and climatic conditions as it is very versatile and can be planted or harvested in a flexible manner; changes in temperature and rainfall can cause changes in cassava starch content (Vieira et al., 2010; Reis et al., 2002; Suja et al., 2009).

Regression relationships between cassava leaf total % N, total % P, and Total % K and cassava tuber starch content and yields of cassava (total tuber weight in kg/plot). Cassava leaf total % N has a slight negative relationship with cassava starch content as well as cassava yields across sites. Higher uptake of leaf N has been shown to increase the vegetative properties of cassava and transfer available nutrients to the leaves instead of the tubers (Howeler et al., 1991). Cassava leaf total % P has no apparent relationship with cassava starch content and a slight positive relationship with cassava yields across sites (Table 2-10). This may be attributed to synthetic fertilizers providing yield improvements Agoramoorthy 2008; Pathak et al., 2010). Finally, cassava leaf total % K has a slight positive relationship with cassava starch content and a slight positive relationship with cassava yields across sites (Table 2-10). Cassava tuber production has been shown by Howeler 1996, and Howeler et al., 1991 to increase with K. Cadavid et al., 1998 demonstrated that moderate applications of N, P and K have been shown to sustain productivity for longer periods, increases in nutrients synthetically or organically can help to increase yields.

It is also important to note that, while not statistically significant, there are price premiums, and penalties for starch content. With a tuber starch content less than 20 receiving a price penalty of 50 rupees/tonne while a price premium of 100 rupees/tonne is given when the average starch content exceeds 25 (2013 local prices in the Kolli Hills).

Legume protein content showed no significant differences from treatment effects during year two (Table 2-6). Mean legume protein content did vary greatly from site to site, with protein content in Aalavadi ranging from 15.56 to 18.44, while Mathyriolovo had mean protein content in the range of 18.5 to 22.69, and Oleyur had mean legume protein content ranging from 13.72 to 18.84 (Table 2-6). The average family size is 4.4 and 36.9% of household income comes directly from crop production, another 22.1% of the income coming from farm wage earnings (Baseline APM study 2013). During seasons of reduced cassava yield, the growth of component crops can help increase household food security and/or income as component crops can be consumed and provide a partial source of dietary protein (Alteiri et al., 2012; Bedoussac and Justes 2011).

2.5.3 Economic Impacts of Fertility and Intercropping Treatments

Many studies undertake to examine yield, or soil impacts of various treatments while not considering the importance of economic analysis prior to making recommendations to farmers. While increases in yields are important, the costs associated with improving yields need to consider how the recommendations and their associated risk may affect the profits of the farmers (Dillon and Hardaker, 1993; Asumadu et al., 2004; Makinde, et al., 2006; Pypers et al., 2011). Marginal Rates of Return are a basic method to compare the various treatments and determine if they would meet a general acceptable minimum rate of return as a way to assess whether to recommend new cropping systems to farmers (Perrin et al., 1988; Makinde, et al., 2006; Pypers et al., 2011). Commonly a marginal rate of return of 100% greater than the control is used as a baseline for recommendations.

Marginal analysis is a method to determine whether it is worthwhile for a farmer to invest in a new practice by determining what return from each extra unit invested equals the cost of the extra unit (Perrin et al., 1988). Figures 2-1 and 2-2 show the Marginal Rates of Return from year one and year two respectively, results from the two seasons varying greatly. Year one results demonstrated that with most treatments there was a marginal rate of return of greater than 100% and thus the risk of adopting the new treatments could be profitable to the farmer (Figure 2-1). It is interesting to note the great difference in the second season with only the mulch treatment with cassava providing a marginal rate of return with acceptable benefit for the farmer to adopt (Figure 2-2). It is important to consider that yields are dependent on rainfall and that there is a strong reliance on rainfed agriculture in India and it depends heavily on monsoon rains (Muthumanickam et al., 2012). Higher moisture is related to increases in yield for cassava (Herrera Campo et al., 2011) since water stress in cassava will increase the above ground biomass growth instead of tuber growth (Fukai and Trenbath 1993).

Consideration for the availability of seed of component crops, equipment requirements, and fertilizers often affect a farmer’s decision to adopt a new farming practice or technology (Kohli and Singh, 1997). The availability of labour, especially for treatments where labour intensity increases, mulching for example, may also affect a farmer’s ability to choose to adopt a new agronomic practice or not.

In addition, agriculture is not static and is strongly influenced by population, global market forces, science, technology, and climate variability (Altieri et al., 2012). To address the changing climates and increased vulnerability of monocropping systems current agricultural practices should be integrative, focusing on efficient crop rotations, intercropping, organic manure and chemical fertilization to provide the greatest yields, conserving soil fertility and biodiversity, and providing food security (Kumar et al., 2008; Altieri et al., 2012; Lithourgidis et al., 2011).

2.6 Summary

Crop yields and crop quality are a major concern for local farmers. Various agronomic practices can greatly affect yields; intercropping with finger millet statistically and significantly reduced crop yields in Mathyriolovo and Oleyur. Fertilizer and farmyard manure plus fertilizer provided increases in intercrop yields and cassava yields in year one and increases in intercrop yields only in year two. The impacts of organic fertilizers in the short term appeared to have negative impacts on yields of cassava and component crops. Starch content and cassava leaf nutrient status was greatly affected by site. A further assessment of site-specific soil, precipitation and temperature would greatly improve the interpretation of the results found in this study.

Economic analysis varied greatly over the two seasons. Recommendations practical during the first year were detrimental to farmer production in the second year. This study was able to examine only the short-term impacts of the treatments and longer-term impacts could result in vastly different recommendations for farmers. Longer-term study can provide a greater amount of information and can result in less risky recommendations for farmers. Finally, assessment of precipitation and temperature at each experimental site could also increase the ability to assess cassava production systems and management recommendations in the Kolli Hills.

2.7 Tables and Figures

Table 2-1: Mean cassava yields year one with standard deviation n=2 in Asakadu and n=4 in Soldaipatti

Fertilizer Treatment	Intercrop Treatment	Soldaipatti (tonnes/ha)	Asakadu (tonnes/ha)
Control	Control	12.25±9.19	14.32±0.32
Control	Finger Millet	9.20±6.17	18.68±4.88
Control	Finger Millet + Legume	7.95±1.59	20.90±2.70
Control	Legume	8.50±4.48	25.30±3.10
Fertilizer	Control	9.87±3.18	23.14±3.66
Fertilizer	Finger Millet	6.80±1.88	25.22±1.58
Fertilizer	Finger Millet + Legume	14.72±5.69	29.68±4.92
Fertilizer	Legume	7.89±1.48	23.88±3.52
Farmyard Manure	Control	9.85±5.00	21.88±0.60
Farmyard Manure	Finger Millet	8.50±5.18	14.46±1.42
Farmyard Manure	Finger Millet + Legume	7.65±4.64	26.76±0.00
Farmyard Manure	Legume	5.95±3.21	17.40±1.92
Farmyard Manure + Fertilizer	Control	16.20±5.89	27.76±0.64
Farmyard Manure + Fertilizer	Finger Millet	13.67±7.11	25.06±3.22
Farmyard Manure + Fertilizer	Finger Millet + Legume	10.93±6.47	25.90±0.26
Farmyard Manure + Fertilizer	Legume	12.73±4.16	26.52±0.08

Table 2-2: Mean cassava yields year two with standard deviation n=3 in Mathyriolovo and n=4 in Oleyur and Aalavadi

Fertilizer Treatment	Intercrop Treatment	Aalavadi (tonnes/ha)	Mathyriolovo (tonnes/ha)	Oleyur (tonnes/ha)
Control	Control	16.10± 1.47	14.99± 2.96*a**	6.70± 0.87*a*
Control	Finger Millet	8.85± 0.91	9.57± 1.04*b***	3.83± 1.51*b**
Control	Finger Millet + Legume	11.32± 3.33	11.80± 2.48*b***	5.90± 3.67*a*
Control	Legume	12.68± 1.63	13.29± 1.05*c**	8.05± 5.43*a*
Fertilizer	Control	13.71± 3.51	16.90± 3.26*a**	5.74± 5.33*a*
Fertilizer	Finger Millet	11.56± 1.36	11.05± 5.32*b***	4.70± 3.09*b**
Fertilizer	Finger Millet + Legume	12.83± 3.93	11.48± 1.38*b***	4.15± 1.51*a*
Fertilizer	Legume	14.51± 3.33	14.67± 2.60*c**	5.26± 2.24*a*
Farmyard Manure	Control	15.31± 2.42	14.35± 0.78*a**	7.41± 3.92*a*
Farmyard Manure	Finger Millet	14.11± 3.03	9.35± 0.80*b***	2.07± 1.25*b**
Farmyard Manure	Finger Millet + Legume	15.78± 2.94	10.52± 0.69*b***	7.10± 3.75*a*
Farmyard Manure	Legume	15.31± 1.61	14.56± 3.95*c**	5.66± 3.69*a*
Farmyard Manure + Fertilizer	Control	12.83± 2.83	16.79± 1.20*a**	9.89± 3.05*a*
Farmyard Manure + Fertilizer	Finger Millet	15.07± 3.38	10.63± 2.73b**	5.10± 2.05*b**
Farmyard Manure + Fertilizer	Finger Millet + Legume	11.96± 2.30	11.59± 1.69b**	8.13± 3.61*a*
Farmyard Manure + Fertilizer	Legume	11.48± 3.95	16.16± 1.23c*	7.65± 3.47*a*
Mulch	Control	13.87± 3.19	16.16± 3.69*a**	9.73± 0.97*a*
Mulch	Finger Millet	14.67± 2.05	9.57± 1.88*b***	4.78± 2.64*b**
Mulch	Finger Millet + Legume	12.99± 3.93	9.25± 4.30*b***	6.06± 2.88*a*
Mulch	Legume	12.52± 0.88	9.46± 1.05*c**	8.85± 2.56*a*

Letters indicate significant differences between sub plot intercrop treatments. Stars indicate the p-values of significance: *=p-value of (0.05) **= p-value (0.0001).

Table 2-3: Mean intercrop yields year one with standard deviation n=2

Fertilizer Treatment	**Intercrop Treatment**	Perikovilo Yield (kg/ha)	Asakadu Yield (kg/ha)
Control	Control	NA	NA
Control	Finger Millet	1710±155.56	1720±282.84
Control	Legume +	112±62.23	251±182.43
	Finger Millet	780±84.85	800±28.28
Control	Legume	86±14.14	86±8.49
Fertilizer	Control	NA	NA
Fertilizer	Finger Millet	2560±1329.36	3216±90.51
Fertilizer	Legume +	210±42.43	244±73.54
	Finger Millet	820±28.28	800±56.57
Fertilizer	Legume	134±19.80	164±28.28
Farmyard Manure	Control	NA	NA
Farmyard Manure	Finger Millet	2342±478.00	2080±339.41
Farmyard Manure	Legume +	66±42.43	213±63.64
	Finger Millet	710±155.56	737±80.61
Farmyard Manure	Legume	90±65.05	112±45.25
Farmyard Manure + Fertilizer	Control	NA	NA
Farmyard Manure + Fertilizer	Finger Millet	2350±777.82	2802±2.83
Farmyard Manure + Fertilizer	Legume +	208±22.63	286±132.94
	Finger Millet	1100±141.42	870±98.99
Farmyard Manure + Fertilizer	Legume	188±62.23	140±28.28

Table 2-4: Mean intercrop yields year two with standard deviation n=3 in Mathyriolovo and n=4 in Oleyur and Aalavadi

Fertilizer Treatment	Intercrop Treatment	Mathyriolovo (Kg/ha)	Oleyur (Kg/ha)	Aalavadi (Kg/ha)
Control	Control	N/A	N/A	N/A
Control	Finger Millet	1071.75±222.88	1203.76±328.43	560.83±316.93
Control	Legume +	216.23±56.78	13.23±9.35	35.95±32.65
	Finger Millet	876.91±402.41	709.50±83.86	248.80±65.06
Control	Legume	472.49±90.72	18.26±19.87	191.07±51.43
Fertilizer	Control	N/A	N/A	N/A
Fertilizer	Finger Millet	1100.13±187.98	1124.04±212.12	579.40±541.58
Fertilizer	Legume +	129.71±158.87	11.88±8.73	189.72±83.65
	Finger Millet	710.03±577.52	641.74±51.05	457.27±268.28
Fertilizer	Legume	525.94±161.47	37.31±16.25	306.54±96.37
Farmyard Manure	Control	N/A	N/A	N/A
Farmyard Manure	Finger Millet	956.63±199.14	1187.82±250.24	517.22±318.92
Farmyard Manure	Legume +	219.33±54.42	13.47±7.85	96.66±49.09
	Finger Millet	578.23±306.21	645.73±169.49	314.57±243.40
Farmyard Manure	Legume	424.88±27.77	26.55±20.71	248.41±140.44
Farmyard Manure + Fertilizer	Control	N/A	N/A	N/A
Farmyard Manure + Fertilizer	Finger Millet	1066.75±85.98	1263.55±81.69	580.28±166.35
Farmyard Manure + Fertilizer	Legume +	265.88±35.38	33.00±40.60	96.66±49.09
	Finger Millet	606.93±73.43	825.10±138.00	663.27±460.39
Farmyard Manure + Fertilizer	Legume	594.32±180.38	105.23±126.67	303.52±98.74
Mulch	Control	N/A	N/A	N/A
Mulch	Finger Millet	646.26±463.49	1143.97±214.06	520.57±330.98
Mulch	Legume +	245.78±89.47	7.97±9.38	132.53±97.53
	Finger Millet	393.28±349.80	880.90±376.71	517.30±148.66
Mulch	Legume	428.22±123.57	29.97±18.81	121.91±41.84

Table 2-5: Mean starch content of cassava year two with one standard deviation n=3 Mathyriolovo, n=4 Aalavadi and Oleyur

Fertilizer Treatment	Intercrop Treatment	Aalavadi	Mathyriolovo	Oleyur
Control	Control	22.58±0.61	26.60±1.05	22.88±2.22
Control	Finger Millet	23.08±0.99	26.60±0.46	22.60±2.58
Control	Finger Millet + Legume	22.53±1.24	26.27±0.42	22.97±2.36
Control	Legume	23.60±1.02	27.07±1.86	22.73±2.40
Fertilizer	Control	22.20±0.63	26.03±0.70	21.73±1.67
Fertilizer	Finger Millet	23.23±1.28	25.93±0.83	20.98±1.95
Fertilizer	Finger Millet + Legume	23.30±1.60	26.50±0.44	23.53±0.77
Fertilizer	Legume	23.03±1.28	27.03±0.49	22.55±1.64
Farmyard Manure	Control	23.05±1.45	26.63±0.15	22.43±2.24
Farmyard Manure	Finger Millet	22.78±1.01	26.77±0.91	22.47±1.97
Farmyard Manure	Finger Millet + Legume	23.38±0.46	26.30±0.50	23.63±0.29
Farmyard Manure	Legume	22.85±1.05	26.17±0.29	23.93±1.08
Farmyard Manure + Fertilizer	Control	23.55±1.02	26.43±1.58	22.78±1.13
Farmyard Manure + Fertilizer	Finger Millet	22.40±1.60	26.27±1.16	23.10±2.22
Farmyard Manure + Fertilizer	Finger Millet + Legume	22.98±0.43	26.20±0.17	21.68±0.95
Farmyard Manure + Fertilizer	Legume	22.65±1.24	26.17±0.81	20.78±1.24
Mulch	Control	22.30±1.13	26.87±0.40	24.18±1.05
Mulch	Finger Millet	22.83±1.09	27.33±1.01	23.13±2.61
Mulch	Finger Millet + Legume	23.43±1.28	26.20±0.70	22.38±1.35
Mulch	Legume	23.10±1.02	25.60±0.66	23.68±0.19

Table 2-6: Mean protein content of legume with one standard deviation year two n=3 Mathyriolovo, n=4 Aalavadi and Oleyur

Fertilizer Treatment	Intercrop Treatment	Mathyriolovo Protein Content	Aalavadi Protein Content	Oleyur Protein Content
Control	Control	N/A	N/A	N/A
Control	Finger Millet	N/A	N/A	N/A
Control	Legume +	18.78±0.57	17.22±1.02	13.72±1.64
	Finger Millet	N/A	N/A	N/A
Control	Legume	19.84±2.43	18.44±3.18	14.03±0.49
Fertilizer	Control	N/A	N/A	N/A
Fertilizer	Finger Millet	N/A	N/A	N/A
Fertilizer	Legume +	20.13±0.09	17.13±0.35	16.53±1.28
	Finger Millet	N/A	N/A	N/A
Fertilizer	Legume	20.75±1.59	16.81±1.06	15.47±0.57
Farmyard Manure	Control	N/A	N/A	N/A
Farmyard Manure	Finger Millet	N/A	N/A	N/A
Farmyard Manure	Legume +	18.72±0.04	15.56±2.30	16.69±2.47
	Finger Millet	N/A	N/A	N/A
Farmyard Manure	Legume	18.50±2.83	17.25±0.44	16.00±1.59
Farmyard Manure + Fertilizer	Control	N/A	N/A	N/A
Farmyard Manure + Fertilizer	Finger Millet	N/A	N/A	N/A
Farmyard Manure + Fertilizer	Legume +	19.81±0.09	17.13±1.15	18.84±3.05
	Finger Millet	N/A	N/A	N/A
Farmyard Manure + Fertilizer	Legume	22.69±2.21	16.31±2.30	16.00±1.50
Mulch	Control	N/A	N/A	N/A
Mulch	Finger Millet	N/A	N/A	N/A
Mulch	Legume +	19.19±0.71	17.91±0.84	14.72±1.37
	Finger Millet	N/A	N/A	N/A
Mulch	Legume	19.31±0.18	15.91±0.40	15.19±0.00

Table 2-7: % Total N from cassava 5th leaf stage with one standard deviation year two sites n=3 Mathyriolovo, n=4 Aalavadi and Oleyur

Fertilizer Treatment	Intercrop Treatment	Aalavadi	Mathyriolovo	Oleyur
Control	Control	4.22±0.30	3.79±0.05	4.21±0.58
Control	Finger Millet + Legume	4.05±0.47	3.69±0.26	4.52±0.35
Control	Finger Millet	4.07±0.33	3.53±0.10	4.29±0.60
Control	Legume	4.22±0.38	3.96±0.24	4.54±0.34
Fertilizer	Control	4.07±0.34	3.84±0.18	4.94±0.17
Fertilizer	Finger Millet + Legume	4.01±0.36	4.02±0.18	4.48±0.34
Fertilizer	Finger Millet	4.02±0.40	3.80±0.34	4.33±0.61
Fertilizer	Legume	4.07±0.28	3.68±0.46	4.58±0.62
Farmyard Manure	Control	3.88±0.23	3.82±0.31	4.57±0.15
Farmyard Manure	Finger Millet + Legume	3.94±0.54	3.87±0.30	4.43±0.25
Farmyard Manure	Finger Millet	3.73±0.09	3.82±0.26	4.26±0.23
Farmyard Manure	Legume	3.94±0.23	3.91±0.13	4.47±0.43
Farmyard Manure + Fertilizer	Control	3.86±0.26	3.92±0.25	4.66±0.49
Farmyard Manure + Fertilizer	Finger Millet + Legume	4.21±0.30	3.84±0.11	4.78±0.30
Farmyard Manure + Fertilizer	Finger Millet	3.93±0.19	3.85±0.20	4.54±0.42
Farmyard Manure + Fertilizer	Legume	3.92±0.27	3.77±0.32	4.67±0.40
Mulch	Control	4.18±0.22	3.80±0.26	4.70±0.35
Mulch	Finger Millet + Legume	3.99±0.24	3.57±0.18	4.30±0.13
Mulch	Finger Millet	3.86±0.31	3.82±0.35	4.16±0.26
Mulch	Legume	3.96±0.23	3.72±0.13	4.68±0.34

Table 2-8: % P from cassava 5th leaf stage with one standard deviation year two sites n=3 Mathyriolovo, n=4 Aalavadi and Oleyur

Fertilizer Treatment	Intercrop Treatment	Aalavadi	Mathyriolovo	Oleyur
Control	Control	0.405±0.031	0.34±0.044	0.285±0.031
Control	Finger Millet + Legume	0.373±0.028	0.37±0.062	0.268±0.042
Control	Finger Millet	0.39±0.034	0.31±0.036	0.3±0.095
Control	Legume	0.41±0.054	0.33±0.056	0.323±0.033
Fertilizer	Control	0.39±0.036	0.347±0.081	0.26±0.042
Fertilizer	Finger Millet + Legume	0.378±0.034	0.373±0.040	0.24±0.039
Fertilizer	Finger Millet	0.385±0.024	0.337±0.050	0.26±0.057
Fertilizer	Legume	0.4±0.042	0.323±0.071	0.243±0.029
Farmyard Manure	Control	0.385±0.042	0.33±0.035	0.31±0.037
Farmyard Manure	Finger Millet + Legume	0.393±0.054	0.337±0.015	0.288±0.077
Farmyard Manure	Finger Millet	0.35±0.024	0.337±0.059	0.255±0.052
Farmyard Manure	Legume	0.373±0.021	0.34±0.036	0.315±0.072
Farmyard Manure + Fertilizer	Control	0.365±0.037	0.33±0.066	0.305±0.113
Farmyard Manure + Fertilizer	Finger Millet + Legume	0.408±0.052	0.32±0.01	0.32±0.117
Farmyard Manure + Fertilizer	Finger Millet	0.368±0.017	0.307±0.029	0.318±0.055
Farmyard Manure + Fertilizer	Legume	0.375±0.031	0.34±0.072	0.305±0.098
Mulch	Control	0.395±0.03	0.36±0.053	0.348±0.066
Mulch	Finger Millet + Legume	0.383±0.022	0.35±0.087	0.293±0.046
Mulch	Finger Millet	0.375±0.054	0.363±0.012	0.28±0.034
Mulch	Legume	0.388±0.017	0.32±0.03	0.33±0.049

Table 2-9: % K from cassava 5th leaf stage with one standard deviation year two sites n=3 Mathyriolovo, n=4 Aalavadi and Oleyur

Fertilizer Treatment	Intercrop Treatment	Aalavadi	Mathyriolovo	Oleyur
Control	Control	1.443±0.281	1.457±0.112	1.198±0.202*a**
Control	Finger Millet + Legume	1.378±0.255	1.62±0.131	1.225±0.124
Control	Finger Millet	1.378±0.197	1.383±0.139	1.115±0.164*b**
Control	Legume	1.43±0.329	1.503±0.133	1.31±0.123
Fertilizer	Control	1.44±0.314	1.413±0.225	1.31±0.284*a**
Fertilizer	Finger Millet + Legume	1.368±0.113	1.563±0.049	1.113±0.294
Fertilizer	Finger Millet	1.358±0.215	1.5±0.263	1.13±0.272*b**
Fertilizer	Legume	1.368±0.265	1.407±0.116	1.228±0.271
Farmyard Manure	Control	1.375±0.292	1.48±0.175	1.195±0.232*a**
Farmyard Manure	Finger Millet + Legume	1.408±0.340	1.41±0.123	1.265±0.137
Farmyard Manure	Finger Millet	1.338±0.245	1.403±0.167	1.01±0.094*b**
Farmyard Manure	Legume	1.258±0.113	1.51±0.118	1.003±0.226
Farmyard Manure + Fertilizer	Control	1.218±0.090	1.347±0.182	1.195±0.297*a**
Farmyard Manure + Fertilizer	Finger Millet + Legume	1.475±0.393	1.337±0.081	1.063±0.194
Farmyard Manure + Fertilizer	Finger Millet	1.308±0.247	1.32±0.079	1.138±0.169*b**
Farmyard Manure + Fertilizer	Legume	1.445±0.307	1.377±0.274	1.085±0.367
Mulch	Control	1.378±0.221	1.457±0.167	1.265±0.131*a**
Mulch	Finger Millet + Legume	1.325±0.237	1.47±0.225	0.988±0.269
Mulch	Finger Millet	1.363±0.267	1.503±0.150	1.038±0.127*b**
Mulch	Legume	1.303±0.237	1.34±0.175	1.178±0.263

Letters indicate significant differences between sub plot intercrop treatments. Stars indicate the p-values of significance: *=p-value of (0.05) **= p-value (0.0001).

Table 2-10: Pearson Correlation Matrix for Cassava Leaf Components, yield and starch content from year two site data n=3 Mathyriolovo, n=4 Aalavadi and Oleyur

	Starch Content	Fertilizer	Intercrop	Site	% Nitrogen	% Phosphorus	% Potassium
Total Tuber Weight (Kg/Plot)	0.249 *	0.00285	-0.084	-0.504*	-0.283 *	0.346 *	0.278 *
	214	220	220	220	220	220	220
Starch Content		0.00526	-0.00154	-0.0286	-0.373*	0.00149	0.257*
		214	214	214	214	214	214
Fertilizer			0	0	-0.0168	0.0577	-0.124
			220	220	220	220	220
Intercrop				0	-0.0507	-0.0275	-0.0645
				220	220	220	220
Site					0.487 *	-0.619 *	-0.379 *
					220	220	220
% Nitrogen						-0.036	-0.145
						220	220
% Phosphorus							0.49 *
							220

Cell Contents:
Correlation Coefficient
Number of Samples
* denotes significance at a p-value less than 0.01. The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

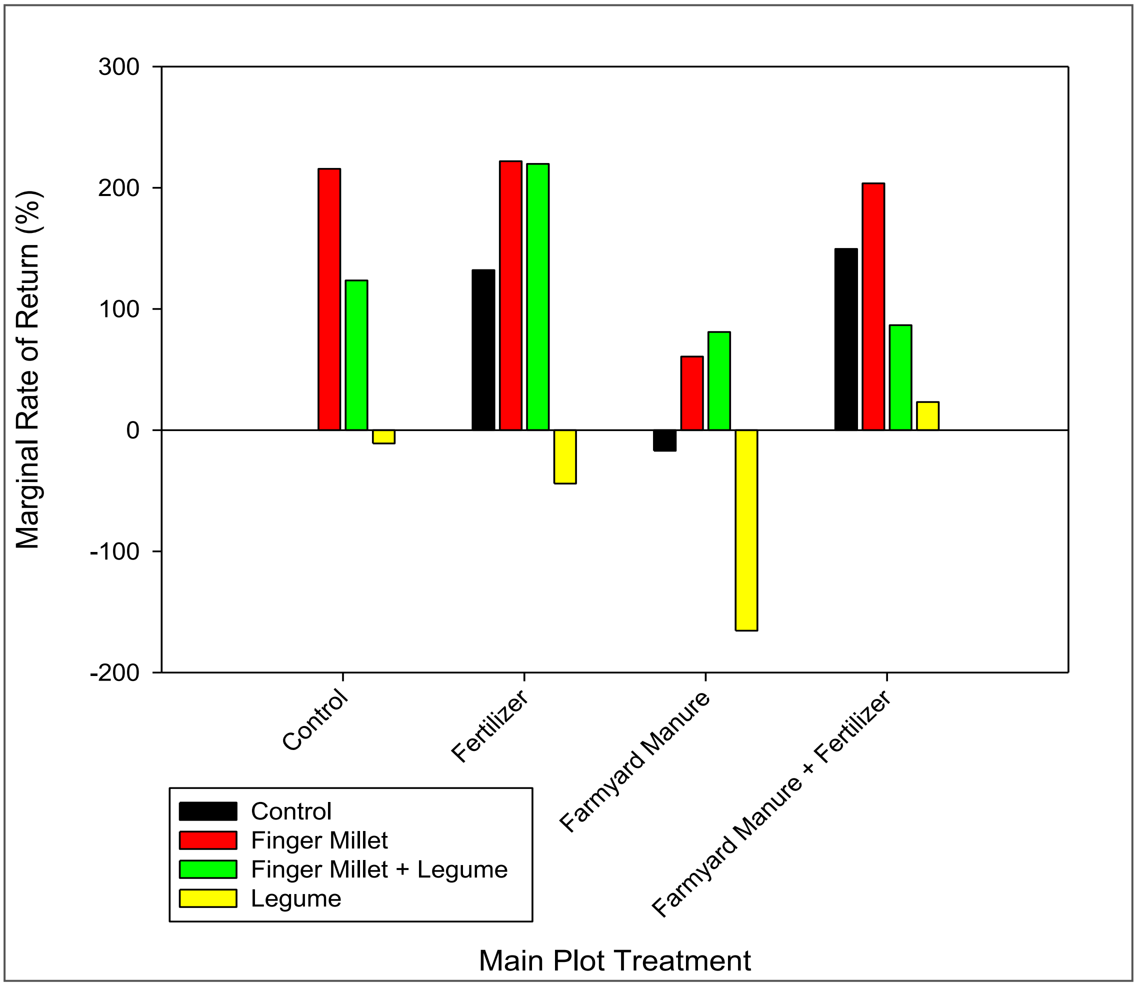

Figure 2-1: Marginal rates of return across fertilizer and intercropping treatments in year one.

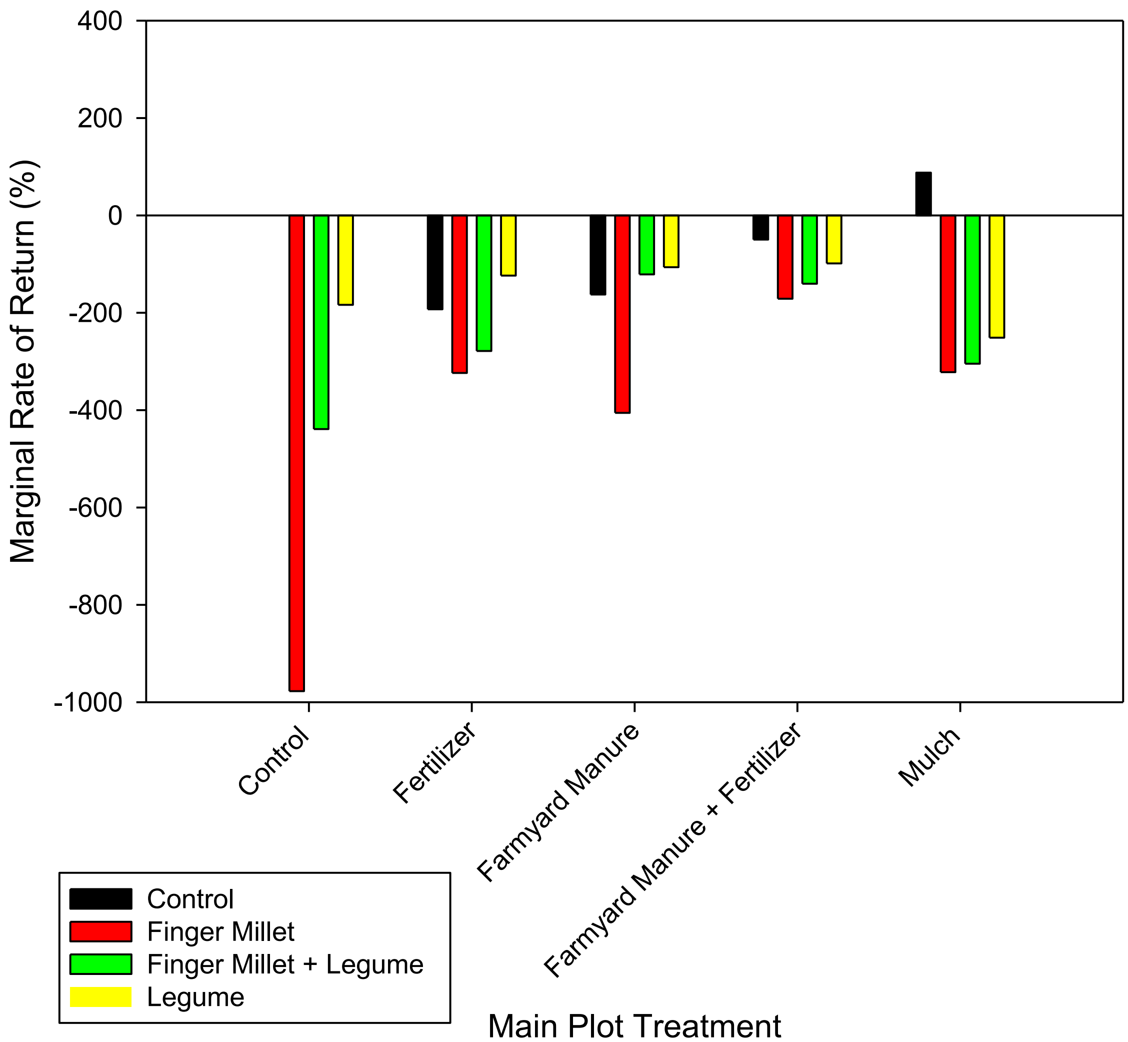

Figure 2-2: Marginal rates of return across fertilizer and intercropping treatments in year two.

2.8 Literature Cited

Agoramoorthy, G. (2008). Can India meet the increasing food demand by 2020? *Futures, 40*(5), 503-506. doi:10.1016/j.futures.2007.10.008

Altieri, M. A., Funes-Monzote, F. R., & Petersen, P. (2012). Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty. *Agronomy for Sustainable Development, 32*(1), 1-13. doi:10.1007/s13593-011-0065-6

Altieri, M. (1999). The ecological role of biodiversity in agroecosystems. *Agriculture Ecosystems & Environment, 74*(1-3), 19-31. doi:10.1016/S0167-8809(99)00028-6

Altieri, M. A., & Nicholls, C. I. (2003). Soil fertility management and insect pests: Harmonizing soil and plant health in agroecosystems. *Soil and Tillage Research, 72*(2), 203-211. doi:10.1016/S0167-1987(03)00089-8

Anil L, Park J, Phipps RH, Miller FA. (1998). Temperate intercropping of cereals for forage: A review of the potential for growth and utilization with particular reference to the UK. Grass Forage Sci 53:301-317.

Amanullah, M. M., Kailasam, C., Safiullah, A. M., Selvam, S., & Sivakumar, K. (2007). Crop simulation growth model in cassava. *Research Journal of Agriculture and Biological Sciences, 3*(4), 255-259.

Amanullah, M. M., Sathyamoorthi, K., Vaiyapuri, K., Alagesan, A., & Pazhanivelan, S. (2007). Influence of organic manures on the nutrient uptake and soil fertility of cassava (manihot esculenta crantz.) intercropping systems. *International Journal of Agricultural Research, 2*(2), 136-144.

Amanullah, M. M., Sathyamoorthi, K., Vaiyapuri, K., & Pazhanivelan, S. (2007). Yield and economics of cassava (manihot esculenta crantz.) as influenced by intercropping and organic manures. *International Journal of Plant Sciences (Muzaffarnagar), 2*(1), 18-22.

Asumadu, H., Sallah, P. Y. K., Boa-Amponsem, P. B., Manu-Aduening, J. A., & Osei-Bonsu, P. (2004). On-farm evaluation and promotion of quality protein maize hybrids in Ghana. *African Crop Science Conference Proceedings*, 4, 358–364.

Banik P, Midya A, Sarkar BK, Ghose SS (2006) Wheat and chickpea intercropping systems in an additive series experiment: Advantages and weed smothering. Eur J Agron 24:325-332.

Baseline APM Survey (2013). M.S. Swaminathan Foundation and the University of Alberta. Alleviating Poverty and Malnutrition in Agrobiodiversity Hotspots: Baseline Report.

Bedoussac, L., & Justes, E. (2011). A comparison of commonly used indices for evaluating species interactions and intercrop efficiency: Application to durum wheat-winter pea intercrops. *Field Crops Research,124*(1), 25-36. doi:10.1016/j.fcr.2011.05.025

Bhatt A, Singh V, Shrotria PK, Baskheti DC (2003). Coarse Grains of Uttaranchal: Ensuring sustainable Food and Nutritional Security. Indian Farmer's Digest. pp. 34-38.

Bulluck, L., Brosius, M., Evanylo, G., & Ristaino, J. (2002). Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. *Applied Soil Ecology,19*(2), 147-160. doi:10.1016/S0929-1393(01)00187-1

Cadavid, L., El-Sharkawy, M., Acosta, A., & Sanchez, T. (1998). Long-term effects of mulch, fertilization and tillage on cassava grown in sandy soils in northern Colombia. *Field Crops Research, 57*(1), 45-56. doi:10.1016/S0378-4290(97)00114-7

Carsky, R.J., and Toukourou, M.A, (2005). Identification of nutrients limiting cassava yield maintenance on a sedimentary soil in southern Benin, West Africa. *Nutrient Cycling in Agroecosys.,* 71. 151-162. Jul. 2005.

Chaisri, S., Panitnok, K., Sarobol, E., Thongpae, S., Chaisri, P., Ngamprasitthi, S., . . . Boonsri, N. (2013). Effects of chicken manure and chemical fertilizer management on yield of cassava grown on map bon, coarse-loamy variant soil. *Communications in Soil Science and Plant Analysis, 44*(1-4), 347-355. doi:10.1080/00103624.2013.742004

Chen, X., Cui, Z., Vitousek, P. M., Cassman, K. G., Matson, P. A., Bai, J., . . . Zhang, F. (2011). Integrated soil-crop system management for food security. *Proceedings of the National Academy of Sciences of the United States of America, 108*(16), 6399-6404. doi:10.1073/pnas.1101419108

Dillon, J. L., & Hardaker, J. B. (1993). Farm management research for small farmer development (2nd ed., pp. 173–189. FAO Systems Management Series). Rome, Italy: Food and Agriculture Organization.

Fukai, S., & Trenbath, B. (1993). Processes determining intercrop productivity and yields of component crops. *Field Crops Research, 34*(3-4), 247-271. doi:10.1016/0378-4290(93)90117-6

Grossmann, J., and Freitas, A.G. (1950). Determinação do teor de matéria seca pelo método peso específico em raízes de mandioca. *Revista Agronô*mica 14: 75-80.

Gruere, G., Nagarajan, L., & King, E. D. I. O. (2009). The role of collective action in the marketing of underutilized plant species: Lessons from a case study on minor millets in south India. *Food Policy, 34*(1), 39-45. doi:10.1016/j.foodpol.2008.10.006

Herrera Campo, B. V., Hyman, G., & Bellotti, A. (2011). Threats to cassava production: Known and potential geographic distribution of four key biotic constraints. *Food Security, 3*(3), 329-345. doi:10.1007/s12571-011-0141-4

Howeler, R.H. (1991). Long-term effect of cassava cultivation on soil productivity. Field Crops Res., 26: 1-18.

Howeler, R. H. (1996). Mineral nutrition of cassava. In: Craswell, E.T., Asher, C.J. and O'Sullivan, J.N. (eds) Mineral Nutrient Disorders of Root Crops in the Pacific. Proceedings Workshop, Nuku'alofa, Kingdom of Tonga, 17-20 April 1995, ACIAR Proceedings no. 5, Canberra, Australia, pp. 110-116

Howeler, R.H., (2002). Cassava mineral nutrition and fertilization. In: Hillocks, R.J., Thresh, M.J., Bellotti, A.C. (Eds.), *Cassava: Biology, Production and Utilization*. CAB International, Wallingford, pp. 115–147.

Islami, T., Guritno, B., & Utomo, W. H. (2011). Performance of cassava (manihot esculenta crantz) based cropping systems and associated soil quality changes in the degraded tropical uplands of east java, Indonesia. *Journal of Tropical Agriculture, 49*(1/2), 31-39.

Jayakumar, S., Ramachandran, A., Bhaskaran, G., & Heo, J. (2009). Forest dynamics in the eastern ghats of Tamil Nadu, India. *Environmental Management, 43*(2), 326-345. doi:10.1007/s00267-008-9219-y

Jones, D.B. (1941). Factors for converting percentages of nitrogen in foods and feeds into percentages of proteins. Circular No. 183. Washington, DC, United States Department of Agriculture.

Kanto, U., Jutamanee, K., Osotsapar, Y., & Jattupornpong, S. (2012). Effect of swine manure extract on leaf nitrogen concentration, chlorophyll content, total potassium in plant parts and starch content in fresh tuber yield of cassava. *Journal of Plant Nutrition, 35*(5), 688-703. doi:10.1080/01904167.2012.653074

King, E.D.I.O., 2005. Sacred Forests of Kolli Hills, Tamil Nadu, India: A Study on Botany, Ecology and Community Interactions. Ph.D. Thesis, M.S. Swaminathan Research Foundation, Chennai, India

Kohli, D.S. and Singh, N. (1997). 'The Green Revolution in Punjab, India: The Economics of Technological Change'. Conference paper.

Kumar, A., Angadi, S. S., & Ravikumar, R. L. (2008). Influence of legumes on yield, quality and economics of pop sorghum under inter and mixed cropping system. *Plant Archives, 8*(1), 351-353.

Liebig, M., Varvel, G., Doran, J. (2001). A Simple Performance-Based Index for Assessing Multiple Agroecosystem Functions. *Agronomy Journal,* 93, 313–318. doi:10.2134/agronj2001.932313x

Leihner, D. (1983). *Management and evaluation of intercropping systems with cassava.*

Lithourgidis, A. S., Dordas, C. A., Damalas, C. A., & Vlachostergios, D. N. (2011). Annual intercrops: An alternative pathway for sustainable agriculture. *Australian Journal of Crop Science, 5*(4), 396-410.

Makinde, E.A., Saka, J.O. (2007). Economic evaluation of soil fertility management options on cassava-based cropping systems in the rain forest ecological zone of South Western Nigeria. *Afr. J. Agric. Res*., 2 (2007), pp. 7–13

Maloles, J. R., Berg, K., Subramanyam Ragupathy, Nirmala, B. C., Althaf, K. A., Palanisamy, V. C., & Newmaster, S. G. (2011). The fine scale ethnotaxa classification of millets in southern India. *Journal of Ethnobiology, 31*(2), 262-287. doi:10.2993/0278-0771-31.2.262

Midmore, D. (1993). Agronomic modification of resource use and intercrop productivity. *Field Crops Research, 34*(3-4), 357-380. doi:10.1016/0378-4290(93)90122-4

Muthumanickam, D., Kannan, P., Kumaraperumal, R., Natarajan, S., Sivasamy, R., & Poongodi, C. (2011). Drought assessment and monitoring through remote sensing and GIS in western tracts of Tamil Nadu, India. *International Journal of Remote Sensing, 32*(18), 5157-5176. doi:10.1080/01431161.2010.494642

Ngigi, S.N. Savenije, H.H. G., Thome, J.N., Rockström, J., Penning de Vries, F.W.T. (2005). Agro-hydrological evaluation of on-farm rainwater storage systems for supplemental irrigation in Laikipia district, Kenya. *Agricultural Water Management*, 73 (1) (2005), pp. 21–41

Pathak, H., Mohanty, S., Jain, N., & Bhatia, A. (2010). Nitrogen, phosphorus, and potassium budgets in Indian agriculture. *Nutrient Cycling in Agroecosystems, 86*(3), 287-299. doi:10.1007/s10705-009-9292-5

Patra DD, Anwar M, Chand S. 1997. Residue recycling for restoring soil fertility and productivity of Japanese mint (Mentha arvensis) mustard (Brassica juncea) cropping system. International Plant Nutrition Colloquium; 1997 Sep 13–19; Tokyo, Japan. In: Ando T, Fujita K, Mae T, Matsumoto H, Mori S, Sekiya J, editors. Plant nutrition for sustainable food production and environment. Tokyo (Japan):Kluwer Academic. p. 587–588.

Perrin, R., Anderson J., Winkelmann, D., and Moscardi, E. (1988). From Agronomic Data to Farmer Recommendations: An Economic Training Manual. *CIMMYT*: Mexico, D.F. Onlinehttp://www.cimmyt.org

Polthanee, A., Wanapat, S., Wanapat, M., Wachirapokorn, C. (2007). Cassava-Legumes inter-cropping: A potential food-feed system for dairy farmers. Thailand Report: Use of Cassava as Animal Feed http://www.mekarn.org/procKK/polt.htm.

Pypers, P., Sanginga, J.M, Kasereka, B., Walangululu, M., and Vanlauwe, B, (2011). Increased. productivity through integrated soil fertility management in cassava-legume intercropping systems in the highlands of Sud-Kivu, DR Congo, *Field Crops Res*., 120, 76-85. Sept. 2011.

Ram M, Kumar S. 1997. Yield improvement in the regenerated and transplanted mint, Mentha arvensis by recycling the organic wastes and manures. Biores Technol. 59:141–149.

Ram D, Ram M, Singh R. 2006. Optimization of water and nitrogen application to menthol mint (Mentha arvensis L.) through sugarcane trash mulch in a sandy loam soil of semi-arid subtropical climate. Biores Technol. 97:886–893.

Ram, M., Singh, M., Prajapati, A. K., Ram, D., & Rawat, G. (2012). Towards sustainable production of peppermint (mentha piperita L.) through integrated use of vermicompost and cowpea green manuring with synthetic nitrogen fertilization. *Archives of Agronomy and Soil Science, 58*(3), 293-301. doi:10.1080/03650340.2010.514266

Reis, M. M., Ferreira, M., Sarmento, S. (2002). A multi-way analysis of starch cassava properties. *Chemometrics and Intelligent Laboratory Systems*, 2002, 64, 123-135.

SAS Institute Inc. 2008. SAS/STAT® 9.2. User's Guide. Cary, NC: SAS Institute Inc.

Saha, S., Mina, B. L., Gopinath, K. A., Kundu, S., & Gupta, H. S. (2008). Organic amendments affect biochemical properties of a subtemperate soil of the Indian Himalayas. *Nutrient Cycling in Agroecosystems, 80*(3), 233-242. doi:10.1007/s10705-007-9139-x

Sharma, K. L., Grace, J. K., Mishra, P. K., Venkateswarlu, B., Nagdeve, M. B., Gabhane, V. V., . . . Ramachandran, K. (2011). Effect of soil and nutrient-management treatments on soil quality indices under cotton-based production system in rainfed semi-arid tropical vertisol. *Communications in Soil Science and Plant Analysis, 42*(11), 1298-1315. doi:10.1080/00103624.2011.571735

Suja, G., John, K. S., Sreekumar, J., & Srinivas, T. (2010). Short-duration cassava genotypes for crop diversification in the humid tropics: Growth dynamics, biomass, yield and quality. *Journal of the Science of Food and Agriculture, 90*(2), 188-198. doi:10.1002/jsfa.3781

Vieira, E.A., Fiahlo J. de F., Faleiro, F.G., Bellon, G., Fonseca, K.G., Carvalho, L.J.C.B., Silva, M.S., Paula-Moraes, S.V., Oliveira, C.M., Denke, M.L. (2011). Characterization of sweet cassava accessions based on molecular, quantitative and qualitative data. *Crop Breeding and Applied Biotechnology,* v.11, p.232-240, 2011. DOI: 10.1590/S1984-70332011000300005

Willey, R. W. (1979). Intercropping - its importance and research needs. 1. competition and yield advantages. *Field Crop Abstracts, 32*(1), 1-10.

Yadav RL, Prasad SR, Singh R, Srivastava VK. 1994. Recycling sugarcane trash to conserve soil organic carbon for sustaining yield of successive ratoon crops in sugarcane. Boires Technol. 49:231–235.

Zuo, Y., & Zhang, F. (2011). Soil and crop management strategies to prevent iron deficiency in crops. *Plant and Soil, 339*(1-2), 83-95. doi:10.1007/s11104-010-0566-0

3.0 Assessing the impacts of various fertilizer and intercropping management recommendations on soil quality in Kolli Hills, South India

3.1 Introduction

Cassava (*Manihot esculenta* Cranz, family *Euphoribiaceae*) production in Asia has grown considerably in the past 30 years (Suresh et al., 2011). Traditionally a food crop produced for its ability to grow in a wide variety of soil and climate regions for low cost (Herrera Campo et al., 2011; Amanullah et al., 2007), it is now becoming a major industrial crop (Suresh et al., 2011; Srinivas and2009; Srinivas 2007). It is being used in India in the textile, pharmaceutical and food production industries (Srinivas 2009). The great diversity in uses has led to cassava production increasing in many areas in India and has led to decreases in the total area of land planted to other crops in the Kolli Hills, Tamil Nadu, South India (Gruere et al., 2007).

Continuous monocropping of cassava has been shown to reduce yields and soil fertility as a result of insufficient nutrient replenishment with inorganic or organic soil amendments (Islami et al., 2011; Polthanee et al., 2007; Howeler et al., 1991). Cassava production is prone to soil erosion due to its slow initial growth and wide row spacing (Polthanee et al., 2007; Islami et al., 2011; Chaisri et al., 2013; Kanto et al., 2012; Howeler 1991). Soil fertility is also reduced since very little of the cassava biomass is re-incorporated into the soil; the tubers are removed and sold and the stems are used for replanting (Polthanee et al., 2007; Howeler 1991). Therefore, to maintain cassava production and to create sustainable soil quality, management changes are required (Cadavid et al., 1998).

With 75 percent of dry land areas in the Kolli Hills now under cassava cultivation (Gruere et al., 2007), crop diversity and food security is very limited in this region of south India. The majority of households are poor, with an average farm size of 0.78 hectares; 0.70 hectares of un-irrigated dry upland fields, the remaining 0.08 hectares lowland, wet areas (Baseline APM study 2013). The farmers are dependent on climate as rain-fed agriculture is predominant in the area (Panda et al., 2011; Jayakumar et al., 2009). The annual nature of cassava production limits other crop production as well as soil health in this area therefore management practices that can intensify this system need to be considered.

Intensification of agriculture, including intercropping, with the application of organic and inorganic fertilizers, affects sustainability and soil quality (Saha et al., 2008; Midmore 1993). Intercropping can increase the efficiency of a system; approximately one third of cassava grown globally is intercropped (Amanullah et al., 2007; Suja et al., 2010). Studies have also shown that organic amendments in intercropping systems will improve soil fertility and available nutrients, including nitrogen to crops (Bulluck et al., 2002; Saha et al., 2008; Singh et al., 2007; Cadavid et al., 1998). The addition of inorganic fertilizers can help to sustain yields (Pathak et al., 2010; Cadavid et al., 1998; Saha et al., 2008). A combination of inorganic and organic fertilizers has been shown to improve yields and soil health (Yadav et al., 1994; Patra et al., 1997; Ram and Kumar 1997; Ram et al., 2006; Ram et al., 2012).

Intercropping, mixed cropping and polyculture is used to define the growth of two or more crops in the same place at the same time providing farmers with increased food security and reduced risk (Altieri and Nicholls 2003; Zuo and Zhang 2011; Lithourgisdis et al., 2011; Bedoussac and Justes 2011). As much as 15 to 20 percent of the food produced worldwide comes from these systems (Altieri et al., 2012). Low N systems are often optimized with intercropping because of the complementary N use by the component crops (Bedoussac and Justes 2011, Ram et al., 2012; Islami et al., 2011; Sharma et al., 2011; Polthanee et al., 2007). As tables 3-2 and 3-3 show, the level of soil available N across all sites over both years is below 170 kg/ha and is defined by the Methods Manual: Soil Testing in India, 2011, as being low to very low. Other benefits of intercropping can include reduced soil erosion (Anil et al., 1998;

Amanullah et al., 2007; Fukai and Trenbath 1993; Sharma et al., 2011), weed control and lower weed competition (Banik et al., 2006; Lithourgisdis et al., 2011), and improved lodging resistance (Anil et al., 1998; Lithourgisdis et al., 2011). However, there can be disadvantages to intercropping systems, competition for light, water, and nutrients (Lithourgisdis et al., 2011; Zuo and Zhang 2011; Islami et al., 2011; Altieri 1999).

To sustain or increase yields and improve soil fertility, nutrient management strategies need to be considered (Ogunwole et al., 2010, Ram et al., 2012; Cadavid et al., 1998; Yadav et al., 1994; Patra et al., 1997; Ram and Kumar 1997; Ram et al., 2006). Organic manures help to increase nutrient recycling in systems (Sharma et al., 2011) as well as providing a more consistent, slower release of N (Altieri and Nicholls 2003), and an increase to soil microbial biomass (Kumar et al., 2008; Drinkwater et al., 1995; Bulluck et al., 2002; Goulding 2000). Organic inputs have also been shown to improve soil physical properties including structure, aggregate stability, bulk density, porosity and water holding capacity (Kumar et al., 2008; Amanullah et al., 2007; Bulluck et al., 2002; Saha et al., 2008; Doran 1995). Inorganic, or synthetic, fertilizers have been shown to sustain productivity for longer periods when applied in moderate amounts (Cadavid et al., 1998). However, it has been shown by many studies that the combination of inorganic and organic soil amendments improves yields and soil health (Yadav et al., 1994; Patra et al., 1997; Ram and Kumar 1997; Ram et al., 2006; Ram et al., 2012).

Soil is an essential part of agroecosystems. The resilience of soil to degradative processes and support of food production are measures to assess soil quality (Schoenholtz et al., 2000; Ogunwole et al., 2010; Karlen et al., 1997; Doran et al., 2002; Knoepp et al., 2000). Soil quality is thus defined as the, soils ability to achieve certain function in managed and natural systems (Karlen et al., 1997; Gregorich et al., 1994). However, soil quality is variable; it is dependent on how the soil was originally formed; what the parent material and topography is, as well as its land use history and management history

(Gregorich et al., 1994). Thus, as Doran argued in 2002, the land manager will determine what the quality of the soil is, and therefore, soil quality could be considered an indicator of sustainable management.

Management practices and the impact that they have on agroecosystems and sustainable agriculture systems is becoming increasingly important (Liebig et al., 2001; Altieri et al., 2012). Management practices can affect many physical, biological and chemical properties of soil quality (Drinkwater et al., 1995). However, there is a limited amount of research or knowledge of the impacts of management practices in regards to the soil and climatic conditions of a particular area (Alteiri et al., 2012; Doran 2002).

Soil fertility management has been adopted in many parts of the world (Ogunwole et al., 2010). It is now common practice for farmers in the developed world to have soil samples collected and analyzed prior to planting and fertilizing. Benefits to farmers include cost savings by reducing the amount of fertilizer used, and therefore minimizing environmental impacts due to run-off and excess nutrient leaching (Hussain et al., 1999). However, in the developing world the cost of nutrient analysis can be prohibitive. The creation of a soil quality index (SQI) could help farmers to identify aspects of the soils that could be improved and thereby create management recommendations that would be site-specific (Hussain et al., 1999). An SQI is a number that scores physical and chemical properties of soil ability to accomplish specific roles in the soil ecosystem (Armenise et al., 2013).

The attributes that are a part of good soil can be variable and can depend on the needs of the end user (Doran et al., 200). The creation of an SQI often begins by defining the management goals (Armenise et al., 2013). Continual and sustainable cassava productivity in the Kolli Hills is a major end product, which depends on many factors, not just sufficient plant nutrients. The physical and chemical properties of soil, including its organic matter content (SOM), pH, texture, cation exchange capacity

(CEC),electrical conductivity (EC), moisture content, and water-retention capacity can impact the soil productivity as well as ecosystem functions (Andrews et al., 2002 ; Doran et al., 200). In 1994, Karlen and Stott created an approach to a SQI that used the integration of weighted soil indicators that related to specific management results: plant productivity and environmental sustainability.

An understanding of the management goals are a first step in the creation of an SQI, this will lead to associating the soil functions that are associated with that management goal (Armenise et al., 2013; Yao et al., 2013). Chemical and physical soil properties can be indirect measures of ecosystem functions and can therefore be important attributes in creating an SQI (Armenise et al., 2013). The indicators should be sensitive to management and changes in the climate as well as accessible (Doran 2002; Armenise et al., 2013; Knoepp et al., 2000; Andrews et al., 2004; Yao et al., 2013). The indicators can be selected statistically as in the framework created by Andrews et al., 2004. Statistical methods of indicator selections would allow the framework to be used across regions, management practices and various soil types (Andrews et al., 2004). The indicators should also be selected from soil properties that are easily measured and reproducible (Gregorich et al., 1994). Once all the potential indicators are selected, they can be grouped into their relative functions in the soil ecosystem and this can be based on the groupings created by Costanza at al. in 1992. Otherwise, the creation of a minimum data based on the work of Doran et al., 1996 can also be used as a framework before statistical weighting and ranking occurs to create a clearly defined SQI.

3.2 Study objectives

This study aims to improve the sustainability of cassava production in the Kolli Hills specifically by:

1. Identifying the various effects that intercropping and fertilizer amendments have on soil physical and chemical properties.

2. Create a soil quality index model that is appropriate for smallholder farms in Kolli Hills, South India
3. Evaluate the impacts that fertilizer amendments and intercropping have on soil quality index and how this relates to crop yields of cassava.

3.3 Materials and methods

3.3.1 Site description

The study was conducted in the Kolli Hills, a mountainous region in the Eastern Ghats, on the Eastern border of the Namakkal District in Tamil Nadu, south India (78°20' to 78°30' E longitude; 11°10' to 11°30' N latitude), and with an area of 28 293 hectares (Gruere et al., 2009; Jayakumar et al., 2009). There are 14 villages and 247 hamlets in this district (Baseline APM survey 2013). Year one sites were located in the hamlets of Perikovilo, Asakadu and Soldaipatti; year two sites were located in the hamlets of Oleyur, Aalavadi, and Mathryilovo. All the sites were located within 4 kilometers of each other. All sites have been continuously planted to cassava for at least the past 5 years. All the sites have not had any additional nutrients added during this period and all are rainfed.

The average annual precipitation is 1440 millimeters, with great variation from year to year with as little as 800 millimeters to as much as 1800 millimeters per annum (Gruere et al., 2009; Maloles et al., 2011). Rainfall is usually heaviest during the monsoon, August to December however; there is a great amount of variation within that period as well. The sites are located in a hilly region and therefore even at a close distance from each other it was possible for variable amounts of rainfall to affect each site.

3.3.2 Soil Characterization

The Kolli Hills region consists of highly weathered laterite soils, also referred to as Kaolisols or Acrisols by the FAO. The bedrock of the Kolli Hills is composed of gneiss of ancient origin. Minerals within the gneiss bedrock include acid charnokite with minor bands of pyroxene and magnetite quartzite. The hills are highly undulating with seasonal and semi-permanent streams throughout that flow in all directions and drain into the Ayyar River and Varattar Nadi (King 2005).

The soils are deep to very deep, non-calcareous and developed from weathered gneiss (Jayakumar et al., 2009). There is high bauxite content in some areas. Soil texture varies with the hilltops characterized by rocky terrain with various sized stones and boulders. The soil is a sandy loam and the bases of the hillsides are characterized by alluvial clay loam texture (King 2005). The soils are excessively drained and have moderate permeability. The sites consist mainly of red, sandy clay loams with relatively low CEC's. All sites were located at elevations of over 1000 meters above seas level (masl) with relatively flat topography. Soil samples were taken of all sites prior to the study and results can be seen in tables (3-2 and 3-3).

3.3.3 Experimental plot design

The study was laid out in a split plot design with the soil fertility amendments as the main plot treatments and the intercrops, additive, as the sub plot treatments. The plots were 5 m x 5 m during year one and 5.6 m x 5.6 m during year two. All sites were soil sampled prior to planting and then ploughed 3 times to a depth of 30 cm. All planting, weeding, plot maintenance and harvesting was done by hand and as per normal farmer practice. At harvest yields were measured in kg/plot and results were then converted to kg/ha.

Year one consisted of four main plot treatments:

1) Control, no added fertilizer or manure;
2) farmyard manure (See table 3-1 for nutrient content) applied at a rate of 5 tonnes/ha;
3) fertilizer, N in the form of urea applied at a rate of 100 kg N/ha, triple superphosate at a rate of 50 kg P/ha, and potash applied at a rate of 100 kg K/ha;

4) farmyard manure plus fertilizer at the same rates as the farmyard manure and fertilizer;

The second year sites had the same main plot fertility treatments with the addition of a mulch treatment that consisted of rice paddy straw applied once at a rate of 6 kg/ha completely covering the soil at the time of application.

The sub plot treatments were the same for year one and year two:

1) Cassava alone spaced at 1 m x 1 m during year one and 0.80 m x 0.80 m during year two;
2) cassava intercropped with rows of finger millet (GPU 48) planted 10 cm apart and at a distance of 0.5 m from the cassava during year one and 0.40 m during year two;
3) cassava intercropped with local black bean planted 30 cm apart with a distance of 0.5 m from the cassava during year one and 0.4 m during year two;
4) cassava with finger millet and black bean intercrop that consisted of one row of cassava, one row of bean, one row of cassava, one row of finger millet;

During year one, the experimental plots at Asakadu and Perikovilo had 2 replications for a total of 32 subplots, while Soldaipatti had 4 replications and therefore 64 subplots. In year two, Mathryilovo had 3 replications for a total of 60 subplots and Aalavadi and Oleyur each had 4 replications for a total of 80 subplots. Years will be differentiated throughout the rest of the chapter due to the great variability in precipitation and temperature between the two seasons and the impact that this non-measured component could have on yield and soil properties.

3.3.4 Planting, Crop Maintenance and Harvesting Data

Plots were planted and then harvested according to plant maturity and local practices. Cassava plants were taken from cuttings and planted by hand; intercrop species were planted concurrently with cassava and then bean plants were harvested approximately 70-80 days after planting, while millet was harvested approximately 120 days after planting. Cassava plants were harvested by uprooting whole plants from centre rows, harvesting occurring 9 months to 16 months after the planting date, dependent on the occurrence of rainfall which was approximately 13 months after planting in year one and 11 months after planting in year 2. Rainfall prior to harvesting is necessary to help increase the ease of harvesting and allow the tubers to take up more water, increasing their final weight. Yields were then calculated on a per hectare basis.

3.3.5 Sampling and Analysis of Soil

Sampling was based on standard methods. Composited soil samples from 0-15 cm and 15-30 cm depth increments were taken in a zigzag pattern, across all sites prior to planting in years one and two. At harvest, samples were taken in each subplot to a depth of 0-15 cm and 15-30 cm. Composite and subplot soil samples were analyzed for: texture, pH, EC, CEC, soil organic matter content, total organic carbon, total available N,P,K, exchangeable Ca, Mg, Na, K and Fe, Zn, Cu and Mn.

Soil physical properties were analyzed as per standard procedures at EcoSave Labs, Salem, Tamil Nadu. Bulk density was determined by oven-dried method. Texture, and sand, silt, clay content was determined by the hand texturing (Department of Agriculture & Cooperation Ministry of Agriculture Government of India, 2011). Samples were air dried, passed through a 2 mm sieve and then analyzed for chemical properties. Soil pH and EC were determined with a pH and EC electrode in a 1:2.5 water to soil extracts (Rhoades 1981). Soil organic carbon was analyzed by oxidation with sulfuric acid (H_2SO_4) and potassium dichromate ($K_2Cr_2O_7$) (Walkley and Black 1934). Available N was determined by alkaline potassium permanganate ($KMnO_4$) oxidizable N method (Subbaiah and Asija 1956). Available P was determined by sodium bicarbonate ($NaHCO_3$) extraction and colorimetric analysis (Olsen et al., 1954). Available K was assessed via with normal neutral ammonium acetate solution and flame photometric method (Toth and Prince 1949). CEC was measured via the barium chloride-triethanolamine method

(Mehlzich 1938), which is buffered at pH 8.2. Exchangeable Ca, Mg, Na and K were determined by neutral normal ammonium acetate. Extractable Zn, Fe, Cu, and Mn by diethylenetriaminepentaacetic acid (DTPA) (0.005 M) with triethanolamine (TEA)(0.1 M) and calcium chloride($CaCl_2 \cdot 2H_2O$) (0.01 M) reagent (pH 7.3) using atomic absorption spectrophotometer (Lindsay and Norvell 1978).

3.3.6 Data Analysis

When assessing the impacts of several different treatments on several variables, as is common in agronomic studies, one of the major challenges is selecting appropriate statistical methods. In addition, in field studies there are always other random impacts that may influence the variable of interest and therefore a linear mixed model was used to analyze all yield and soil data. All analysis of treatment differences was conducted via an analysis of variance (ANOVA), correlations and regressions were done in the mixed procedure with SAS software (Mixed Procedure SAS Institute 2008).The use of a split plot design influences the precision that the results of the statistical analysis will determine for both main and sub plot treatments. There is greater precision in results pertaining to the intercropping in this study, as they were the sub plot treatment. Soil properties can vary greatly in one site and the variation between sites can be very great because of this heterogeneity. Therefore, after testing for normality, homogeneity of variance, the data was assessed in each site individually.

3.3.7 Creation of a Soil Quality Index (SQI)

A minimum data set needs to be created in order to be able to create an SQI (Doran and Parkin 1994; Andrews et al., 2002; Sharma et al., 2008). Chemical and physical soil properties that farmers in the Kolli Hills would be able to have analyzed were included in the minimum data set. The indicators were sand, silt, clay, OM, pH, CEC, EC, available N, available P, available K, exchangeable Ca, exchangeable Mg, exchangeable Na, exchangeable K, as well as Zn, Cu, Fe, Mn and bulk density. OM and total N were derived mathematically from the SOC measurements, therefore only SOC was included as an indicator.

After the establishment of a minimum data set al., 19 indicators were standardized in SAS. The standardized factors have unit-variance; therefore the total variance in the Principal Component Analysis (PCA) is 19. PCA analysis is a method of data reduction; it uses standardized data from all raw data to create components (Mixed Procedure SAS Institute 2008). Components are chosen based on the Eigen value criteria: any Eigen value greater than one (Brejda et al., 2000). In addition, the scree test shows where major breaks occur in the data and help determine which components to include in the SQI. For this work, any PCA that accounted for more than 5% of the total variance of the data was included in the SQI (Wander and Bollero 1999). It is important to include enough PCA's to account for over 70% of the variance in the data set. Once the components were determined, a correlation was run between the components to determine whether any factor was correlated to another. If the square of the correlation coefficient was greater than 0.70, then one or the other or both indicators were not included, this would consider what the indicator represented and whether the indicators represented soil factors that act very similarly in the soil (Andrews et al., 2002; Sharma et al., 2011; Armenise et al., 2013).

Once the components were determined, they were transformed using one of three curvi-linear functions: 1) "more is better," where there is a direct benefit seen with the increase of that particular soil property; 2) "less is better," where there is a direct detrimental impact with the increase of that soil property; and 3) "optimum" where there is a direct benefit up to an optimum level and then a determent if the soil property continues to decrease (Andrews et al., 2002; Sharma et al., 2011; Armenise et al., 2013). Transformation of the data to a scale between 0 and 1 was necessary to be able to include it in the soil quality equation, the transformation values were based on literature and levels of each soil property and the level that it was considered low, adequate or high. Figure 3-3 shows the scoring functions used to transform the measured indicator values. CEC, Zn, available K, and Cu followed a more is better function, while pH and % clay content followed an optimum function. Once all data was transformed the indicators were weighted for the principal components. Equation 1 shows the SQI formula where Wi represents the weight of the variance established by PCA analysis and Si represents the transformed value of the soil parameter selected for inclusion in the SQI.

Equation 1: Soil Quality Index Formula

$$SQI = \sum_{i=1}^{n} (Wi \; x \; Si)$$

The assumption is that the higher the total sum the greater the quality of the soil from the weighted formula (Sharma et al., 2011; Armenise et al., 2013).

In split-plot analysis the sub-plot treatment is assessed with the most precision. Analysis of each individual site resulted in intercropping impacting available P in Soldaipatti and Oleyur. There was also a significant impact of intercropping on available N, exchangeable Mg, and Na in Perikovilo; EC in Mathyriolovo; and exchangeable K, Mn and Cu in Oleyur. Fertilizer treatments impacted soil pH in Soldaipatti; Zn in Mathyriolovo; and EC in Oleyur. Therefore based on statistical analysis of treatment effects, soil available N, available P, exchangeable Na, exchangeable Mg, exchangeable K, pH, EC, Zn, Cu and Mn were all impacted. This also indicates that these measures should be included in a minimum data set for soil quality in the Kolli Hills.

The PCA analysis resulted in 5 components that accounted for more than 5% of the variance in the data (Table 3-7). The scree test confirmed that these five components accounted for the most variation and were separated in pattern from the remaining indicators (Figure 3-2). The PCA results showed that component 1 accounted for approximately 27% of the variance and centered around micronutrients in the soil; component 2 focused on soil texture and CEC and represented 21% of the variance; component 3 was most heavily weighted on Cu and represented 13% of the variance; component 4 is weighted to pH and represents 11% of the variance, and component 5 available K represents 6% of the total variance (Table 3-7). Table 3-8 indicates that ex Ca (-0.66015), Na (0.65163) are highly correlated and therefore only Zn will be included as component one in the SQI. Sand, silt and clay are highly correlated, from 93 to 98% and therefore only clay will be considered in the SQI. According to table 3-8 the CEC is not strongly correlated to clay and an important factor and will therefore be included in the SQI with clay a part of component two (0.39413)(Table 3-7, Table 3-8). Component 3 is just weighed for Cu and component 4 included pH and Na which are correlated (0.52792) and therefore only pH will be included (Table 3-7 and 3-8). Finally component 5 is weighted on available K only and thus included in the SQI. Therefore, the SQI equation will include Zn, clay, CEC, Cu, pH and available K.

Equation 2: Soil Quality Index for Cassava Based Systems in the Kolli Hills

$$SQI = (0.27SZn + 0.105SClay + 0.105SCEC + 0.13SCu + 0.11SpH + 0.06SAK)/0.78$$

Non-linear scoring functions were used to transform the measured soil properties to a value between 0 and 1; figure 3-3 demonstrates the transformation. CEC, Zn, available K, and Cu followed a more is better function, while pH and % clay content followed an optimum function (Figure 3-3).

3.4 Results

A summary of the P-values for main plot (fertilizer), subplot (inter-cropping) and main plot X subplot (fertilizer X inter-crop) interaction effects are presented in Table 3-4. Significant fertilizer, inter-cropping and fertilizer X intercropping interaction effects were inconsistent across sites.

3.4.1 Cassava yields

Across the sites in year one and year two there was a great variation in the cassava yields under all the intercropping and fertility treatments. Year one yields were higher than year two yields across all intercrop and fertilizer treatments (Figure 3-1). Year one data showed that there were no significant differences in treatments for cassava yields at Asakadu or Soldaipatti and yield data was not taken from Perikovilo because of labour availability (Figure 3-1). During year two, site wise there were no statistically significant ($P<0.05$) differences in treatment means in Aalavadi, however, both Mathyriolovo and Oleyur had significant intercrop treatment differences (Table 3-5). In Mathyriolovo, cassava yield in the control treatment was significantly greater than all the intercrop treatments; the cassava yield in the cassava-legume inter-crop was significantly lower than the control, but significantly higher than the cassava-finger millet and the cassava-finger millet plus legume treatment (Table 3-5). In Oleyur, the cassava yields in the control were significantly higher than the cassava-finger millet, which was significantly lower than the cassava-finger millet plus legume and the cassava-legume treatment (Figure 3-1).

3.4.2 Impacts of treatments on soil properties

Soil samples across the sites were significantly different from each other (See tables 3-2 and 3-3) and therefore soil property impacts were examined at each site from 0-15 cm, the depth that most affects plant growth and yield. There was great variability in the results of the intercropping and fertility treatments analyzed by multivariate ANOVA's (Mixed Procedure SAS Institute 2008) to all sites during both years on measured soil physical and chemical properties: sand, silt clay content, pH, EC, CEC, soil organic matter content, total organic carbon, total available N, P, K, exchangeable Ca, Mg, Na, K and Fe, Zn, Cu and Mn and bulk density at a p-value of 0.05 or less.

Significant fertilizer X inter-cropping interaction effects were limited to two sites (Table 3-4) for EC (Aalavadi) and exchangeable Na (Soldaipatti). Interaction effects showed that with the addition of fertilizer and farmyard manure and fertilizer with legume and legume plus finger millet there was an increase in soil EC. Soil Na in Soldaipatti increased with farmyard manure and farmyard manure plus fertilizer when intercropped with legume and legume with finger millet.

Inter-cropping treatment effects (P<0.05; Table 3-4) were apparent in (See table 3-5 for treatment means and standard errors):

1) post-harvest EC measured at Mathryilovo, with the cassava-finger millet and cassava-legume intercrop being significantly higher than the control, cassava-finger millet and cassava-legume treatments (f-stat=2.88 f sem=0.002 (mS/cm)
2) available N at Perikovilo, with the cassava-finger millet intercropping treatment having significantly lower post-harvest available N than the cassava-legume and cassava-legume plus finger millet treatment (f-stat=3.58 sem=29.38(kg/ha))
3) available P at Oleyur, with the cassava-finger millet treatment being significantly higher than the cassava monocrop, cassava-legume and cassava-finger millet plus legume treatments (f-stat=2.80 sem=1.02 (kg/ha);

   in addition, at Soldaipatti, with the cassava-finger millet plus legume being significantly higher than the cassava-finger millet or cassava monocrop treatments (f-stat=3.10 sem=3.56 (kg/ha)).
4) exchangeable Mg at Perikovilo, the control being significantly higher than all other treatments (f-stat=5.44 sem=0.075 ((me/100 g soil))
5) exchangeable Na at Perikovilio, with the cassava-finger millet plus legume treatment having significantly higher exchangeable Na than the cassava-finger millet and the cassava-legume

and the cassava monocrop being significantly higher than the cassava-legume (f-stat=4.34 sem=0.02 (me/100 g soil))

6) soil Mn at Oleyur, with the cassava-finger millet plus legume and cassava-finger millet treatments being significantly higher than the cassava monocrop (F-stat=2.83 sem=1.19 (ppm))
7) soil Cu at Oleyur, with the cassava-finger millet treatment being significantly higher than the cassava monocrop or the cassava-finger millet plus legume treatment (f-stat=2.91 sem=0.08 (ppm)).
8) soil exchangeable K at Oleyur, with the cassava-finger millet plus legume being significantly higher than the cassava monocrop or the cassava-legume (p-value=0.026 f-stat=3.37 sem=0.04(kg/ha).

Fertilizer treatment differences (P<0.05; Table 3-4) were apparent in (see Table 3-6 for a summary of means and standard errors):

1) post-harvest soil pH at Soldaipatti, with the farmyard manure treatment being significantly higher than the control, fertilizer and farmyard manure plus fertilizer, while the farmyard manure plus fertilizer was significantly higher than the control or the fertilizer treatments (f-stat=13.32 sem=0.12)
2) post-harvest Zn at Mathryilovo, with the control, fertilizer and mulch treatments all significantly higher than the farmyard manure or the farmyard manure and fertilizer treatments (p-value=0.01 f-stat=6.77 and sem=0.129 (ppm)
3) post-harvest EC at Oleyur, with the fertilizer treatment being significantly higher than the control and the mulch, and the farmyard manure and the farmyard plus fertilizer being

significantly higher than the mulch treatment although lower than the fertilizer (p-value=0.01 f-stat=4.92 sem=0.007 (eS/cm)

3.4.3 Creation of SQI

The SQI formula was used to compare the fertilizer treatments and effects. First year results showed that there were no significant impacts of treatments on SQI in Asakadu, Perikovilo or Soldaipatti. Second year results showed that treatments of fertilizer and intercropping did not have an impact on SQI in Aalavadi, Oleyur. However, it did show a significant impact of fertilizer treatments in Mathyriolovo p-value0.01 (f-stat6.78 sem= 0.03) (Table 3-6). The mulch and the control treatment are significantly better for the SQI than the farmyard manure and farmyard manure plus fertilizer, also the fertilizer is significantly better than the farmyard manure (Figure 3-6). When all sites are combined from year one and two there is no significant impact of intercrop or fertilizer treatment on SQI. SQI however, was created to be predictive of overall soil health and sustain cassava yields. A regression analysis resulted in an r-value of 0.56 showing that there was a strong relationship between the SQI % and the tuber yield with the SQI % explaining 31 % of the yield, which is high considering that yield is not solely based on soil, but also on precipitation and variety (Figure 3-6). Overall site wise means follow a general trend that the higher the SQI % the higher the yield with the exception of Soldaipatti (Figure 3-6).

3.5 Discussion

3.5.1 Cassava yields and nutrient requirements

Growth conditions required for adequate cassava yields include well-drained, light-textured soils (Howeler 1996). All sites were classified as sandy clay loams, therefore light textured, and well drained. A pH in the range of 4.5 to 7.5 is also needed for cassava production (Howeler 1996); all sites fell within this range of pH pre- and post-treatment. Zn in soil needs to be higher than 1 ppm, and according to Howeler 1996, and crop removal of 99kg/ha soil available N, 23kg/ha soil available P, and 77 kg/ha soil available P rates are needed to achieve a yield of 18 tonnes/ha of fresh tubers. Oleyur was the only site that had very low levels of soil Zn pre-treatment which could account for the very low yields attained across all treatments at this site; post treatment indicated that Aalavadi as well as Oleyur were deficient in Zn (Table 3-2, Table 3-3 and Figure 3-1). All sites had relatively low amounts of soil available N prior to treatments and Aalavadi and Mathyriolovo had less than the minimum uptake requirements for cassava yields of 18 tonnes/ha (Table 3-2 and 3-3). Nitrogen deficiency is common in cassava production systems in light textured soils likely because it is prone to leaching, and low organic matter content and pH reduce N mineralization (Howeler 1991). All sites had low levels of SOM pre- and post-treatment (Table 3-2 and 3-3) which could contribute to the lower yields seen across the sites. Cassava requires a high amount of K for root growth and therefore deficiency of K can be a limiting nutrient in continuous cultivation practices (Howeler 1996). Oleyur was the only site that had a relatively low level of soil available K, which would also have contributed to the overall lower yields at this site (Table 3-3 and 3-9).

Cassava can be produced in a wide variety of soil conditions and provide yields even under drought conditions (Howeler 1991; Herrera Campo et al., 2011; Amanullah et al., 2007; Polthanee et al., 2007; Howeler 1991; Kanto et al., 2012; Islami et al., 2011; Chaisri et al., 2013). Soil health and nutrient contents are highly variable both spatially and temporally. Pre-treatment analysis of soil indicated, according to the *Methods Manual Soil Testing in India 2011,* the soils in the Kolli Hills were very deficient in soil available N, falling far below the 220kg/ha that are considered sufficient for crop production (Table 3-2 and 3-3). Available P and K were adequate or high falling between 10-24 kg/ha P and 108-220 kg/ha K respectively (Table 3-2 and 3-3). Finally pH was measured prior to treatment addition and all sites were acidic, with all second year sites having a pH below the 5.5 to 6.5 range that generally influences the availability of nutrients for crop production (Table 3-2 and 3-3)(*Methods Manual Soil Testing in India 2011)*. The variation in the site-wise soil properties prior to treatment could help to explain the variation in results seen in soil and yields, and perhaps, an overall lack of nutrients or the inability of the nutrients to be available to crops was affecting all sites prior to treatments.

Yields of only the fresh cassava tubers within the various intercropping and fertilizer treatments varied greatly from site to site and year to year (Figure 3-1). First year (2012) yields were higher overall across all sites in contrast to second year (2013) trials. This may be attributed to the great variation in climatic conditions, annually there is great variation in precipitation from 800mm to 1800mm (Gruere et al., 2007; Maloles et al., 2011). Mean fresh cassava yields in the first year sites were impacted by fertilizer and fertilizer and farmyard manure treatments, control and intercropping treatments (Figure 3-1). Nutrient replenishment, inorganic and organic, has been shown to increase yields and soil fertility in cassava based systems (Islami et al., 2011; Polthanee et al., 2007; Howeler et al., 1991). The use of organic and inorganic fertilizers has also been shown to increase yields and improve soil fertility in agricultural systems (Ram et al., 2012; Cadavid et al., 1998; Yadav et a. 1994; Patra et al., 1997; Ram and Kumar 1997; Ram et al., 2006). Second season results across sites for fertilizer treatments saw no great differences between fertilizer treatments, only a slightly higher yields in the mulch treatment (Figure 3-1). Cadavid et al., 1998 also found increased yields with the use of a mulching treatment. The use of plant mulch has been shown to reduce soil erosion, maintain soil structure, conserve soil water, reduce soil temperature, and maintain soil fertility via nutrient cycling (Cadavid et al., 1998). Finally, yields with only farmyard manure applied were lower than all fertilizer and control treatments across intercrop treatments (Figure 3-1). Datta el al. in 2009 demonstrated that yields in organic systems were lower than yields in synthetic fertilizer systems. This could be attributed to a higher C:N ratio that would result in net N immobilization. Although not significant, first year results did indicate that the addition of fertilizer did increase yields of cassava across intercropping treatments (Figure 3-1). Many studies have also shown that the addition of inorganic fertilizers can help to sustain yields (Pathak et al., 2009; Cadavid et al., 1998; Saha et al., 2007).

The impacts of intercropping on crop yields was not statistically significant during year one, however the millet treatment over all reduced cassava yields across the fertilizer treatments. The addition of legumes often slightly increased or had a negligible impact on cassava yields. Similarly, Amanuallah et al., found in 2006 that intercropping cassava with cowpea resulted in a non-significant decrease in cassava yields. Sharma et al., 2011 also found increases or non-significant decreases to cassava when it was intercropped with a legume. Legumes within an intercropping system can provide available nitrogen to component crops (Ram et al., 2012; Islami et al., 2011). Year two, site wise there were no statistically significant differences in treatment means in Aalavadi; however, both Mathyriolovo and Oleyur had significant intercrop treatment differences (Figure 3-1 and Table 3-4). In Mathyriolovo, the control yielded highest and the legume had a yield significantly higher than any of the finger millet treatments (Figure 3-1 and Table 3-4). In Oleyur the control, legume and finger millet and legume also yielded significantly higher than the finger millet treatment (Figure 3-1 and Table 3-4). Finger millet treatments yielded lower across sites and fertilizer treatments and demonstrated that there may have been some competition for light, water, or nutrients. Intercropping has been found to have several disadvantages as component crops compete for light, water, nutrients or cause allelopathic effects (Lithourgisdis et al., 2011; Zuo and Zhang 2008; Islami et al., 2011; Altieri 1999). Additional difficulties researchers have encountered include experimental results that are site specific and vary by season, which also happens in monocropping systems, however with intercrops you have higher levels of competition at one growth stage or another and several crops to assess (Fukai and Trenbath 1993; Islami et al., 2011).

3.5.2 Impacts of treatments on soil properties

Fertilizer and intercropping treatments over a one-year season were examined to determine what impact they had on soils in cassava based cropping seasons. Post treatment results demonstrated that there was great variability across sites for any significant impacts of the treatments. Year one site

Asakadu and year two site Aalavadi saw no significant impact of fertility or intercropping treatments on soil properties (Tables 3-9 and 3-10). The high variability of soil chemical properties and the relatively short scope of the study could help to explain this result.

The impacts of intercropping treatments on macronutrients were seen in several sites. Perikovilo soil available N results were significantly higher with the legume and the legume and finger millet treatment than the finger millet al., one, the control being lower, although not significantly, than the treatments that included legumes (Table 3-5). Intercropping with legumes has been shown to lead to an increase in available N to component non-legume crops and therefore a higher level of soil available N(Ram et al., 2012; Islami et al., 2011; Sharma et al., 2011; Polthanee et al., 2007). Available P was impacted in both Soldaipatti and Oleyur (Table 3-5). In Soldaipatti, available P was also significantly impacted by intercropping treatments the finger millet plus legume was significantly higher than the finger millet or control treatments (Table 3-5). In Oleyur, the finger millet treatment was significantly higher than the control, legume and finger millet plus legume treatments for soil available P (Table 3-5). Monocropping of cassava has shown to decrease SOM and thereby impact the CEC of soil after 4 years as well as a decrease in soil available P (Islami et al., 2011). Very little has been written on the impacts of intercropping on soil micronutrient contents. In general the treatments with legumes and finger millets most often resulted in higher overall soil micronutrient contents. The results indicate that there are impacts of treatments on micronutrients Mg, Cu, and Mn at various sites and lack of micronutrients can result in reduced yields as shown by Howeler in 1996. However, when considering intercrops, research results have often been shown to be seasonal or site specific and therefore further research into the impacts of intercropping on soil properties in cassava based systems needs to be conducted (Fukai and Trenbath 1993; Islami et al., 2011).

The impacts of the fertilizer treatments on soil properties varied across sites. Soldaipatti results indicated a significant impact of fertilizer on pH with the farmyard manure treatment attaining a significantly higher pH than the control, fertilizer and farmyard manure plus fertilizer, while the farmyard manure plus fertilizer was significantly higher than the control or the fertilizer treatments (Table 3-6). The addition of synthetic fertilizers has been shown to decrease the pH in the soil (Doran and Parkin 1994; Sharma et al., 2011). In Mathyriolovo there was also a significant impact on soil Zn when looking at fertilizer treatments; the control, fertilizer and mulch treatment were all significantly higher than the farmyard manure or the farmyard manure and fertilizer (Table 3-6). The pH increase caused by the addition of the manure could have resulted in less extracting Zn. Finally, in Oleyur there was a significant impact of fertilizer on EC; the fertilizer treatment being significantly higher than the control and the mulch, and the farmyard manure and the farmyard plus fertilizer being significantly higher than the mulch treatment although lower than the fertilizer (Table 3-6).

Many studies have concluded that organic fertility amendments improve overall soil quality (Drinkwater et al., 1995; Saha et al., 2008; Singh et al., 2007; Datta et al., 2009).The physical properties of soil aggregate stability, bulk density, porosity and water holding capacity as well as infiltration can be improved in intercropping systems with the application of organic fertilizers (Kumar et al., 2008; Amanullah et al., 2007; Bulluck et al., 2002; Saha et al., 2008; Doran 1995). It has also been demonstrated that organic amendments in intercropping systems will improve soil fertility and available nutrients, including nitrogen to crops (Bulluck et al., 2002; Saha et al., 2008; Singh et al., 2007; Cadavid et al., 1998). There have been many benefits seen from the application of synthetic fertilizers. The application of fertilizer was shown to increase the organic matter in soil in a study (Saha et al., 2007). Organic with inorganic input management practices that incorporated crop residues into soils enhanced macro-aggregate stability, bulk density, soil porosity and soil fertility status of the soil (Ogunwole et al., 2010; Datta et al., 2009; Chen et al., 2011; Miao et al., 2011). Monocropping of cassava has shown to decrease SOM and thereby impact the CEC of soil after 4 years as well as a decrease in soil available P (Islami et al., 2011). Finally, mulching significantly reduced soil temperatures and increased SOC, K, P, calcium (Ca) and magnesium (Mg) in a study by Cadavid et al., 1998.

3.5.3 Impacts of treatments on SQI

Results from site wise ANOVA's indicated that treatment impacts were significant with available N, exchangeable Na, EC, pH, available P, EC, Zn, Cu, Mn and exchangeable K (Table 3-4, 3-5 and 3-6). The results of the PCA analysis and correlation analysis indicated that the factors that explained the most amount of the variance within the sample included clay content, CEC, pH, Zn, Cu and available K (Table 3-7 and 3-8). The parameters that were found to be significantly impacted by treatments that were also included based on PCA analysis were Zn, Cu and pH. Available N, exchangeable Na, EC, available P, Mn and exchangeable K were not included. Parameters included based solely on PCA analysis included soil clay content, CEC and available K.

Xua et al., (2006) included CEC and available P as well as biological parameters in an SQI to look at different land uses in the Loess region of China. Expert selected indicators included SOM, EC, pH, P and SAR and PCA analysis included Na, pH, and Zn, as well as total N, SOM, exchangeable Ca, and S in a study done by Andrews et al., 2002. Yao et al., 2013 included many soil properties linked with water movement and holding capacity however, they also included EC. Armenise et al., 2012 included clay content, available P, plant available water, exchange K and SOM. In alkaline vertisols, a study by Sharma et al., 2013 found that soil indicators available K and Cu as well as EC were found from PCA analysis. Several of the studies included similar parameters included in the SQI developed for cassava cropping systems; however there is a great variation in methods to establish the SQI as well as the parameters assessed and finally included. Letey et al., in 2003 pointed out that the physical, chemical and biological properties of soil can be very variable (Letey et al., 2003). They also indicated that the parameters that are used for indicators can be more variable across the field than any variation that could result as a change over time (Letey et al., 2003) which are important considerations in the creation of an SQI.

One site demonstrated that there was an impact of treatment on SQI. In Mathryiolovo there was a significant impact of fertilizer treatments on SQI the mulch and the control treatment being significantly better for the SQI than the farmyard manure and farmyard manure plus fertilizer, also the fertilizer is significantly better than the farmyard manure (Figure 3-4). Armenise et al., in 2013 found that fertilizer applications also increased SQI. What is interesting is that the control and the mulching treatment were still better than the fertilizer for SQI. While the parameters did not directly look at yields when examining yields from this site the mulch and the control were higher for this season. Lack of precipitation may be a major cause for this. When all sites are combined from year one and two there is no significant impact of intercrop or fertilizer treatment on SQI.

The SQI was created as measure to predict yields of cassava, the management goal of the smallholder farmers in the Kolli Hills, as indicted by Doran et al., 2004, and Armenise et al., 2013. Erkossa et al., 2007 and Letey et al., 2003 note that any relationship that may exist between an SQI and yield is often based on climate, soil, crop type and variety and how these interact within time and space. A regression analysis resulted in an r-squared of 0.31 showing that there was a significant, but weak relationship between the SQI % and the cassava tuber yield (Figure 3-6). Overall site wise means follow a general trend that higher the SQI % higher the yield, with the exception of Soldaipatti (Figure 3-6). The differences in the field characteristics prior to treatments could account for the variations. The quality of the soil is often a reflection of management and as Sharma et al., 2013 showed soil and nutrient management practices played an important role in influencing key SQI factors.

3.6 Summary

Maintaining and sustaining crop yields is an important goal, especially for smallholder farmers. Management practices can greatly affect yields, and soil properties; intercropping with finger millet statistically and significantly reduced crop yields in Mathyriolovo and Oleyur. Intercropping with finger millets had both negative and positive impacts on soil: lowering available N in some sites as well as exchangeable Mn, while having increases in available P in some locations. However, greater benefits were seen when legumes as well as finger millets were intercropped with cassava, resulting in significant increases in exchangeable Na, available P, EC, Cu and exchangeable K in comparison to other treatments. Fertilizer treatments impacted soil pH, with control and fertilizer treatments increasing or maintaining soil acidity, while treatments with manures increasing soil pH. The addition of farmyard manure significantly reduced soil Zn in some sites. EC was increased with the addition of any fertilizer in contrast to the control and mulching treatment. Many of the most impacted soil properties were also found to be significant in the creation of the SQI: Zn, clay content, CEC, Cu, pH and available K. When using the pre-defined parameter yield, overall site means of yields regardless of treatments showed that higher mean SQI's resulted in higher yields in four of five sites. Therefore, the parameters suggested in the SQI could be used as a recommendation for farmers to assess and manage to increase and sustain yields.

Farmers have seen that intercropping, especially with the inclusion of legumes could improve yields and soil quality and provide a greater amount of production on a small section of land. The addition of fertilizers can increase yields; however, the overall impact on soil quality needs to be further assessed before broad recommendations are made. The impacts of organic fertilizers in the short term appeared to have negative impacts on soil health and yields. This study was able to examine only the short-term impacts of the treatments and longer-term impacts could result in vastly different recommendations for farmers. Therefore, additional assessments of water infiltration parameters and biological parameters as well as a long-term study could improve the success of an SQI for the Kolli Hills cassava production system and management recommendations.

3.7 Tables and Figures

Table 3-1: Mean manure nutrient analysis 2012 n=5 with standard deviation

Nutrient	Mean Total (%)
N	1.51 ± 0.346
P	0.242 ± 0.021
K	0.594 ± 0.036

Table 3-2: Year one pre-treatment soil chemical analysis n=2

Site	Asakadu	Perikovilo	Soldaipatti
pH (H_20)	6.2	5.59	5.69
EC(mS/cm)	0.05	0.195	0.05
N (kg/ha)	105	168	130
P (kg/ha)	48.2	30.1	92.4
K (kg/ha)	232	168.5	153.7

Table 3-3: Year two pre-treatment soil chemical analysis n=4

Site	Oleyur	Aalavadi	Mathyriolovo
SOC (%)	0.67	0.54	0.75
pH (H_20)	4.81	5.36	5.30
CEC (cmol/kg)	6.50	7.53	9.50
EC (mS/cm)	0.07	0.11	0.20
N (ka/ha)	101.50	79.68	91.00
P (kg/ha)	49.38	54.38	37.50
K (kg/ha)	90.15	166.55	150.50
Exchangeable Ca (me/100 g soil)	3.58	4.30	6.03
Exchangeable Mg (me/100 g soil)	0.63	0.98	1.20
Exchangeable Na (me/100 g soil)	0.10	0.12	0.12
Exchangeable K (me/100 g soil)	0.26	0.25	0.31
Zn (ppm)	0.60	3.08	2.53
Cu (ppm)	1.83	3.18	3.18
Fe (ppm)	3.25	7.00	5.93
Mn (ppm)	35.48	35.13	34.80

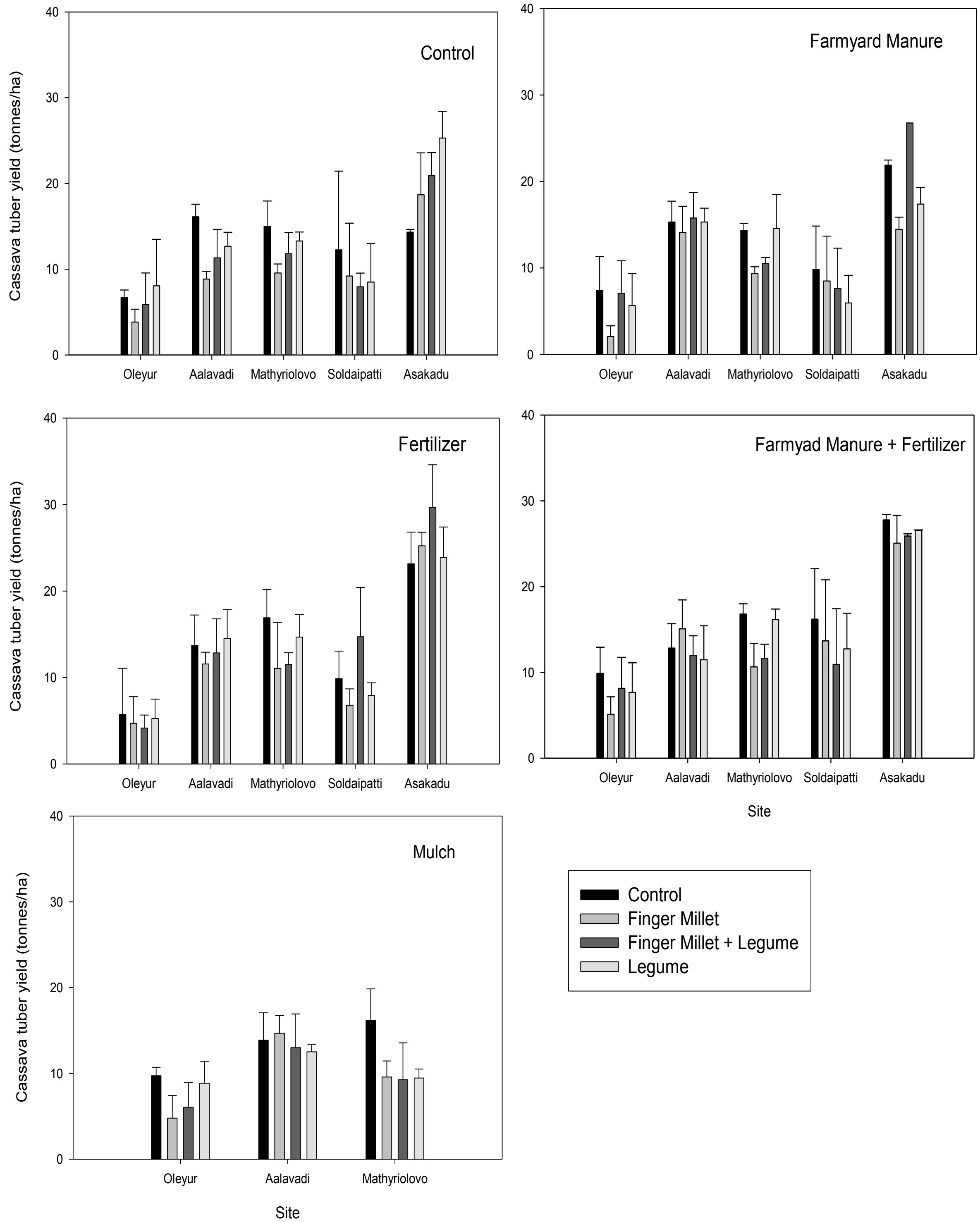

Figure 3-1: Mean cassava yields (tonnes/ha) Soldaipatti (n=4) and Asakadu year one (n=2) and Oleyur, Aalavadi and Mathyriolovo year two (n=3 or 4). Main fertilizer treatments represented with each graph, subplot intercropping treatments represented within each graph

Table 3-4: Analysis of variance of intercropping and soil fertility amendments to yields and soil chemical properties

		P-value		
Variable/Site		Fertilizer treatment	Inter-crop Treatment	Fertilizer X Intercrop
Cassava Tuber Yield				
	Perikovilo	No data	No data	No data
	Asakadu	0.0736	0.0910	0.1342
	Soldaipatti	0.2558	0.2307	0.5274
	Oleyur	0.6194	0.0023*	0.8431
	Aalavadi	0.1544	0.3949	0.2393
	Mathryilovo	0.2437	<0.0001*	0.8509
Soil pH				
	Perikovilo	0.0714	0.3047	0.4303
	Asakadu	0.6074	0.1003	0.8916
	Soldaipatti	0.0012*	0.6561	0.9949
	Oleyur	0.9310	0.0642	0.4704
	Aalavadi	0.1013	0.6129	0.3853
	Mathryilovo	0.2074	0.3991	0.2665
CEC				
	Perikovilo	0.5844	0.1027	0.9317
	Asakadu	0.2609	0.2987	0.8750
	Soldaipatti	0.5397	0.2732	0.7781
	Oleyur	0.0951	0.3253	0.4620
	Aalavadi	0.7466	0.3565	0.5319
	Mathryilovo	0.5028	0.5966	0.6372
Zn				
	Perikovilo	0.4088	0.6709	0.6710
	Asakadu	0.7579	0.2022	0.3819
	Soldaipatti	0.9134	0.3742	0.3045
	Oleyur	0.9746	0.9071	0.8162
	Aalavadi	0.1652	0.4091	0.5289
	Mathryilovo	0.0111*	0.2343	0.9211
EC				
	Perikovilo	0.3810	0.2041	0.7255
	Asakadu	0.7476	0.7797	0.8548
	Soldaipatti	0.4828	0.6265	0.4803
	Oleyur	0.0140*	0.4362	0.1757
	Aalavadi	0.0921	0.1417	0.0461*
	Mathryilovo	0.6441	0.0524*	0.7849
Available N				
	Perikovilo	0.5343	0.046*	0.6185
	Asakadu	0.9675	0.4583	0.4492
	Soldaipatti	0.2678	0.5516	0.2494
	Oleyur	0.3919	0.3930	0.8206
	Aalavadi	0.9620	0.4019	0.2348
	Mathryilovo	0.7431	0.7455	0.2781

Available K				
	Perikovilo	0.5664	0.6186	0.3404
	Asakadu	0.5732	0.7222	0.3147
	Soldaipatti	0.1925	0.8338	0.8300
	Oleyur	0.1793	0.7882	0.1398
	Aalavadi	0.8280	0.8545	0.8159
	Mathryilovo	0.5894	0.9321	0.9049
Available P				
	Perikovilo	0.6065	0.4210	0.4919
	Asakadu	0.2216	0.3536	0.7760
	Soldaipatti	0.2303	0.0389*	0.0960
	Oleyur	0.7668	0.0507*	0.6981
	Aalavadi	0.6474	0.4645	0.6574
	Mathryilovo	0.3814	0.3176	0.2272
Exchangeable Mg				
	Perikovilo	0.5606	0.0135*	0.2011
	Asakadu	0.4533	0.7487	0.9531
	Soldaipatti	0.5920	0.6558	0.9191
	Oleyur	0.1486	0.4992	0.8451
	Aalavadi	0.7587	0.7993	0.2962
	Mathryilovo	0.9794	0.7088	0.9252
Exchangeable Na				
	Perikovilo	0.4876	0.0274*	0.1299
	Asakadu	0.4898	0.2821	0.5039
	Soldaipatti	0.3286	0.8023	0.7783
	Oleyur	0.8276	0.5358	0.0369*
	Aalavadi	0.1194	0.7005	0.4317
	Mathryilovo	0.3618	0.6237	0.2994

Stars indicate the p-values of significance: *=p-value of (0.05)

Table 3-5: Summary of inter-cropping treatment effects on soil properties. Mean (standard error of mean). Asakadu and Perikovilo (n=8) Soldaipatti (n=16) year one; Oleyur, Aalavadi and Mathyriolovo year two (n=15 or 20).

		Inter-crop treatment			
Variable/Site		cassava monocrop	cassava-finger millet and legume	cassava-finger millet	Cassava-Legume
Mn					
	Perikovilo	39.2 (2.526)	35.838 (2.526)	34.6 (2.526)	35.2 (2.526)
	Asakadu	34.599 (2.444)	32.655 (2.444)	31.424 (2.444)	31.613 (2.444)
	Soldaipatti	33.002 (1.823)	32.36 (1.823)	37.844 (1.823)	35.119 (1.823)
	Oleyur	33.402 (1.478)	32.931 (1.478)	34.081 (1.478)	32.026 (1.478)
	Aalavadi	30.425 (1.508)	32.065 (1.508)	32.335 (1.508)	34.015 (1.508)
	Mathryilovo	33.074 (1.737)	31.787 (1.737)	29.934 (1.737)	30.157 (1.737)
CEC					
	Perikovilo	7.138 (0.352)	7.675 (0.352)	7.0375 (0.353)	7.4 (0.352)
	Asakadu	7.688 (0.455)	8.138 (0.455)	7.725 (0.455)	8.25 (0.455)
	Soldaipatti	7.95 (0.325)	7.588 (0.325)	7.706 (0.325)	8.05 (0.325)
	Oleyur	8.335 (0.272)	8.18 (0.272)	8.42 (0.272)	8.38 (0.272)
	Aalavadi	7.265 (0.194)	7.2 (0.194)	7.475 (0.194)	7.69 (0.194)
	Mathryilovo	7.253 (0.237)	7.753 (0.237)	7.707 (0.237)	7.873 (0.237)
Zn					
	Perikovilo	0.425 (0.107)	0.563 (0.107)	0.288 (0.107)	0.35 (0.107)
	Asakadu	1.063 (0.514)	2.013 (0.514)	1.278 (0.514)	1.638 (0.514)
	Soldaipatti	1.159 (0.328)	1.7163 (0.328)	1.181 (0.328)	1.584 (0.328)
	Oleyur	2.841 (0.138)	2.631 (0.138)	2.709 (0.138)	2.734 (0.138)
	Aalavadi	0.965 (0.155)	0.83 (0.155)	0.985 (0.155)	1.24 (0.155)
	Mathryilovo	0.836 (0.234)	0.808 (0.234)	0.684 (0.234)	0.903 (0.234)
EC					
	Perikovilo	0.145 (0.013)	0.103 (0.0125)	0.101 (0.013)	0.108 (0.013)
	Asakadu	0.104 (0.009)	0.1 (0.009)	0.101 (0.009)	0.078 (0.009)
	Soldaipatti	0.1 (0.009)	0.107 (0.009)	0.112 (0.009)	0.1 (0.009)
	Oleyur	0.080 (0.005)	0.068 (0.005)	0.071 (0.005)	0.075 (0.005)
	Aalavadi	0.093 (0.006)	0.099 (0.006)	0.088 (0.006)	0.097 (0.006)
	Mathryilovo	0.09 (0.006)	0.085 (0.006)	0.089 (0.006)	0.083 (0.006)
Available N					
	Perikovilo	63.875 (4.805)	71.75 (4.805)	52.85 (4.805)	73.963 (4.805)
	Asakadu	82.363 (9.819)	65.625 (9.819)	86.988 (9.819)	79.038 (9.819)
	Soldaipatti	72.056 (6.900)	69.388 (6.900)	66.325 (6.900)	77 (6.900)
	Oleyur	111.62 (6.035)	108.75 (6.035)	114.94 (6.0354)	110.32 (6.035)
	Aalavadi	48.415 (7.237)	61.995 (7.237)	68.825 (7.237)	52.895 (7.237)
	Mathryilovo	84.187 (7.390)	80.573 (7.390)	65.88 (7.390)	81.353 (7.390)
Available P					
	Perikovilo	19.375 (6.731)	27.344 (6.731)	25.625 (6.731)	44.688 (6.731)
	Asakadu	41.719 (8.757)	38.281 (8.757)	36.563 (8.757)	39.219 (8.757)
	Soldaipatti	32.109 (6.769)	35.156 (6.769)	26.734 (6.769)	37.5 (6.7690)
	Oleyur	43.625 (4.375)	46 (4.375)	46.25 (4.375)	47 (4.375)
	Aalavadi	13.563 (1.931)	14.253 (1.931)	12.188 (1.931)	12.938 (1.931)

	Mathryilovo	22.75 (7.2693)	24.837 (7.269)	21.42 (7.269)	27.5 (7.269)
Exchangeable Mg					
	Perikovilo	1.445 (0.089)	1.375 (0.089)	1.475 (0.089)	1.465 (0.089)
	Asakadu	1.1 (0.141)	1.15 (0.141)	0.888 (0.141)	1.338 (0.141)
	Soldaipatti	0.863 (0.061)	0.925 (0.061)	0.775 (0.061)	0.9 (0.061)
	Oleyur	1.063 (0.088)	1.006 (0.088)	0.963 (0.088)	1.119 (0.088)
	Aalavadi	1 (0.058)	0.895 (0.058)	0.985 (0.058)	1.005 (0.058)
	Mathryilovo	1.033 (0.077)	1.087 (0.0773)	1.12 (0.077)	1.147 (0.077)
Exchangeable Na					
	Perikovilo	0.121 (0.018)	0.171 (0.018)	0.15 (0.018)	0.144 (0.018)
	Asakadu	0.158 (0.022)	0.2 (0.022)	0.139 (0.022)	0.139 (0.022)
	Soldaipatti	0.147 (0.014)	0.166 (0.014)	0.152 (0.014)	0.16 (0.014)
	Oleyur	0.129 (0.009)	0.108 (0.009)	0.129 (0.009)	0.132 (0.009)
	Aalavadi	0.149 (0.010)	0.143 (0.010)	0.147 (0.010)	0.157 (0.010)
	Mathryilovo	0.126 (0.009)	0.117 (0.009)	0.121 (0.009)	0.131 (0.009)
Cu					
	Perikovilo	3.575 (0.172)	3.363 (0.172)	3.3 (0.172)	3.588 (0.172)
	Asakadu	3.259 (0.290)	3 (0.290)	2.884 (0.290)	2.939 (0.290)
	Soldaipatti	2.916 (0.184)	3.041 (0.184)	3.219 (0.184)	3.072 (0.184)
	Oleyur	3.017 (0.293)	2.839 (0.293)	3.241 (0.293)	2.837 (0.293)
	Aalavadi	2.06 (0.152)	2 (0.152)	2.02 (0.152)	2.3 (0.152)
	Mathryilovo	1.576 (0.114)	1.503 (0.114)	1.551 (0.114)	1.497 (0.114)

Table 3-6: Summary of fertilizer treatment effects on soil properties. Mean (standard error of mean). Asakadu and Perikovilo (n=8) Soldaipatti (n=16) year one; Oleyur, Aalavadi and Mathyriolovo year two (n=12 or 16).

		Fertilizer treatment				
Variable/Site		No fertilizer	fertilizer	manure	Fertilizer plus manure	mulch
Soil pH						
	Perikovilo	5.819 (0.095)	5.813 (0.061)	6.281 (0.044)	5.989 (0.059)	No data
	Asakadu	5.939 (0.148)	5.659 (0.124)	6.035 (0.107)	5.662 (0.11)	5.914 (0.074)
	Soldaipatti	5.346 (0.050)	5.266 (0.05)	5.731 (0.089)	5.544 (0.086)	No data
	Oleyur	5.406 (0.066)	5.338 (0.095)	5.381 (0.086)	5.362 (0.057)	5.263 (0.034)
	Aalavadi	5.75 (0.05)	5.781 (0.069)	5.938 (0.047)	5.991 (0.053)	5.95 (0.0736)
	Mathryilovo	5.975 (0.079)	5.967 (0.051)	6.083 (0.035)	6.083 (0.053)	6.042 (0.057
Zn						
	Perikovilo	1.888 (0.118)	2.039 (0.088)	2.155 (0.221)	2.395 (0.183)	No data
	Asakadu	2.962 (0.576)	2.995 (0.186)	2.547 (0.313)	2.978 (0.635)	0.615 (0.235)
	Soldaipatti	2.918 (0.115)	2.966 (0.183)	2.939 (0.086)	2.769 (0.121)	No data
	Oleyur	0.35 (0.0664)	0.314 (0.087)	0.332 (0.045)	0.352 (0.041)	0.283 (0.042)
	Aalavadi	0.378 (0.080)	0.401 (0.075)	0.301 (0.057)	0.509 (0.114)	0.611 (0.12)
	Mathryilovo	1.759 (0.118)	1.683 (0.125)	1.208 (0.055)	1.354 (0.065)	1.684 (0.099)
EC						
	Perikovilo	0.075 (0.005)	0.101 (0.008)	0.089 (0.005)	0.104 (0.010)	No data
	Asakadu	0.09 (0.0105)	0.103 (0.020)	0.066 (0.006)	0.094 (0.010)	0.10 (0)
	Soldaipatti	0.069 (0.004)	0.062 (0.004)	0.071 (0.004)	0.072 (0.004)	No data
	Oleyur	0.074 (0.004)	0.102 (0.011)	0.088 (0.004)	0.094 (0.008)	0.063 (0.004)
	Aalavadi	0.105 (0.003)	0.128 (0.014)	0.106 (0.003)	0.122 (0.013)	0.102 (0.001)
	Mathryilovo	0.104 (0.004)	0.10 (0)	0.102 (0.001)	0.10 (0)	0.102 (0.003)

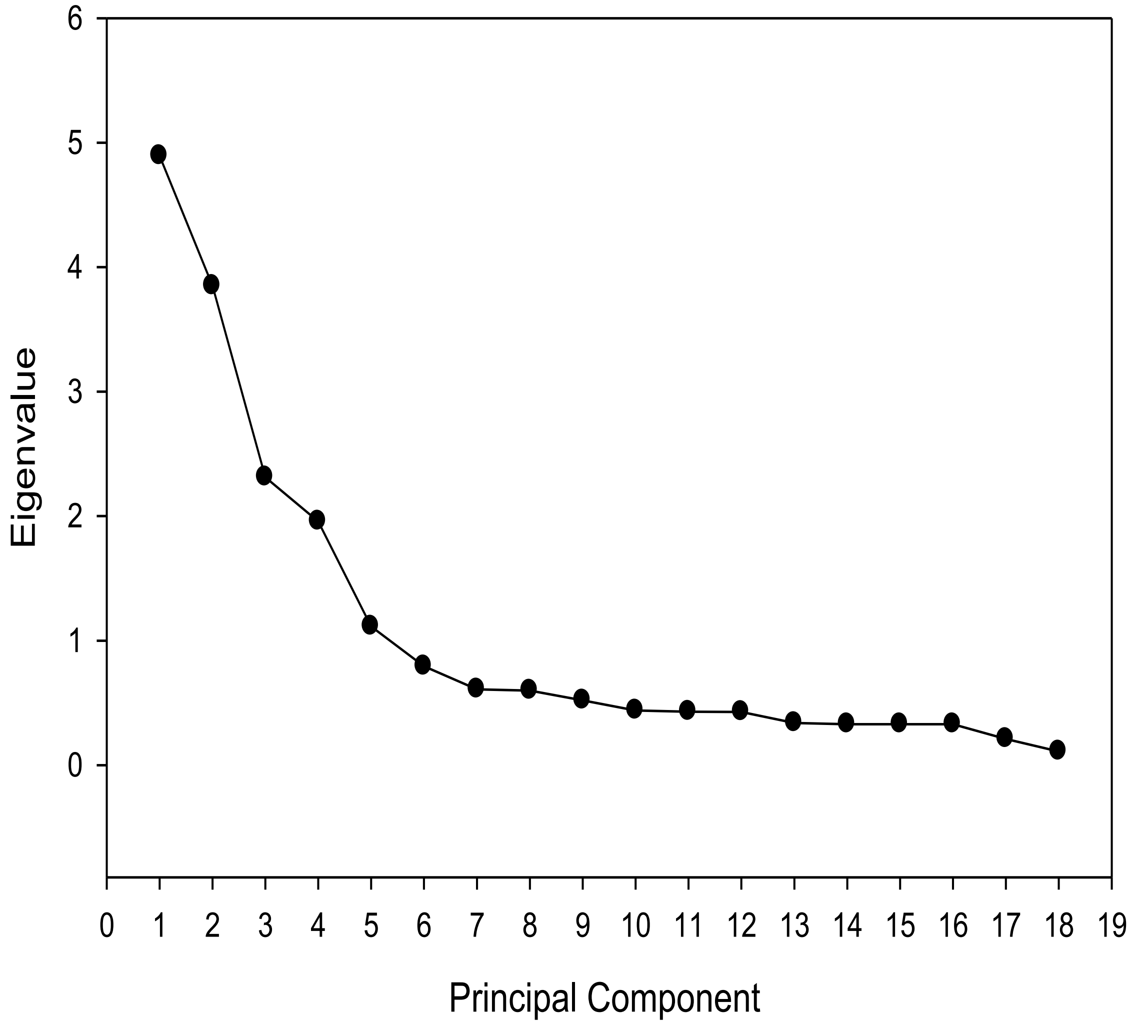

Figure 3-2 Figure 3-1: Scree Plot of Eigenvalues for 18 principal components

Table 3-7: Results of Principal Component Analysis: Component 1 accounts for 27.18 % of the variation in soil quality, component 2 represents 21.39%

	Prin1	**Prin2**	**Prin3**	**Prin4**	**Prin5**	**Prin6**
Eigenvalue	4.892317	3.849338	2.312355	1.957476	1.113312	0.794848
Proportion	0.2718	0.2139	0.1285	0.1087	0.0619	0.0442
Cumulative	0.2718	0.4856	0.6141	0.7229	0.7847	0.8289
Eigenvectors						
Sand	0.26518	**-0.39264**	0.078875	-0.06336	-0.04083	-0.00181
Silt	-0.24535	**0.362899**	-0.13245	0.115929	0.109259	0.047779
Clay	-0.26226	**0.390315**	-0.05121	0.039269	0.010447	-0.01935
SOC	-0.12943	0.047022	0.346873	-0.1545	0.396021	-0.52765
pH	-0.03298	-0.14494	0.025454	**0.610811**	-0.07549	-0.11066
CEC	0.177563	**0.413336**	-0.015	0.172587	0.137152	0.100959
EC	-0.16779	-0.15571	0.146034	0.167918	0.316936	0.725944
A N	0.2598	0.166717	0.159454	-0.21702	0.293517	0.03498
A P	0.299262	-0.05226	0.141737	0.235874	0.206064	0.123503
A K	-0.16339	-0.15845	0.325316	0.232846	**0.445886**	-0.06867
Ex Ca	**0.330611**	0.314536	-0.00454	0.072008	0.035753	0.049176
Ex Mg	0.258044	0.352226	0.023867	0.008076	0.033177	0.031748
Ex Na	-0.03758	0.06977	-0.00352	**0.550233**	-0.14979	-0.25971
Ex K	**-0.34849**	0.107063	-0.21154	0.033499	0.129551	0.099846
Zn	**0.350906**	0.08007	0.18858	0.141097	-0.27848	0.1162
Cu	-0.03652	0.109227	**0.56536**	0.069333	-0.16504	-0.06089
Fe	-0.30768	0.033435	0.265159	-0.03034	-0.43206	0.101721
Mn	-0.14679	0.170467	0.457047	-0.18534	-0.20977	0.199749

Table 3-8: Correlations matrix for the highly weighted variables under the first three PCs.

	Sand	Silt	Clay	Ex K	pH	Ex Na	Zn	Ex Ca	Cu
Sand									
Silt	**-0.93481**								
Clay	**-0.98688**	**0.86633**							
K1	**-0.61059**	**0.61209**	**0.58595**						
pH	0.1101	-0.04806	-0.13154	0.00854					
Na	-0.17731	0.20625	0.15869	0.09169	**0.52792**				
Zn	**0.32883**	**-0.32398**	**-0.31523**	**-0.66015**	0.08159	0.08548			
Ca	-0.04179	0.03583	0.04543	**-0.41046**	-0.15675	0.08811	**0.65163**		
Cu	-0.12399	0.01859	0.1669	-0.18957	0.07528	0.05801	0.26938	0.06425	
CEC	**-0.40285**	**0.39119**	**0.39413**	-0.0746	-0.04392	0.16279	**0.41315**	**0.83422**	0.12455

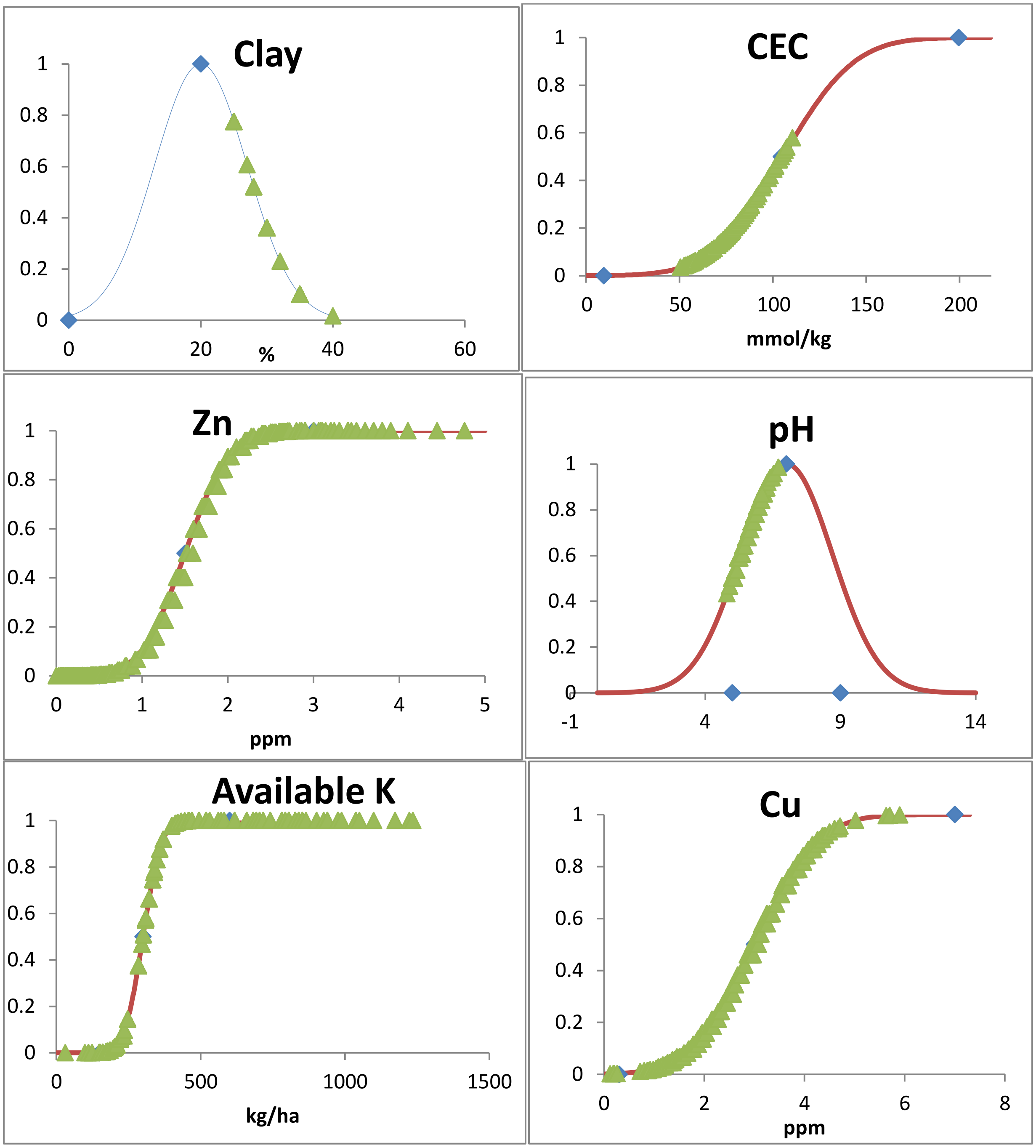

Figure 3-3: Scoring functions that transformed measured indicators: ▲ indicates observed values, ◆ represents lower upper and mid-point parameters found in literature

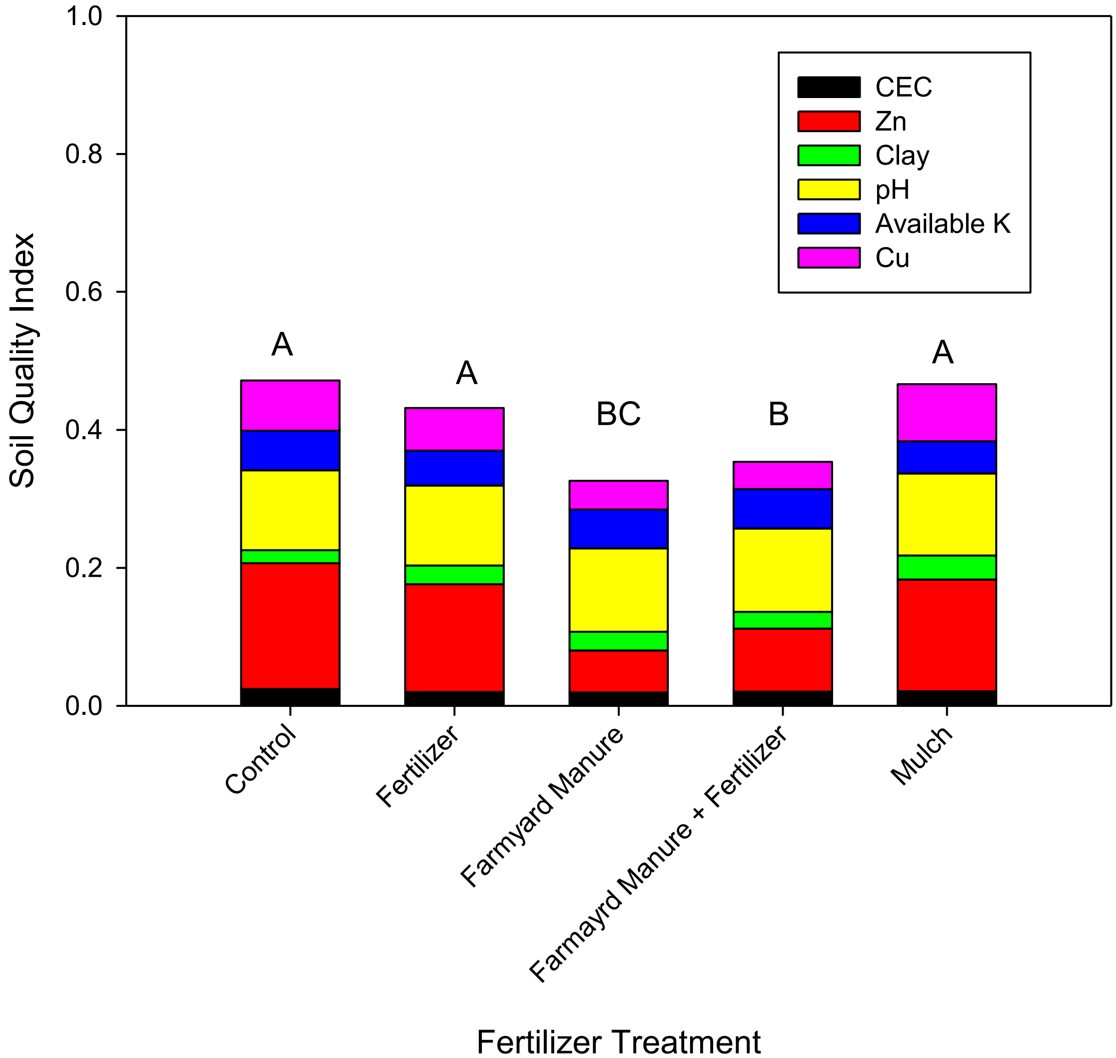

Figure 3-4: Soil quality index Mathryiolovo capital letters denote significant differences at p=0.05 n=12

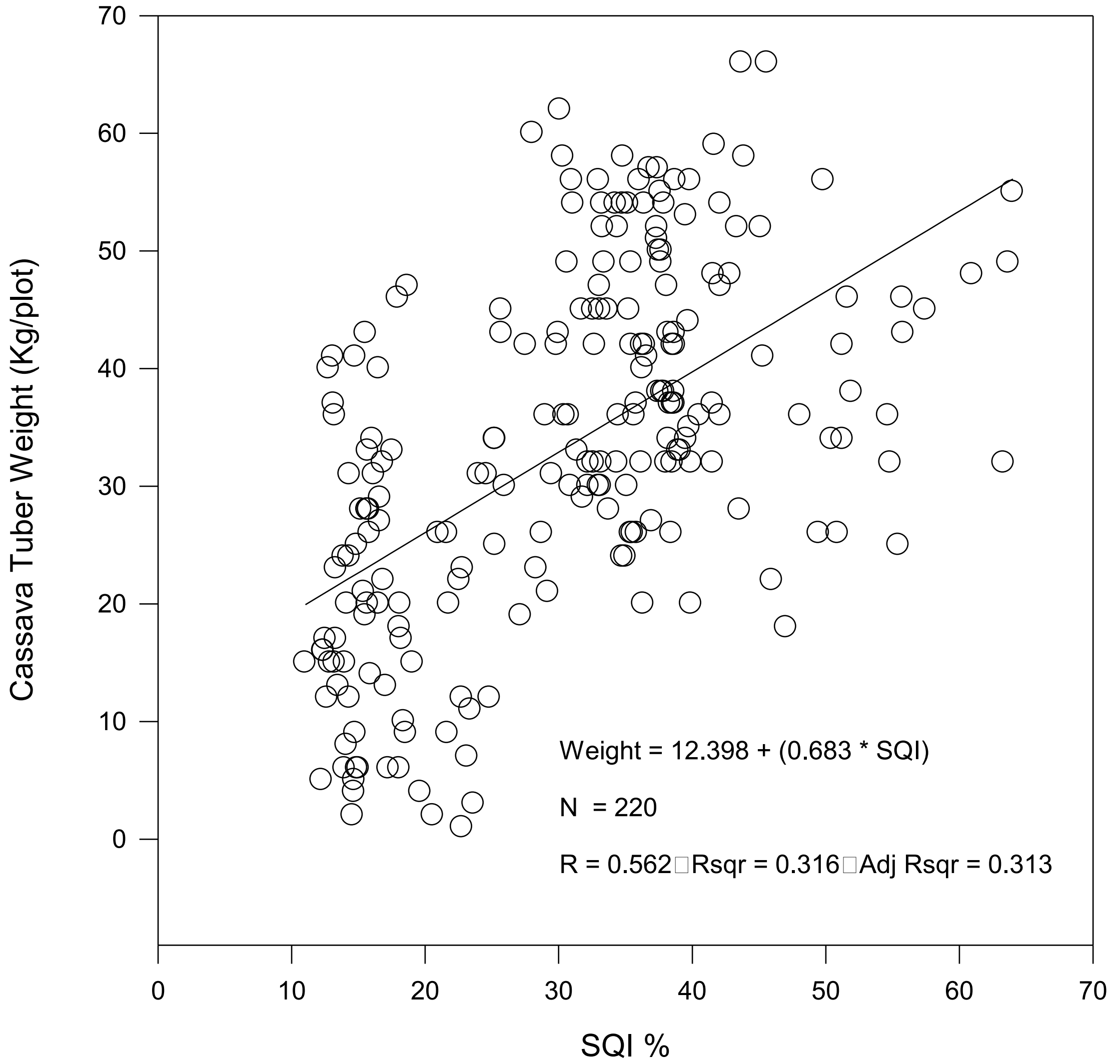

Figure 3-5: Regression relationship year 2 between cassava yield and soil quality index % n=220.

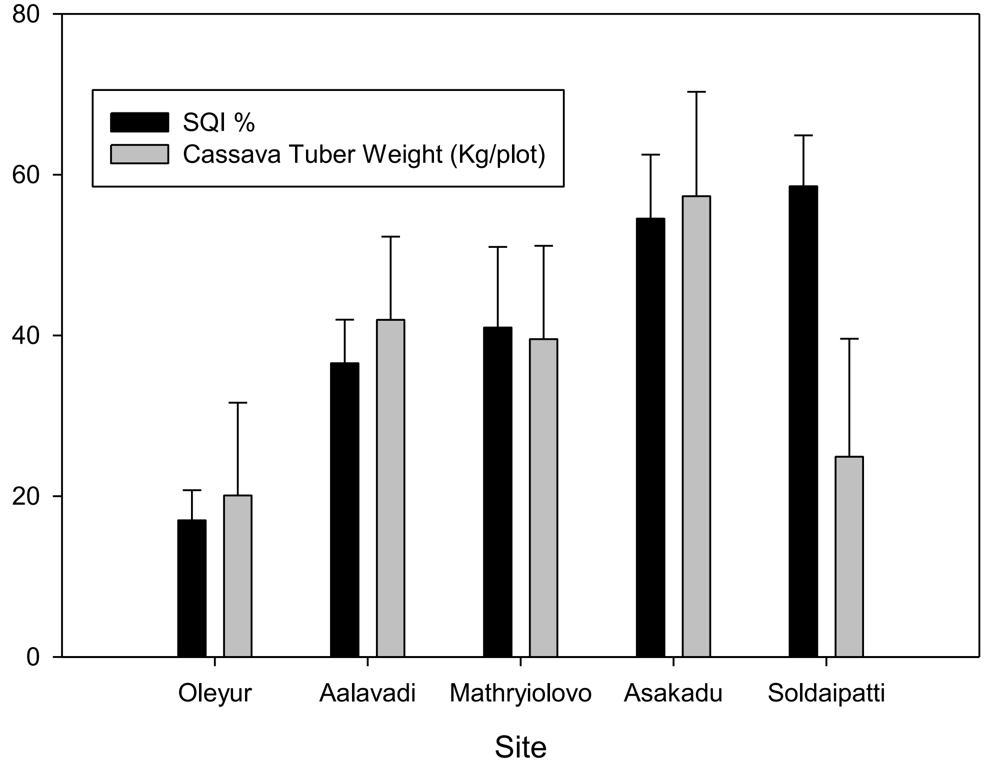

Figure 3-6: Site wise mean cassava yields and mean percent soil quality index year 1 and year 2 with standard error bars n=32-80

3.8 Literature Cited

Altieri, M. A., Funes-Monzote, F. R., & Petersen, P. (2012). Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty. *Agronomy for Sustainable Development, 32*(1), 1-13. doi:10.1007/s13593-011-0065-6

Andrews, S.S., Karlen, D.L., Cambardella, C.A., 2004. The soil management assessment framework: a quantitative soil quality evaluation method. *Soil Science Society of America Journal* 68, 1945–1962.

Andrews, S., Karlen, D., & Mitchell, J. (2002). A comparison of soil quality indexing methods for vegetable production systems in northern California. Agriculture Ecosystems & Environment, 90(1), 25-45. doi:10.1016/S0167-8809(01)00174-8

Amanullah, M. M., Kailasam, C., Safiullah, A. M., Selvam, S., & Sivakumar, K. (2007). Crop simulation growth model in cassava. *Research Journal of Agriculture and Biological Sciences, 3*(4), 255-259.

Amanullah, M. M., Sathyamoorthi, K., Vaiyapuri, K., Alagesan, A., & Pazhanivelan, S. (2007). Influence of organic manures on the nutrient uptake and soil fertility of cassava (manihot esculenta crantz.) intercropping systems. *International Journal of Agricultural Research, 2*(2), 136-144.

Amanullah, M. M., Sathyamoorthi, K., Vaiyapuri, K., & Pazhanivelan, S. (2007). Yield and economics of cassava (manihot esculenta crantz.) as influenced by intercropping and organic manures. *International Journal of Plant Sciences (Muzaffarnagar), 2*(1), 18-22.

Armenise, E., Redmile-Gordon, M. A., Stellacci, A. M., Ciccarese, A., & Rubino, P. (2013). Developing a soil quality index to compare soil fitness for agricultural use under different managements in the mediterranean environment. Soil & Tillage Research, 130, 91-98. doi:10.1016/j.still.2013.02.013

Baseline APM Survey (2013). M.S. Swaminathan Foundation and the University of Alberta. Alleviating Poverty and Malnutrition in Agrobiodiversity Hotspots: Baseline Report.

Bulluck, L., Brosius, M., Evanylo, G., & Ristaino, J. (2002). Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. *Applied Soil Ecology,19*(2), 147-160. doi:10.1016/S0929-1393(01)00187-1

Cadavid, L., El-Sharkawy, M., Acosta, A., & Sanchez, T. (1998). Long-term effects of mulch, fertilization and tillage on cassava grown in sandy soils in northern Colombia. *Field Crops Research, 57*(1), 45-56. doi:10.1016/S0378-4290(97)00114-7

Chaisri, S., Panitnok, K., Sarobol, E., Thongpae, S., Chaisri, P., Ngamprasitthi, S., . . . Boonsri, N. (2013). Effects of chicken manure and chemical fertilizer management on yield of cassava grown on map bon, coarse-loamy variant soil. *Communications in Soil Science and Plant Analysis, 44*(1-4), 347-355. doi:10.1080/00103624.2013.742004

Costanza, R., Norton, B.G., Haskell, B.D., 1992. Ecosystem Health: New Goals for Environmental Management. Island Press, Washington, DC.

Doran, J.W., Sarrantonio, M., Janke, R., 1994. Strategies to promote soil quality and soil health. In: Pankhurst, et al., (Eds.),Soil Biota: Management in Sustainable Farming Systems. CSIRO, Vic., Australia, pp. 230–237.

Doran, J. W., Parkin, T. B., & Jones, A. J. (1996). Quantitative indicators of soil quality: a minimum data set. Methods for assessing soil quality., 25-37.

Doran, J.W. (2002). Soil health and global sustainability: translating science into practice. Agriculture, Ecosystems and Environment 88, 119–127.

Drinkwater, L. E., Letourneau, D. K., Workneh, F., Vanbruggen, A. H. C., & Shennan, C. (1995). Fundamental differences between conventional and organic tomato agroecosystems in California. *Ecological Applications, 5*(4), 1098-1112. doi:10.2307/2269357

Gregorich, E.G., Carter, M.R., Angers, D.A., Monreal, C.M. & Ellert, B.H. 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. Canadian Journal of Soil Science, 74, 367–385.

Gruere, G., Nagarajan, L., & King, E. D. I. O. (2009). The role of collective action in the marketing of underutilized plant species: Lessons from a case study on minor millets in south India. *Food Policy, 34*(1), 39-45. doi:10.1016/j.foodpol.2008.10.006

Herrera Campo, B. V., Hyman, G., & Bellotti, A. (2011). Threats to cassava production: Known and potential geographic distribution of four key biotic constraints. *Food Security, 3*(3), 329-345. doi:10.1007/s12571-011-0141-4

Howeler, R.H. (1991). Long-term effect of cassava cultivation on soil productivity. Field Crops Res., 26: 1-18.

Hussain, I., Olson, K., Wander, M., & Karlen, D. (1999). Adaptation of soil quality indices and application to three tillage systems in southern Illinois. Soil & Tillage Research, 50(3-4), 237-249. doi:10.1016/S0167-1987(99)00012-4

Islami, T., Guritno, B., & Utomo, W. H. (2011). Performance of cassava (manihot esculenta crantz) based cropping systems and associated soil quality changes in the degraded tropical uplands of east java, Indonesia. *Journal of Tropical Agriculture, 49*(1/2), 31-39.

Jayakumar, S., Ramachandran, A., Bhaskaran, G., & Heo, J. (2009). Forest dynamics in the eastern ghats of Tamil Nadu, India. *Environmental Management, 43*(2), 326-345. doi:10.1007/s00267-008-9219-y

Kanto, U., Jutamanee, K., Osotsapar, Y., & Jattupornpong, S. (2012). Effect of swine manure extract on leaf nitrogen concentration, chlorophyll content, total potassium in plant parts and starch content in fresh tuber yield of cassava. *Journal of Plant Nutrition, 35*(5), 688-703. doi:10.1080/01904167.2012.653074

Karlen, D.L., Stott, D.E., (1994). A framework for evaluating physical and chemical indicators of soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), Defining Soil Quality for Sustainable Environment. SSSA Special Publication no. 35. ASA and SSSA, Madison, WI, 53–72.

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F., Schuman, G.E., 1997. Soil quality: a concept, definition, and framework for evaluation. Soil Sci. Soc. Am. J. 61, 4–10.

King, E.D.I.O., 2005. Sacred Forests of Kolli Hills, Tamil Nadu, India: A Study on Botany, Ecology and Community Interactions. Ph.D. Thesis, M.S. Swaminathan Research Foundation, Chennai, India

Knoepp, J.D., D.C. Coleman, D.A. Crosseley, J.S. Clark. 2000. Biological indices of soil quality: an ecosystem case study of their use. For. Ecol. Manage., 138 (2000), pp. 357–368

Liebig, M., Varvel, G., Doran, J. (2001). A Simple Performance-Based Index for Assessing Multiple Agroecosystem Functions. *Agronomy Journal ,* 93, 313–318. doi:10.2134/agronj2001.932313x

Maloles, J. R., Berg, K., Subramanyam Ragupathy, Nirmala, B. C., Althaf, K. A., Palanisamy, V. C., & Newmaster, S. G. (2011). The fine scale ethnotaxa classification of millets in southern India. *Journal of Ethnobiology, 31*(2), 262-287. doi:10.2993/0278-0771-31.2.262

Midmore, D. (1993). Agronomic modification of resource use and intercrop productivity. *Field Crops Research, 34*(3-4), 357-380. doi:10.1016/0378-4290(93)90122-4

Ogunwole, J. O., Iwuafor, E. N. O., Eche, N. M., & Diels, J. (2010). Effect of organic and inorganic soil amendments on soil physical and chemical properties in a West Africa savanna agroecosystem. *Tropical and Subtropical Agroecosystems, 12*(2), 247-255.

Panda, R. K., Arora, C. P., Gore, K. P., Jakhar, P., & Dash, B. K. (2011). Managing terraced lowland and medium sloping land for sustainable agriculture: A study from the eastern ghat region of India. *Irrigation and Drainage, 60*(5), 694-702. doi:10.1002/ird.643

Pathak, H., Mohanty, S., Jain, N., & Bhatia, A. (2010). Nitrogen, phosphorus, and potassium budgets in Indian agriculture. *Nutrient Cycling in Agroecosystems, 86*(3), 287-299. doi:10.1007/s10705-009-9292-5

Patra DD, Anwar M, Chand S. 1997. Residue recycling for restoring soil fertility and productivity of Japanese mint (Mentha arvensis) mustard (Brassica juncea) cropping system. International Plant Nutrition Colloquium; 1997 Sep 13–19; Tokyo, Japan. In: Ando T, Fujita K, Mae T, Matsumoto H, Mori S, Sekiya J, editors. Plant nutrition for sustainable food production and environment. Tokyo (Japan):Kluwer Academic. p. 587–588.

Polthanee, A., Wanapat, S., Wanapat, M., Wachirapokorn, C. (2007). Cassava-Legumes inter-cropping: A potential food-feed system for dairy farmers. Thailand Report: Use of Cassava as Animal Feed http://www.mekarn.org/procKK/polt.htm.

Ram M, Kumar S. 1997. Yield improvement in the regenerated and transplanted mint, Mentha arvensis by recycling the organic wastes and manures. Biores Technol. 59:141–149.

Ram D, Ram M, Singh R. 2006. Optimization of water and nitrogen application to menthol mint (Mentha arvensis L.) through sugarcane trash mulch in a sandy loam soil of semi-arid subtropical climate. Biores Technol. 97:886–893.

Ram, M., Singh, M., Prajapati, A. K., Ram, D., & Rawat, G. (2012). Towards sustainable production of peppermint (mentha piperita L.) through integrated use of vermicompost and cowpea green manuring with synthetic nitrogen fertilization. *Archives of Agronomy and Soil Science, 58*(3), 293-301. doi:10.1080/03650340.2010.514266

Rhoades, J.D. and Corwin, D.L. 1981. Determining soil electrical conductivity-depth relations using an inductive electromagnetic soil conductivity meter. *Soil Sci. Soc. Am. J*. 42: 255–260.

Saha, S., Mina, B. L., Gopinath, K. A., Kundu, S., & Gupta, H. S. (2008). Organic amendments affect biochemical properties of a subtemperate soil of the Indian Himalayas. *Nutrient Cycling in Agroecosystems, 80*(3), 233-242. doi:10.1007/s10705-007-9139-x

SAS Institute Inc. 2008. SAS/STAT® 9.2. User's Guide. Cary, NC: SAS Institute Inc.

Schoenholtz, S. H., Miegroet, H. V., & Burger, J. A. (2000). A review of chemical and physical properties as indicators of forest soil quality: Challenges and opportunities. *Forest Ecology and Management, 138*(1–3), 335-356. doi:10.1016/S0378-1127(00)00423-0

Singh, K. P., Suman, A., Singh, P. N., & Srivastava, T. K. (2007). Improving quality of sugarcane-growing soils by organic amendments under subtropical climatic conditions of India. *Biology and Fertility of Soils, 44*(2), 367-376. doi:10.1007/s00374-007-0216-8

Srinivas, T. (2007). Industrial demand for cassava starch in India. *Starch-Starke, 59*(10), 477-481. doi:10.1002/star.200700657

Srinivas, T. (2009). Impact of research investment on cassava production technologies in India. *Australian Journal of Agricultural and Resource Economics, 53*(3), 367-383. doi:10.1111/j.1467-8489.2009.00453.x

Suja, G., John, K. S., Sreekumar, J., & Srinivas, T. (2010). Short-duration cassava genotypes for crop diversification in the humid tropics: Growth dynamics, biomass, yield and quality. *Journal of the Science of Food and Agriculture, 90*(2), 188-198. doi:10.1002/jsfa.3781

Suresh, R., Saravanakumar, M., & Suganyadevi, P. (2011). Anthocyanins from Indian cassava (Manihot esculenta Crantz) and its antioxidant properties. Int. J. Pharm. Sci. Res, 2, 1819-1828.

Walkley, A. and I.A. Black. 1934. An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. *Soil Sci*. 63:251-263.

Yadav RL, Prasad SR, Singh R, Srivastava VK. 1994. Recycling sugarcane trash to conserve soil organic carbon for sustaining yield of successive ratoon crops in sugarcane. Boires Technol. 49:231–235.

Yao, R.-J., Yang, J.-S., Gao, P., Zhang, J.-B., Jin, W.-H. and Yu, S.-P. (2013), Soil-quality-index model for assessing the impact of groundwater on soil in an intensively farmed coastal area of E China. Z. Pflanzenernähr. Bodenk.. doi: 10.1002/jpln.201200383

4.0 General Discussion and Conclusions

4.1 Introduction

Agriculture is a means to sustain human life; it is also the source of income and a basis of culture for many of the world's people. The goal of development projects is often to provide modern technological solutions. However, these solutions do not always take into consideration the fact that modern high-input cropping systems have created numerous environmental, social and economic problems, including contamination, increased farm specialization, insect and disease pressures, soil erosion, energy dependency, high input expenses, and less farm economic resilience (Alteiri et al., 2012; Bedoussac and Justes 2011). There is a need for agroecological systems that are filled with biodiversity, resilience, productivity and energy efficiency as well as being socially just (Altieri et al., 2012). To create sustainable agroecosystems we need to look beyond the basics of crop production and consider the ecological and environmental as well as the sociological impacts of agricultural systems to develop a system of production that is truly sustainable.

This study aimed to investigate whether local intensification (achieved through intercropping and fertilizer treatments) of the cassava cropping system could improve overall yields, soil quality, and crop biodiversity with the overall goal of increasing food security in these communities. More specifically the study aimed to determine the sustainability of the recommendations by assessing the economic and environmental suitability. The study also focused on the creation of an SQI focused on cassava yields. Field trials conducted in a split plot design included various intercropping rotations of cassava with leguminous crops and minor millets and the addition of organic and synthetic fertilizer amendments and mulching of paddy straw. These trials were tested in three locations in the Kolli Hills during the 2011-2012 season and three locations during the 2012-2013 season.

4.2 Assessments of Intercropping and Fertilizer amendments to soil on yields, crop quality and economic sustainability

Subsistence and smallholder farmers are dependent on the yields and quality of their crops. Field studies conducted in the Kolli Hills discovered that there was great variation in yields under many different soil fertility amendments and intercropping treatments. Intercropping with finger millet statistically and significantly reduced crop yields in Mathyriolovo and Oleyur. Fertilizer and farmyard manure plus fertilizer provided increases in intercrop yields and cassava yields in year one and increases in intercrop yields only in year two. The impacts of organic fertilizers in the short term appeared to have negative impacts on yields of cassava and component crops. Starch content and cassava leaf nutrient status was greatly affected by site.

Seasonal differences can greatly affect yields and subsequent economic assessments. Most treatments from season one had marginal rates of return from 100-150% representing viable options for farmers to adopt these practices. However, the second year showed that, aside from the mulching treatment with a marginal rate of return of 100%, that none of the recommendations had any beneficial returns for the farmers. This variability often occurs in rainfed systems and it is essential when making recommendations to adopt new treatments that longer periods are considered.

4.3 Assessing the impacts of various management recommendations on soil quality

Soils can have a great impact on crop yield and farmer success. Management practices can greatly affect yields, and soil properties; intercropping with finger millet significantly reduced crop yields in Mathyriolovo and Oleyur. Intercropping with finger millets had both negative and positive impacts on soil: lowering available N in some sites as well as exchangeable Mn, while having increases in available P in some locations. However, greater benefits were seen when legumes as well as finger millets were intercropped with cassava, resulting in significant increases in exchangeable Na, available P, EC, Cu and exchangeable K in comparison to other treatments. Fertilizer treatments impacted soil pH, with control and fertilizer treatments increasing or maintaining soil acidity, while treatments with manures increased soil pH. The addition of farmyard manure significantly reduced soil Zn in some sites. EC was increased with the addition of any fertilizer in contrast to the control and mulching treatment. Many of the most impacted soil properties were also found to be significant in the creation of the SQI: Zn, clay content, CEC, Cu, pH and available K. The creation of the SQI focused on selecting parameters in the soil that could be measured and managed by local farmers to increase yields in cassava based systems. The soils clay content, although not easily managed was essential in in the creation of the SQI and clay content is an important component of soil fertility. CEC was also included in the SQI and can be managed by adding more organic material to the soil. Zn and available K in cassava production has an important role in increasing the plants ability to establish and develop its rooting system (Howeler, 1996).Soil pH can impact the availability of nutrients within the soil and therefore is also an important component of the SQI. When using the pre-defined parameter yield, overall site means of yields regardless of treatments showed that higher mean SQI resulted in higher yields in four of five sites. Therefore, the parameters suggested in the SQI could be used as a recommendation for farmers to assess and manage to increase and sustain yields.

Farmers have seen that intercropping, especially with the inclusion of legumes, could improve yields and soil quality and provide a greater amount of production on a small section of land. The addition of fertilizers can increase yields; however, the overall impact on soil quality needs to be further assessed before broad recommendations are made. The impacts of organic fertilizers in the short term appeared to have negative impacts on soil health and yields.

4.4 General Discussion

Research was conducted in areas where local farmers were given the ability to observe and participate. There are many advantages from field studies, regardless of the outcomes, the control is the farmer practice and thus any comparison can be seen by the farmer. Also, environmental conditions, which are constantly changing can greatly affect the yields and crop quality and thus in field studies can try to capture some of these random effects. There is also a great amount of variation from field to field and this variation can be attributed to variations in soil nutrient status; however, this is not sufficient to completely describe site differences. In-field studies, therefore, demonstrate the yield differences that can occur from site to site. This study demonstrated that site and seasonal differences were often more significant in their effect on yields than the impact of any of the intercropping or fertilizer treatments. Although there are many benefits to infield studies, there are several disadvantages as well. Insect impacts, impacts from farmers and the community can affect the results of the study.

This study examined the impacts of soil fertility amendments as well as intercrops. This study could have been improved by assessing each of the intercrops separately as well as within the main cassava crop. This was not done as local farmer land was being used for this study and local farmers have great dependence on cassava yields for their annual incomes. Also, a more in-depth assessment of economics, considering factors that affect smallholder farmer adoption decisions would have improved this work. However, large scale surveys are often necessary to understand adoption practices for small scale farmers.

Economic analysis took into consideration the difference in costs, including labour and the costs of amendments and seeds prior to estimating the net returns to the farmer. This analysis therefore can vary greatly as the costs and the crop sale prices can vary greatly year over year in response to lower worldwide yields, increase in demand or supply. Therefore, to create a more in-depth and comprehensive study sensitivity analysis for variability in crop prices should also be conducted. Also, there are often local subsidies for fertilizer price and therefore this would change the overall analysis and potentially lower the risk involved in adopting fertilizer amendment treatments for farmers. Other considerations for farmers include the availability of labour, in seasons where there are few opportunities for alternative work or income, more labour intensive treatments might be adopted by farmers, versus times when labour is scarce and less labour intensive intercropping with legumes, for example, may seem more viable for local farmers. Finally, the study looked at solely the economic costs and benefits to farmers, in instances where local farmers have sufficient labour the cost analysis could be very different and the benefits of having legume or finger millet to consume or replant may have greater value then the standard sale price of these crops.

Often during the cassava growing season, males will attempt to find work harvesting throughout the province, this results in many more females working in the local fields. Therefore, it is often women who are aware of the risks or benefits to adopting new ideas. In addition, the data did not show statistically significant differences in yields generally speaking, local farmers in small plot research do not often note the differences in yields therefore many local farmers have begun to adopt intercropping into their cassava based system. The low input cost of intercropping legumes or other crops (some farmers have begun to intercrop onions) and the possible reduced labour cost from weeding as well as the benefit of being able to harvest a crop midway through the cassava growing season are often inducements to adopt intercropping. In addition, there has been great variability in the price of cassava over the past several years; this increases the risks that local farmers face to produce sufficient amounts to be able to purchase food and necessities of life. Therefore, intercropping adoption seems a good option, especially with essential food crops, like legumes, finger millets or onions.

4.5 Recommendations for Future Research

Further research to establish recommendations that would be beneficial economically and environmentally to local farmers need to be conducted over a longer period of time and over larger areas. Research examining the effects of intercropping and fertility amendments to soil on soil microbial communities should also be assessed, it is possible that many of the site variations could be a result not only of the site nutrient status but also of the microbial communities within the soil. Finally, adding additional assessments of precipitation and temperature in each experimental site could also increase the ability to assess cassava production systems and management recommendations in the Kolli Hills.

4.6 Literature Cited

Altieri, M. A., Funes-Monzote, F. R., & Petersen, P. (2012). Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty. *Agronomy for Sustainable Development, 32*(1), 1-13. doi:10.1007/s13593-011-0065-6

Bedoussac, L., & Justes, E. (2011). A comparison of commonly used indices for evaluating species interactions and intercrop efficiency: Application to durum wheat-winter pea intercrops. *Field Crops Research,124*(1), 25-36. doi:10.1016/j.fcr.2011.05.025

Howeler, R. H. (1996). Mineral nutrition of cassava. In: Craswell, E.T., Asher, C.J. and O'Sullivan, J.N. (eds) Mineral Nutrient Disorders of Root Crops in the Pacific. Proceedings Workshop, Nuku'alofa, Kingdom of Tonga, 17-20 April 1995, ACIAR Proceedings no. 5, Canberra, Australia, pp. 110-116

All Literature Cited

Abawi, G. S., & Widmer, T. L. (2000). Impact of soil health management practices on soilborne pathogens, nematodes and root diseases of vegetable crops. *Applied Soil Ecology, 15*(1), 37-47. doi:10.1016/S0929-1393(00)00070-6

Agoramoorthy, G. (2008). Can India meet the increasing food demand by 2020? *Futures, 40*(5), 503-506. doi:10.1016/j.futures.2007.10.008

Altieri, M. (1999). The ecological role of biodiversity in agroecosystems. *Agriculture Ecosystems & Environment, 74*(1-3), 19-31. doi:10.1016/S0167-8809(99)00028-6

Altieri, M. A., & Nicholls, C. I. (2003). Soil fertility management and insect pests: Harmonizing soil and plant health in agroecosystems. *Soil and Tillage Research, 72*(2), 203-211. doi:10.1016/S0167-1987(03)00089-8

Altieri, M. A., Funes-Monzote, F. R., & Petersen, P. (2012). Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty. *Agronomy for Sustainable Development, 32*(1), 1-13. doi:10.1007/s13593-011-0065-6

Amanullah, M. M., Kailasam, C., Safiullah, A. M., Selvam, S., & Sivakumar, K. (2007). Crop simulation growth model in cassava. *Research Journal of Agriculture and Biological Sciences, 3*(4), 255-259.

Amanullah, M. M., Sathyamoorthi, K., Vaiyapuri, K., Alagesan, A., & Pazhanivelan, S. (2007). Influence of organic manures on the nutrient uptake and soil fertility of cassava (manihot esculenta crantz.) intercropping systems. *International Journal of Agricultural Research, 2*(2), 136-144.

Amanullah, M. M., Sathyamoorthi, K., Vaiyapuri, K., & Pazhanivelan, S. (2007). Yield and economics of cassava (manihot esculenta crantz.) as influenced by intercropping and organic manures. *International Journal of Plant Sciences (Muzaffarnagar), 2*(1), 18-22.

Andrews, S., Karlen, D., & Mitchell, J. (2002). A comparison of soil quality indexing methods for vegetable production systems in northern California. Agriculture Ecosystems & Environment, 90(1), 25-45. doi:10.1016/S0167-8809(01)00174-8

Andrews, S.S., Karlen, D.L., Cambardella, C.A., 2004. The soil management assessment framework: a quantitative soil quality evaluation method. *Soil Science Society of America Journal* 68, 1945–1962.

Anil L, Park J, Phipps RH, Miller FA. (1998). Temperate intercropping of cereals for forage: A review of the potential for growth and utilization with particular reference to the UK. Grass Forage Sci 53:301-317.

Armenise, E., Redmile-Gordon, M. A., Stellacci, A. M., Ciccarese, A., & Rubino, P. (2013). Developing a soil quality index to compare soil fitness for agricultural use under different managements in the mediterranean environment. Soil & Tillage Research, 130, 91-98. doi:10.1016/j.still.2013.02.013

Asumadu, H., Sallah, P. Y. K., Boa-Amponsem, P. B., Manu-Aduening, J. A., & Osei-Bonsu, P. (2004). On-farm evaluation and promotion of quality protein maize hybrids in Ghana. *African Crop Science Conference Proceedings*, 4, 358–364.

Banik P, Midya A, Sarkar BK, Ghose SS (2006) Wheat and chickpea intercropping systems in an additive series experiment: Advantages and weed smothering. Eur J Agron 24:325-332.

Baseline APM Survey (2013). M.S. Swaminathan Foundation and the University of Alberta. Alleviating Poverty and Malnutrition in Agrobiodiversity Hotspots: Baseline Report.

Bedoussac, L., & Justes, E. (2011). A comparison of commonly used indices for evaluating species interactions and intercrop efficiency: Application to durum wheat-winter pea intercrops. *Field Crops Research,124*(1), 25-36. doi:10.1016/j.fcr.2011.05.025

Bhatt A, Singh V, Shrotria PK, Baskheti DC (2003). Coarse Grains of Uttaranchal: Ensuring sustainable Food and Nutritional Security. Indian Farmer's Digest. pp. 34-38.

Brady, Nyle and Ray Weil. 2008. The Nature and Properties of Soils. 14th ed. Prentice Hall, Upper Saddle River, NJ. 975 p. ISBN 13-978-0-13-227938-3.

Bulluck, L., Brosius, M., Evanylo, G., & Ristaino, J. (2002). Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. *Applied Soil Ecology,19*(2), 147-160. doi:10.1016/S0929-1393(01)00187-1

Cadavid, L., El-Sharkawy, M., Acosta, A., & Sanchez, T. (1998). Long-term effects of mulch, fertilization and tillage on cassava grown in sandy soils in northern Colombia. *Field Crops Research, 57*(1), 45-56. doi:10.1016/S0378-4290(97)00114-7

Carsky, R.J., and Toukourou, M.A, (2005). Identification of nutrients limiting cassava yield maintenance on a sedimentary soil in southern Benin, West Africa. *Nutrient Cycling in Agroecosys.,* 71. 151-162. Jul. 2005.

Census of India. (2011). Population Enumeration Data (Final Population) Tamilnadu. Retrieved November 25, 2011, from http://www.censusindia.gov.in/2011census/population_enumeration.aspx

Chaisri, S., Panitnok, K., Sarobol, E., Thongpae, S., Chaisri, P., Ngamprasitthi, S., . . . Boonsri, N. (2013). Effects of chicken manure and chemical fertilizer management on yield of cassava grown on map bon, coarse-loamy variant soil. *Communications in Soil Science and Plant Analysis, 44*(1-4), 347-355. doi:10.1080/00103624.2013.742004

Chen, X., Cui, Z., Vitousek, P. M., Cassman, K. G., Matson, P. A., Bai, J., . . . Zhang, F. (2011). Integrated soil-crop system management for food security. *Proceedings of the National Academy of Sciences of the United States of America, 108*(16), 6399-6404. doi:10.1073/pnas.1101419108

Costanza, R., Norton, B.G., Haskell, B.D., 1992. Ecosystem Health: New Goals for Environmental Management. Island Press, Washington, DC.

Craswell, E., & Lefroy, R. (2001). The role and function of organic matter in tropical soils. *Nutrient Cycling in Agroecosystems, 61*(1-2), 7-18. doi:10.1023/A:1013656024633

Datta, S. P., Rattan, R. K., & Chandra, S. (2010). Labile soil organic carbon, soil fertility, and crop productivity as influenced by manure and mineral fertilizers in the tropics. *Journal of Plant Nutrition and Soil Science,173*(5), 715-726. doi:10.1002/jpln.200900010

Deugd, M., Röling, N., & Smaling, E. M. A. (1998). A new praxeology for integrated nutrient management, facilitating innovation with and by farmers. *Agriculture, Ecosystems & Environment, 71*(1–3), 269-283. doi:10.1016/S0167-8809(98)00146-7

Dillon, J. L., & Hardaker, J. B. (1993). Farm management research for small farmer development (2nd ed., pp. 173–189. FAO Systems Management Series). Rome, Italy: Food and Agriculture Organization.

Doran, J.W., Sarrantonio, M., Janke, R., 1994. Strategies to promote soil quality and soil health. In: Pankhurst, et al., (Eds.),Soil Biota: Management in Sustainable Farming Systems. CSIRO, Vic., Australia, pp. 230–237.

Doran JW, Parkin TB (1994) Defining and assessing soil quality. In: Doran JW, Coleman DC, Bezdicek DF, Stewart BA (Eds.) Defining soil quality for a sustainable environment. SSSA Spec. Publ. 35. ASA, Madison, WI, pp 3–21

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

Doran, J.W. (2002). Soil health and global sustainability: translating science into practice. Agriculture, Ecosystems and Environment 88, 119–127.

Drinkwater, L. E., Letourneau, D. K., Workneh, F., Vanbruggen, A. H. C., & Shennan, C. (1995). Fundamental differences between conventional and organic tomato agroecosystems in California. *Ecological Applications, 5*(4), 1098-1112. doi:10.2307/2269357

Finnis, E. (2007). The political ecology of dietary transitions: Changing production and consumption patterns in the kolli hills, India. *Agriculture and Human Values, 24*(3), 343-353. doi:10.1007/s10460-007-9070-4

Fukai, S., & Trenbath, B. (1993). Processes determining intercrop productivity and yields of component crops. *Field Crops Research, 34*(3-4), 247-271. doi:10.1016/0378-4290(93)90117-6

Goulding, K., Poulton, P., Webster, C., & Howe, M. (2000). Nitrate leaching from the broadbalk wheat experiment, Rothamsted, UK, as influenced by fertilizer and manure inputs and the weather. *Soil use and Management, 16*(4), 244-250.

Gregorich, E.G., Carter, M.R., Angers, D.A., Monreal, C.M. & Ellert, B.H. 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. Canadian Journal of Soil Science, 74, 367–385.

Grossmann, J., and Freitas, A.G. (1950). Determinação do teor de matéria seca pelo método peso específico em raízes de mandioca. *Revista Agronô*mica 14: 75-80.

Gruere, G., Nagarajan, L., & King, E. D. I. O. (2009). The role of collective action in the marketing of underutilized plant species: Lessons from a case study on minor millets in south India. *Food Policy, 34*(1), 39-45. doi:10.1016/j.foodpol.2008.10.006

Herrera Campo, B. V., Hyman, G., & Bellotti, A. (2011). Threats to cassava production: Known and potential geographic distribution of four key biotic constraints. *Food Security, 3*(3), 329-345. doi:10.1007/s12571-011-0141-4

Howeler, R., & Cadavid, L. (1990). Short-and long-term fertility trials in Colombia to determine the nutrient-requirements of cassava. *Fertilizer Research, 26*(1-3), 61-80. doi:10.1007/BF01048744

Howeler, R.H. (1991). Long-term effect of cassava cultivation on soil productivity. Field Crops Res., 26: 1-18.

Howeler, R. H. (1996) Mineral nutrition of cassava. In: Craswell, E.T., Asher, C.J. and O'Sullivan, J.N. (eds) Mineral Nutrient Disorders of Root Crops in the Pacific. Proceedings Workshop, Nuku'alofa, Kingdom of Tonga, 17-20 April 1995, ACIAR Proceedings no. 5, Canberra, Australia, pp. 110-116

Howeler, R.H., (2002). Cassava mineral nutrition and fertilization. In: Hillocks, R.J., Thresh, M.J., Bellotti, A.C. (Eds.), *Cassava: Biology, Production and Utilization*. CAB International, Wallingford, pp. 115–147.

Hussain, I., Olson, K., Wander, M., & Karlen, D. (1999). Adaptation of soil quality indices and application to three tillage systems in southern Illinois. Soil & Tillage Research, 50(3-4), 237-249. doi:10.1016/S0167-1987(99)00012-4

Islami, T., Guritno, B., & Utomo, W. H. (2011). Performance of cassava (manihot esculenta crantz) based cropping systems and associated soil quality changes in the degraded tropical uplands of east java, Indonesia. *Journal of Tropical Agriculture, 49*(1/2), 31-39.

IUSS Working Group WRB, 2006. World Reference Base for Soil Resources 2006: a Framework for International Classification, Correlation and Communication, 2ndedition. Food and Agriculture Organization of the United Nations, Rome

Jayakumar, S., Ramachandran, A., Bhaskaran, G., & Heo, J. (2009). Forest dynamics in the eastern ghats of Tamil Nadu, India. *Environmental Management, 43*(2), 326-345. doi:10.1007/s00267-008-9219-y

Jones, D.B. (1941). Factors for converting percentages of nitrogen in foods and feeds into percentages of proteins. Circular No. 183. Washington, DC, United States Department of Agriculture.

Kanto, U., Jutamanee, K., Osotsapar, Y., & Jattupornpong, S. (2012). Effect of swine manure extract on leaf nitrogen concentration, chlorophyll content, total potassium in plant parts and starch content in fresh tuber yield of cassava. *Journal of Plant Nutrition, 35*(5), 688-703. doi:10.1080/01904167.2012.653074

Karlen, D.L., Stott, D.E., (1994). A framework for evaluating physical and chemical indicators of soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), Defining Soil Quality for Sustainable Environment. SSSA Special Publication no. 35. ASA and SSSA, Madison, WI, 53–72.

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F., Schuman, G.E., (1997). Soil quality: a concept, definition, and framework for evaluation. Soil Sci. Soc. Am. J. 61, 4–10.

Knoepp, J.D., D.C. Coleman, D.A. Crosseley, J.S. Clark. 2000. Biological indices of soil quality: an ecosystem case study of their use. For. Ecol. Manage., 138 (2000), pp. 357–368

Khan, Z., Midega, C., Pittchar, J., Pickett, J., & Bruce, T. (2011). Push-pull technology: A conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa UK government's foresight food and farming futures project RID B-8523-2009. *International Journal of Agricultural Sustainability, 9*(1), 162-170. doi:10.3763/ijas.2010.0558

Kohli, D.S. and Singh, N. (1997). 'The Green Revolution in Punjab, India: The Economics of Technological Change'. Conference paper.

King, E.D.I.O., 2005. Sacred Forests of Kolli Hills, Tamil Nadu, India: A Study on Botany, Ecology and Community Interactions. Ph.D. Thesis, M.S. Swaminathan Research Foundation, Chennai, India

Kumar, A., Angadi, S. S., & Ravikumar, R. L. (2008). Influence of legumes on yield, quality and economics of pop sorghum under inter and mixed cropping system. *Plant Archives, 8*(1), 351-353.

Leihner, D. (1983). *Management and evaluation of intercropping systems with cassava.*

Liebig, M., Varvel, G., Doran, J. (2001). A Simple Performance-Based Index for Assessing Multiple Agroecosystem Functions. *Agronomy Journal,* 93, 313–318. doi:10.2134/agronj2001.932313x

Lithourgidis, A. S., Dordas, C. A., Damalas, C. A., & Vlachostergios, D. N. (2011). Annual intercrops: An alternative pathway for sustainable agriculture. *Australian Journal of Crop Science, 5*(4), 396-410.

Makinde, E.A., Saka, J.O. (2007). Economic evaluation of soil fertility management options on cassava-based cropping systems in the rain forest ecological zone of South Western Nigeria. *Afr. J. Agric. Res*., 2 (2007), pp. 7–13

Maloles, J. R., Berg, K., Subramanyam Ragupathy, Nirmala, B. C., Althaf, K. A., Palanisamy, V. C., & Newmaster, S. G. (2011). The fine scale ethnotaxa classification of millets in southern India. *Journal of Ethnobiology, 31*(2), 262-287. doi:10.2993/0278-0771-31.2.262

Miao, Y., Stewart, B. A., & Zhang, F. (2011). Long-term experiments for sustainable nutrient management in china. A review. *Agronomy for Sustainable Development, 31*(2), 397-414. doi:10.1051/agro/2010034

Midmore, D. (1993). Agronomic modification of resource use and intercrop productivity. *Field Crops Research, 34*(3-4), 357-380. doi:10.1016/0378-4290(93)90122-4

MSSRF, 2002. Rural and Tribal Women in Agro-Biodiversity Conservation. Food and Agriculture Organization (FAO) RAP Publication 2002/08. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.

Muthumanickam, D., Kannan, P., Kumaraperumal, R., Natarajan, S., Sivasamy, R., & Poongodi, C. (2011). Drought assessment and monitoring through remote sensing and GIS in western tracts of Tamil Nadu, India. *International Journal of Remote Sensing, 32*(18), 5157-5176. doi:10.1080/01431161.2010.494642

Ngigi, S.N. Savenije, H.H. G., Thome, J.N., Rockström, J., Penning de Vries, F.W.T. (2005). Agro-hydrological evaluation of on-farm rainwater storage systems for supplemental irrigation in Laikipia district, Kenya. *Agricultural Water Management*, 73 (1) (2005), pp. 21–41

Ogunwole, J. O., Iwuafor, E. N. O., Eche, N. M., & Diels, J. (2010). Effect of organic and inorganic soil amendments on soil physical and chemical properties in a West Africa savanna agroecosystem. *Tropical and Subtropical Agroecosystems, 12*(2), 247-255.

Panda, R. K., Arora, C. P., Gore, K. P., Jakhar, P., & Dash, B. K. (2011). Managing terraced lowland and medium sloping land for sustainable agriculture: A study from the eastern ghat region of India. *Irrigation and Drainage, 60*(5), 694-702. doi:10.1002/ird.643

Pathak, H., Mohanty, S., Jain, N., & Bhatia, A. (2010). Nitrogen, phosphorus, and potassium budgets in Indian agriculture. *Nutrient Cycling in Agroecosystems, 86*(3), 287-299. doi:10.1007/s10705-009-9292-5

Patra DD, Anwar M, Chand S. 1997. Residue recycling for restoring soil fertility and productivity of Japanese mint (Mentha arvensis) mustard (Brassica juncea) cropping system. International Plant Nutrition Colloquium; 1997 Sep 13–19; Tokyo, Japan. In: Ando T, Fujita K, Mae T, Matsumoto H, Mori S, Sekiya J, editors. Plant nutrition for sustainable food production and environment. Tokyo (Japan):Kluwer Academic. p. 587–588.

Perrin, R., Anderson J., Winkelmann, D., and Moscardi, E. (1988). From Agronomic Data to Farmer Recommendations: An Economic Training Manual. *CIMMYT*: Mexico, D.F. Onlinehttp://www.cimmyt.org

Polthanee, A., Wanapat, S., Wanapat, M., Wachirapokorn, C. (2007). Cassava-Legumes inter-cropping: A potential food-feed system for dairy farmers. Thailand Report: Use of Cassava as Animal Feed http://www.mekarn.org/procKK/polt.htm.

Pypers, P., Sanginga, J.M, Kasereka, B., Walangululu, M., and Vanlauwe, B, (2011). Increased. productivity through integrated soil fertility management in cassava-legume intercropping systems in the highlands of Sud-Kivu, DR Congo, *Field Crops Res*., 120, 76-85. Sept. 2011.

Ram M, Kumar S. 1997. Yield improvement in the regenerated and transplanted mint, Mentha arvensis by recycling the organic wastes and manures. Biores Technol. 59:141–149.

Ram D, Ram M, Singh R. 2006. Optimization of water and nitrogen application to menthol mint (Mentha arvensis L.) through sugarcane trash mulch in a sandy loam soil of semi-arid subtropical climate. Biores Technol. 97:886–893.

Ram, M., Singh, M., Prajapati, A. K., Ram, D., & Rawat, G. (2012). Towards sustainable production of peppermint (mentha piperita L.) through integrated use of vermicompost and cowpea green manuring with synthetic nitrogen fertilization. *Archives of Agronomy and Soil Science, 58*(3), 293-301. doi:10.1080/03650340.2010.514266

Reis, M. M., Ferreira, M., Sarmento, S. (2002). A multi-way analysis of starch cassava properties. *Chemometrics and Intelligent Laboratory Systems*, 2002, 64, 123-135.

Rhoades, J.D. and Corwin, D.L. 1981. Determining soil electrical conductivity-depth relations using an inductive electromagnetic soil conductivity meter. *Soil Sci. Soc. Am. J*. 42: 255–260.

Saha, S., Mina, B. L., Gopinath, K. A., Kundu, S., & Gupta, H. S. (2008). Organic amendments affect biochemical properties of a subtemperate soil of the Indian Himalayas. *Nutrient Cycling in Agroecosystems, 80*(3), 233-242. doi:10.1007/s10705-007-9139-x

SAS Institute Inc. 2008. SAS/STAT® 9.2. User's Guide. Cary, NC: SAS Institute Inc.

Schoenholtz, S. H., Miegroet, H. V., & Burger, J. A. (2000). A review of chemical and physical properties as indicators of forest soil quality: Challenges and opportunities. *Forest Ecology and Management, 138*(1–3), 335-356. doi:10.1016/S0378-1127(00)00423-0

Sharma, K. L., Grace, J. K., Mishra, P. K., Venkateswarlu, B., Nagdeve, M. B., Gabhane, V. V., . . . Ramachandran, K. (2011). Effect of soil and nutrient-management treatments on soil quality indices under cotton-based production system in rainfed semi-arid tropical vertisol. *Communications in Soil Science and Plant Analysis, 42*(11), 1298-1315. doi:10.1080/00103624.2011.571735

Sharma, K. L., Grace, J. K., Raj, M., Mittal, S. B., Singh, J., Sharma, S. K., . . . Rani, K. U. (2013). Improvement and assessment of soil quality under long-term conservation agricultural practices in hot, arid tropical aridisol. *Communications in Soil Science and Plant Analysis, 44*(6), 1033-1055. doi:10.1080/00103624.2012.750338

Singh, K. P., Suman, A., Singh, P. N., & Srivastava, T. K. (2007). Improving quality of sugarcane-growing soils by organic amendments under subtropical climatic conditions of India. *Biology and Fertility of Soils, 44*(2), 367-376. doi:10.1007/s00374-007-0216-8

Sittibusaya, C., Narkaviroj, C., Tunmaphirom, D. (1988). Cassava soils research in Thailand. In. R.H. Howeler and K. Kawano (Eds). Cassava Breeding and Agronomy Research in Asia. Proc. Regional Workshop, Held in Rayong, Thailand. Oct. 26-28, 1987. Pp. 145-156.

Srinivas, T. (2007). Industrial demand for cassava starch in India. *Starch-Starke, 59*(10), 477-481. doi:10.1002/star.200700657

Srinivas, T. (2009). Impact of research investment on cassava production technologies in India. *Australian Journal of Agricultural and Resource Economics, 53*(3), 367-383. doi:10.1111/j.1467-8489.2009.00453.x

Suja, G., John, K. S., Sreekumar, J., & Srinivas, T. (2010). Short-duration cassava genotypes for crop diversification in the humid tropics: Growth dynamics, biomass, yield and quality. *Journal of the Science of Food and Agriculture, 90*(2), 188-198. doi:10.1002/jsfa.3781

Suresh, R., Saravanakumar, M., & Suganyadevi, P. (2011). Anthocyanins from Indian cassava (Manihot esculenta Crantz) and its antioxidant properties. Int. J. Pharm. Sci. Res, 2, 1819-1828.

Vieira, E.A., Fiahlo J. de F., Faleiro, F.G., Bellon, G., Fonseca, K.G., Carvalho, L.J.C.B., Silva, M.S., Paula-Moraes, S.V., Oliveira, C.M., Denke, M.L. (2011). Characterization of sweet cassava accessions based on molecular, quantitative and qualitative data. *Crop Breeding and Applied Biotechnology,* v.11, p.232-240, 2011. DOI: 10.1590/S1984-70332011000300005

Walkley, A. and I.A. Black. (1934). An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. *Soil Sci*. 63:251-263.

Willey, R. W. (1979). Intercropping - its importance and research needs. 1. competition and yield advantages. *Field Crop Abstracts, 32*(1), 1-10.

Yadav RL, Prasad SR, Singh R, Srivastava VK. (1994). Recycling sugarcane trash to conserve soil organic carbon for sustaining yield of successive ratoon crops in sugarcane. Boires Technol. 49:231–235.

Yao, R.-J., Yang, J.-S., Gao, P., Zhang, J.-B., Jin, W.-H. and Yu, S.-P. (2013), Soil-quality-index model for assessing the impact of groundwater on soil in an intensively farmed coastal area of E China. Z. Pflanzenernähr. Bodenk. doi: 10.1002/jpln.201200383

Zuo, Y., & Zhang, F. (2011). Soil and crop management strategies to prevent iron deficiency in crops. *Plant and Soil, 339*(1-2), 83-95. doi:10.1007/s11104-010-0566-0