The agronomic and economic costs and benefits of cassava cropping systems in Northern Vietnam

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Abstract

Soil erosion is a threat to the productivity of smallholder operations engaged in agriculture in sloped regions of Vietnam. Developing and evaluating alternative systems to combat soil erosion is important to maintain yields and incomes in these upland regions. Cassava is typically grown on these slopes, as it can survive in low nutrient soils; however, nutrient loss through soil erosion can lead to substantial cassava yield declines over time with repeated production. The International Center for Tropical Agriculture directed an intervention in 1999 to understand the agronomic effects of soil erosion minimization techniques to increase cassava yields, incomes, and improve smallholder livelihoods in Southeast Asia. Smallholder cassava growers in Văn Yên District, Vietnam were participants in that initial intervention. Growers in this region adopted the technique of growing *Paspalum atratum* grass strips on hedgerows to minimize soil erosion. Our research is a follow-up study of this initial intervention in Văn Yên to compare the grass strip system to the traditional monocrop system to understand the impact on soil erosion, yields, and economic profitability.

Contents

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List of Tables

List of Figures

Chapter 1: Background

1.1 Initial intervention: Participatory Farmer Research

Cassava (*Manihot esculenta*) is a root grown in the tropics as a sustenance crop and as an industrial crop grown for processing into animal feed, chips, ethanol, and flours for exportation (Howeler, 2014). Due to the increase of demand for processed cassava products in China, land dedicated to cassava has increased throughout Southeast Asia. Production has expanded to marginal upland regions as cassava is a resilient crop that can be grown in nutrient depleted soils (Howeler and Aye, 2014). However, continual cassava production with limited nutrient inputs decreases cassava yield potential through time leading to declines in grower incomes (Howeler, 1993). To address this issue, in 1999, the International Center for Tropical Agriculture (CIAT) collaborated with local government extension services throughout China, Thailand, and Vietnam to assist farmers with cassava production (Howeler et al., 2004). Through grower surveys administered by CIAT, growers indicated that with repeated annual production, cassava yields were declining over time. Researchers found that the farmers were dealing with high deficiencies of nutrients in the soil due to erosion and nutrient extraction with repeated cassava production. Many of the farmers were aware of these issues; however, chose not to change practices or use fertilizer due to high labor requirements or input costs. CIAT and the Vietnam government extension service used the Farmer Participatory Research Method (FPR) to test and spread practices that would help farmers increase production (Howeler, 2004). In the FPR methodology, researchers and farmers work together at every stage to address the issue starting with diagnosis of the problem, through the research and trial process, and finish at the adoption and scaling stage once a new practice has been tested and approved. This is a continuous cycle of discovery and testing to create stronger and more resilient production systems over time that fit the needs of the growers (Figure 1).

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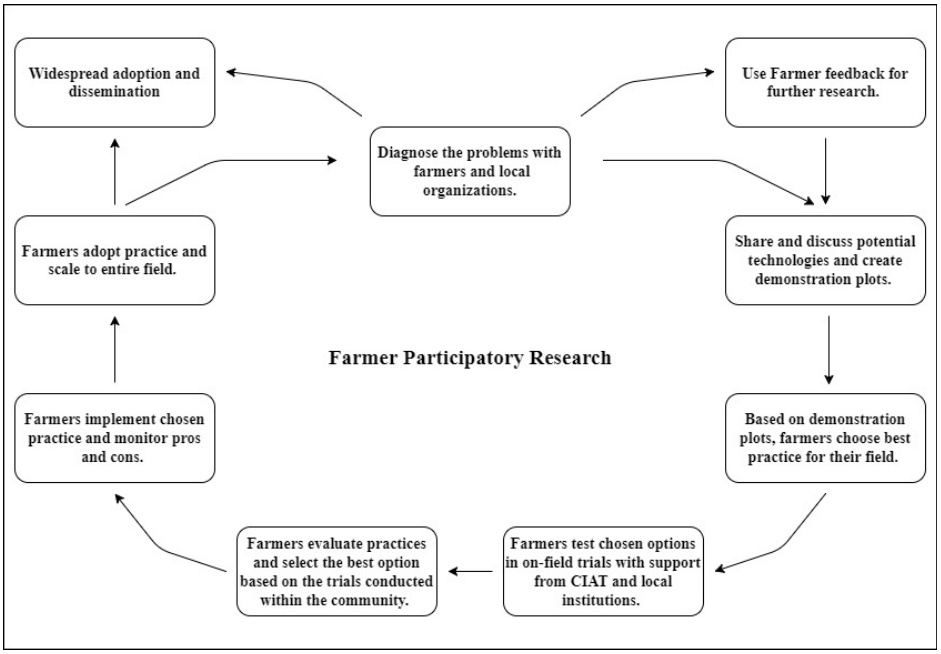


Figure 1: The cycle of the Farmer Participatory Research model as implemented by CIAT in 1999 – 2003 with cassava farmers in China, Thailand, and Vietnam (Howeler et al., 2004)

In the first phase of the project, CIAT collaborated with extension centers and local research organizations to choose the sites for the initial stages of the project in China, Thailand, and Vietnam, starting with 3 sites per country in 1999 and eventually spreading to 99 villages over the three countries by 2003. After choosing the two to three villages per country with help from local officials and interested farmers, CIAT facilitated discussions to characterize farmer challenges and foster communication among farmers to discuss these challenges. This lead to proposed strategies including, soil conservation practices, new cassava varieties, fertilization, and different cropping systems with a focus on nutrient retention to address local issues. From the gathered information, researchers created a list of four technologies to conduct research trials at local experimental stations and on-farm trials with a subset of voluntary growers in each country. These four technologies included: soil conservation practices, new varieties, fertilization, and alternative cropping systems. There were a total of 467 on-farm trials conducted with 177 erosion trials, 157 variety trials, 98 fertilizer trials, and 35 intercropping trials (Howeler et al., 2004). For each treatment researchers and farmers collected data on cassava yields, intercrop yield, soil loss due to erosion, gross income, production costs, and net income. CIAT conducted field days during the harvest season, where farmers in each region gathered at the on-farm trials to evaluate pros and cons of the treatment and the yield. The farmers learned from each other's experiences through these field days and through an end of season workshop that gathered all farmers together to discuss the results. From these interactions farmers chose a treatment to apply on their entire cassava plot depending on their own experiences and the experiences of their fellow farmers.

The second phase of the project focused on dissemination, incorporation of more sites, and continuation of trials on participating farmers' plots. Farmers who participated in phase I assisted in extension work to share their experiences for each of the proposed technologies. The local extension services and CIAT facilitated cross-visits to bring farmers in the new sites to the on-farm trials from phase I. This not only demonstrated the impacts of the treatment but, also connected farmers. Through this process, the success of the various practices and varieties quickly spread to neighboring villages and increased the adoption of the practices. In Vietnam, 126 out of 584 trials included soil erosion mitigation over the two phases (Howeler et al., 2004). Trainings on new technologies, fields days to experimental stations, and community self-help groups were created to foster communication and support among farmers who decide to participate. CIAT and extension services trained two to three farmers on a voluntary basis to assist during trainings and train other farmers who were interested in adopting any of the practices. The community self-help groups encouraged farmers to gather to troubleshoot, create seed banks, establish nurseries for hedgerow and intercrops, and gather questions when necessary to seek support from CIAT or government extension services.

In Văn Yên, many of the farmers chose to plant grass strips along contour lines to mitigate soil erosion. *Paspalum atratum*, a tall grass typically used in Brazilian forage systems was chosen because of benefits for forage production and mitigation of soil erosion (D Hare et al., 2009). CIAT, the local government extension service, and the cassava factory located in Văn Yên collaborated to assist farmers with implementation by providing planting material of both the cassava variety and the grass. Early adoption began in 2001 and adoption in the region has steadily increased.

1.2 Description of research study

The purpose of this study was to compare the agronomic and economic costs and benefits associated with a *Paspalum atratum* cassava system, proposed in 2001, compared to a traditional monocrop cassava in smallholder systems in the upland mountainous regions of Vietnam. Our research evaluated the effectiveness of incorporation of grass strips to mitigate soil erosion and improve yields over time through the collection of socioeconomic (system input and output) data and soil samples from smallholder cassava farms in three Vietnam communes. In 2016, ee surveyed households that fit within 3 categories, i) monocrop cassava production, ii) grass strip cassava production implemented 5 – 7 years ago, iii) grass strip cassava production implemented 10 – 12 years ago, to create a chrono-sequence of adoption. The main hypotheses of the research were:

(i) The *Paspalum atratum* strip cassava cropping system can retain more topsoil by reducing erosion potential of sloped marginal cassava land.

Rationale: Văn Yên is a mountainous region with steep slopes that contain cassava production, due to the lack of soil coverage and the high intensity of rainfall, soils easily erode. Grass strips planted along contour lines can prevent soil erosion from occurring. The grass strips behave as a barrier across the field and prevent topsoil and organic matter from eroding down the slope.

(ii) The *Paspalum atratum* cassava system will result in lower yields than the monocrop system initially. However, after several years in production, this will reverse due to increased nutrient availability for cassava uptake leading to more robust cassava roots.

Rationale: In the Paspalum atratum grass strip production system, strips of land are reallocated from cassava production to grass production. Removing this land from cassava production will lead to an initial decrease in yield per hectare. However, growers in this region are unable to increase chemical fertilizers annually due to limited capital. Nutrient retention through the prevention of soil erosion with the grass strips will be integral to *maintaining yields. The ability of the grass barriers to retain soil nutrients will lead to increased yield in the grass strip production system overtime.*

Chapter 2: The agronomic and economic costs and benefits of cassava cropping systems in Northern Vietnam

2.1 Abstract

This study was conducted in collaboration with International Center for Tropical Agriculture (CIAT) to evaluate the biophysical and economic impacts of an agricultural intervention in 1999 to improve cassava yields and minimize soil erosion in the mountainous region of Văn Yên, Vietnam. The intervention promoted planting *Paspalum atratum* grass strips along man-made contour lines in cassava fields to prevent soil erosion, increase nutrient retention, and improve soil fertility. In August 2016, socioeconomic surveys were administered, and soil samples were collected on 45 farmer cassava fields within 3 cassava treatments; a monocrop cassava system, a grass strip cassava system in production for 5 – 7 years, and a grass strip cassava system in production for 10 – 12 years. Soil chemical and physical parameters, seed and fertilizer inputs, yields, and economic returns were analyzed. The difference in available phosphorus (P_2O_5) between the top and bottom of the slopes suggest that more sediment is lost to soil erosion in the monocrop system as compared to the systems with grass strips. We found no significant differences in yields between the two systems and no significant differences in economic performance. The findings suggest that incorporating *Paspalum atratum* grass strips into traditional monocrop cassava production can assist with nutrient retention and mitigate rapid yield declines in mountainous cassava producing regions.

2.2 Introduction

Cassava (*Manihot esculenta*) is an economically important woody shrub harvested for the starchy root throughout Asia, Africa, and Latin America. An increase in demand for cassava in recent decades to process into chips, flours, and starch for both animal and human consumption has led to an increase in land dedicated to cassava production. Since 1980, throughout Asia, productive cassava land has expanded from 3.89 million hectares to 4.18 million hectares in production, which is a 7% increase of land dedicated to cassava production. The increased land in production, use of fertilizers, and improved varieties have led to an increase in total production from 46.94 million tons in 1980 to 89 million tons in 2016, due to increased land in production, use of fertilizers, and improved varieties (FAOSTAT, 2016; Howeler, 2014). Vietnam is the 8th largest producer of cassava worldwide producing 9.7 million tons of cassava root in 2016 (FAOSTAT, 2016). Cassava is a drought tolerant, water efficient crop that can survive in acidic soils; therefore, cassava can be grown on marginal land where other crops cannot grow (Howeler, 2014). In Vietnam, approximately 60% of agricultural land is covered in mountains and plateaus, and most of the cassava is grown in these regions. Approximately 80% of the total average annual rainfall (1,689 mm) occurs between April and October corresponding to the early growth stages of cassava when ground cover is limited (Anh et al., 2004). This land is vulnerable to increased runoff, soil erosion, nutrient loss, and leads to crop production declines (Van De et al., 2008). Soil erosion and nutrient retention must be addressed to ensure the long-term productivity of these hilly landscapes. Through alternative cropping practices, smallholder farmers can address soil erosion and improve soil health for future production.

An intervention in 1999 by CIAT and the Vietnam Ministry of Agriculture revealed that growers experienced cassava yield declines in the Northern upland regions of Vietnam (Howeler et al., 2004). Through the farmer participatory research method, smallholder growers identified soil erosion as a major issue in the cassava plots, which is consistent with research conducted in this region (Anh et al., 2014; Harwood and Kassam, 2003; The Dang and Klinnert, 2001). There is a strong link between loss of soil nutrients due to land use and soil erosion in the upland sloped regions of Vietnam (Anh et al., 2014; Bui Dung, 2003). The soils in the upland regions contain, on average, less than 2% organic matter, which is both a cause and effect of soil erosion (The Dang and Klinnert, 2001). Soil organic matter is a combination of plant, animal, and microbial residues that combines with soil minerals in the top of the soil horizon (Montgomery, 2007). Accumulation of soil organic matter is necessary to provide a long term nutrient source for plant growth, water infiltration **(**Franzluebbers, 2002)**,** and aggregate stability**,** which contributes to soil structure and strength (Tisdall and Oades, 1982). Without sufficient organic matter to assist in aggregate formation and stability the soils become crusted and easily erodible. As cassava only provides 47% to 56% ground cover during peak maturity, the unstructured soils combined with limited ground cover and severe rainfall events, lead to continued loss of soil organic matter through erosion and runoff (Harwood and Kassam, 2003). The loss of nutrients via soil erosion must be replaced to ensure the productivity of cassava, which is problematic in rural areas where farmers have limited resources and limited access to chemical inputs. Thus, creating strategies to minimize soil erosion and runoff and evaluating the effectiveness of these interventions over the long-term is necessary to maintain agricultural production in these regions and improve smallholder farmer livelihoods.

The most widely adopted practice, promoted by the initial intervention in 1999, incorporated grass strips (*Paspalum atratum*) along contour lines on the sloped cassava fields to prevent soil erosion. *Paspalum atratum* is a native Brazil perennial grass with an extensive fibrous root system and is adapted to acidic soils (Cook et al., 2005). It was traditionally used for long term pasture; however, due to its long blades and extensive roots, it is also used in cut and carry forage systems and as a hedgerow for erosion control (Cook et al., 2005). Promotion and adoption of planting grass strips to increase soil coverage and prevent soil erosion can aid in addressing land degradation and food security through increased incomes. In Northern Vietnam, recent studies have identified the major problems in sloped farms to be low soil fertility, poor water quality, and downstream property damages, especially during the long rainy season (Phan Ha et al., 2012; Valentin et al., 2008). Throughout Southeast Asia, studies have analyzed the soil loss in upland region to understand the impact of agricultural intensification on land degradation (The Dang and Klinnert, 2001; Valentin et al., 2008). These projects illuminated the positive effects of intercropped trees, contoured grass strip hedgerows, terracing, and crop rotations with native grasses and legumes through an increase in organic matter by 50% and a decrease in soil erosion by 67% (The Dang and Klinnert, 2001).

Despite the beneficial characteristics of planting hedgerows in cassava production systems for farmers and the environment, adoption rates remain low. Before implementation can occur, consideration of the regional socioeconomic situation is vital. To be successful, promotion of a new agricultural practice must incorporate discussions about local land use, access to inputs, market access for growers, and agricultural development policies in the region (Cramb, 2005). The barriers of adoption frequently include limited access to necessary resources, including equipment, materials, support, difficulties in shifting traditional practices, and labor (Hobbs, 2007). Initial investment in seeds, knowledge and labor, in additional to lack of short-term benefits, often dissuade growers from adopting new practices. In this system, land is taken out of the cash crop to grow grass, which does not provide the grower with immediate benefits.

The effectiveness of hedgerows in preventing soil erosion has been studied throughout Southeast Asia in controlled studies. Our research addresses a critical knowledge gap by understanding the implications of the cultivation method for farmers at the field level and to also evaluate its economic viability. This study seeks to incorporate agronomic and socio-economic data to understand the benefits and costs of the *Paspalum atratum* grass strip system in Northern Vietnam and to provide suggestions for the promotion of this practice across mountainous regions throughout Southeast Asia.

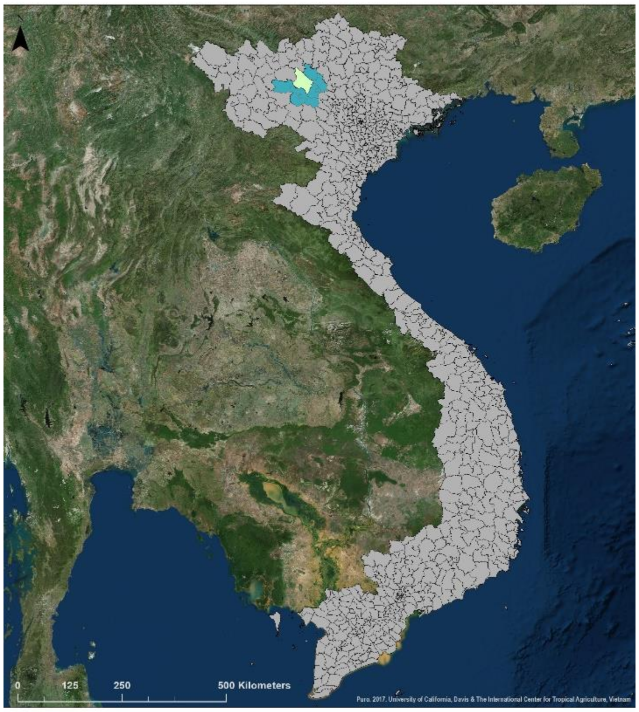
2.3 Methods

2.3.1 Site characteristics

Yên Bái is a province in Northern Vietnam (21° 30′ 0″ N and 104° 40′ 0″ E) bordering Sơn La to the west, Lai Châu, Lào Cai, and Hà Giang to the north, Tuyên Quang and Việt Tri to the East. The total land in commercial agricultural production 786 km^2 out of a total area of l 6,899.5 km^2. Văn Yên is a district located in the North central region of Yên Bái (21° 49′ 58.8″ N, 104° 34′ 58.8″ E). Văn Yên is a land locked district that covers an area of 1,289 km^2 (Figure 2a). Hanoi, is the closest major city to Văn Yên located 200 km to the South. A major highway runs from Hanoi northwest to China directly through Văn Yên parallel to the Red River. This major highway is integral for the transportation of agricultural goods in and out of the district allowing easy exportation to China. The Red River bisects Văn Yên from the northwest to the southwest of the district and is an important water source for the region for human consumption, agricultural production, and livestock. The average elevation in Văn Yên is 600 meters with an elevation low of 16 meters and an elevation high of 2,490 meters. The topography in the region includes steep and rolling hills. Rice and maize crops are grown in the valleys whereas cassava, cinnamon, and fruit trees are grown on the hillsides.

Northern Vietnam has two distinct seasons, a dry winter season and a rainy summer season. The dry winter season is from November to March and the rainy summer season is from April through October. In the winter months the temperature ranges from 0ºC to 15ºC and in the summer months the temperatures range from 15ºC to 28ºC. The average annual rainfall is 1,500 mm to 3,000 mm. Most rainfall occurs in June through August.

a.



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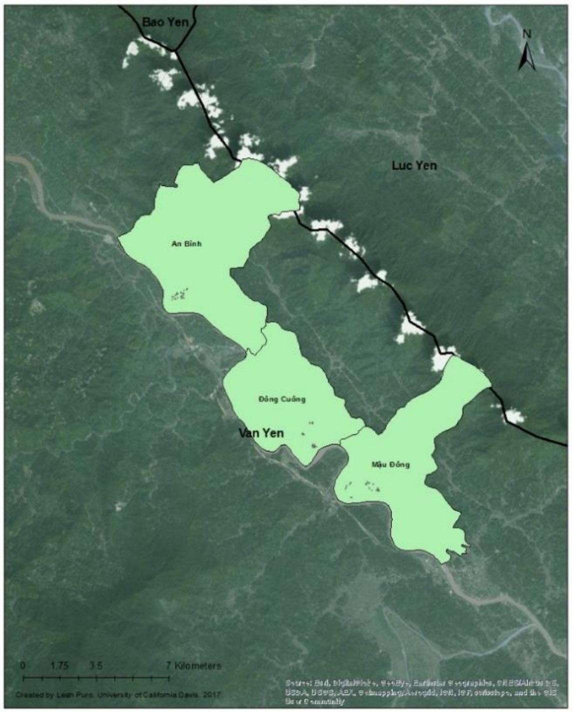

Figure 2: a) Map of Vietnam. The colored region is Yên Bái Province and the light green region in the northern part of the province is Văn Yên District. b) Map Of the three communes studied, Mậu ĐôngĐông Cuông, and An Bình, all located along the Red River in Văn Yên District, Vietnam.

The research was conducted in three communes in the Văn Yên District. These communes include; Mậu Đông, Đông Cuông, and An Bình (Figure 2b). These communes are all located within 10 kilometers of each other. Farmers from Mậu Đông and Đông Cuông communes were participants in the 1999 – 2003 field trials conducted by CIAT and the Ministry of Agriculture. In this area, due to the steeply sloped landscapes, eroded soils, and proximity to a cassava processing facility, many farmers grow cassava for processing and export, cinnamon for processing, as well as rice and maize for home consumption and livestock feed. The main cash crop in this region is cassava.

2.3.2 Experimental design

In 2016, a total of 45 households were chosen across three communes in collaboration with the district, commune, and village leaders. Meetings with district level officials led to connections with commune leaders who assisted with farmer selection. The three cropping systems studied included: monocrop cassava production (n = 15); grass-strip and cassava intercrop implemented five to seven years ago (n = 15); and grass strip and cassava intercrop implemented ten to twelve years ago (n = 15) (Table 1). The chosen cassava plots were located on hillsides with slopes of 20% - 40%. Commune officials made a list of all farmers in the area that fit the three categories and facilitated meetings with farmers willing to participate.

Commune	Practice	Number of Households
Mậu Đông	Monocrop	5
	Grass strip 5-7 years	5
	Grass strip 10-12 years	5
Đông Cuông	Monocrop	6
	Grass strip 5-7 years	6
	Grass strip 10-12 years	3
An Bình	Monocrop	4
	Grass strip 5-7 years	4
	Grass strip 10-12 years	7

Table 1: Number of households from each commune practicing each cultivation treatment.

2.3.3 Socioeconomic survey for economic value of the system

A socioeconomic survey was administered to gather detailed input and output data for the cassava plots. The full survey is provided in Appendix 1. Prior to conducting surveys, plots were viewed to ensure the household fit the above criteria. Surveys were translated into Vietnamese and conducted in an interview format between researcher, interpreter, and participant. Each interview was conducted in the participant's home and was approximately two hours long. Participants were compensated for time spent with the researchers.

The survey collected detailed information on input quantities and costs. These inputs included capital costs, fertilizers, seeds, pesticides, and hired labor. Input amounts were collected to evaluate differences between the monocrop and the grass-strip production systems. The timing of the input application was included to understand the annual labor flows and to assist in the interpretation and analysis of soil parameters. The amount of cassava inputs per hectare were based on recommendations from the Ministry of Agriculture Extension network and CIAT. The recommended seeding rate was 10,000 stalks per hectare at a spacing of 1 m^2. The spacing in the three communes ranged from 0.7 m^2 to 1.2 m^2. The mean *Paspalum atratum* seed inputs for the grass strip system were 0.5 kg /hectare and recommended that growers replant the grass strips every 4 to 5 years. The government provided the seed to the growers and the government also provided the labor to plant the initial grass strips for early adopters. Labor requirement data was collected to analyze differences in labor inputs necessary for the grass strip and cassava production system in comparison to the monocrop production system. Most labor in the region is household labor that growers do not associate with a cost. In this study, the opportunity cost associated with the labor was calculated using the average daily wage for a farm laborer in the area (Wiggins, 2014).

Data was collected on the household output including cassava yields and grass yields when applicable. Cassava yields for the last 3 to 5 years were recorded and participants were asked to provide perceived reasons for any yield changes. The cassava yields were collected on a per plot basis and converted into a per hectare basis for analysis. Yields for the grass strip production systems include the grass strips as part of the one hectare, as our study compared two systems on 1 hectare of total production. For example, in the monocrop system, there was 1 hectare of cassava, and there was approximately 0.80 hectare of cassava with 0.20 hectare of grass in the grass strip production system (Figure 3). Due to difficulty of participants to estimate the land in grass strip production, the yields and inputs for the grass strips were multiplied by the same conversion as the plot to a 1-hectare scale of the entire system. Data were collected only from cassava plots on hillsides in cases where households had multiple cassava plots in different locations. Data were collected on livestock types, amounts, feed, waste products, and use of livestock to explore potential linkages between livestock owned and the type of cassava production system adopted. Information on feed and animal waste was collected to understand the fate of crop residues and manure on the plots. The survey included data on cassava prices for 2015 to capture the income from cassava for each household, which was representative of the average price of cassava during the period of data collection in the region. Revenues for 2015 were calculated using the mean yield values for each cropping treatment as determined by the yield models (section 2.3.9), the mean price for cassava for the 2015 season reported in the surveys, and the farmgate price of dry maize as an estimation of the value of the forage. To determine the monetary value of the forage, farmgate maize prices were used, which is a replacement feed with similar dry weight to protein ratio of 7% - 9% (D Hare et al., 2009; FAOSTAT, 2016)

The interviews ended with a discussion about the challenges that participants faced with the chosen cassava production system and future production plans. This section of the survey was an open dialogue, allowing the participant to lead the discussion. Topics participants identified included pests, disease, changes in climate in recent years, perceived soil health and quality, perceived cassava health and quality, and future production plans.

2.3.4 Soil sampling

Soil samples, GPS coordinates, and slopes were recorded on each cassava plot to gather soil level information about the effects of each of the three cassava practices. Soil samples were collected in August 2016, towards the end of the heavy rains in the area. A total of six soil samples were taken from each of the 45 cassava plots of the households surveyed (Table 1). Each plot was split into three sections, top, middle, and bottom of the slope and two samples were taken per section (Figure 3). Soil was collected from each section at two depths, 0 – 20 cm, and 20 – 30 cm. Due to limited funds, only 0 – 20 cm samples for the upper and lower slope positions were analyzed. Soils were air dried for several days before being packaged for delivery to the analytical lab.

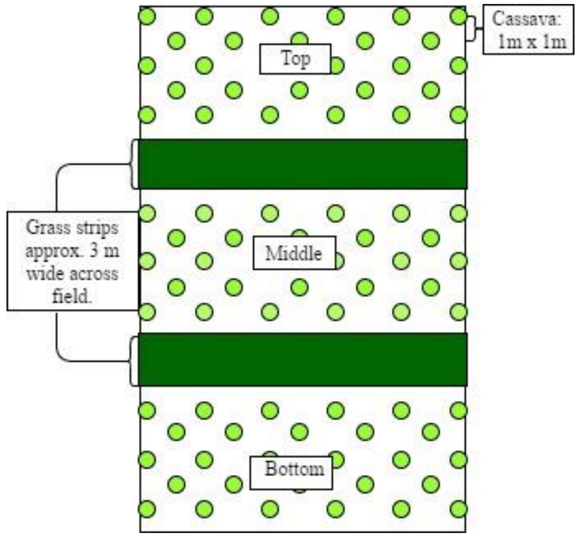

Figure 3: Diagram of example cassava field with grass strips. Labels top and bottom represent the locations of the soil sampling.

2.3.5 Soil physical and chemical properties

Soil samples were analyzed at the Soils and Fertilizers Research Institute in Hanoi, Vietnam. Samples were dried, crushed, and sieved through a 2-mm sieve prior to analysis. These samples were analyzed for texture, pH (water method), total organic carbon (Buret titration, Walkley-Black method), total nitrogen (Kjeldahl method), available phosphorous (Bray method), exchangeable cations (Mg, Ca, Na, K) and bulk density (Bray and Kurtz, 1945; Jones, 1991; Walkley and Black, 1934). Bulk density measurements of each of the plots were taken in November of 2016, prior to harvest, due to lack of proper equipment in August during the initial sampling period.

2.3.6 Phosphorus and Phosphorus (P) Erosion Index

Phosphorus (P_2O_5) was tested and quantified using the Bray method (Bray and Kurtz, 1945). Phosphorus concentrations were also used to compare the estimate of soil erosion across the treatments. Phosphorus has low solubility and remains tightly bound to fine soils particles. The sediment removed from the slope during intense rainfall events contains the phosphorus bound in the soil particles (Cox and Hendricks, 2000). Repeated rainfall events can lead to phosphorus depletion on the top of the slope and phosphorus accumulation at the bottom of the slope (Fraser et al., 1999). Agricultural soil catchment studies have demonstrated a correlation between loss of sediment and loss of phosphorus during high intensity rainfall events on slopes ($r^2 = 0.92 – 0.97$) (Fraser et al., 1999; Sharpley, 1993; Stevens et al., 2009). Due to this correlation between sediment loss and phosphorus loss, we defined and used a P erosion index as an indicator of sediment loss through soil erosion. The P erosion index was calculated by,

P erosion index = measured P_2O_5 at the top of the slope – measured P_2O_5 at the bottom of the slope

which was the difference in available phosphorus (P_2O_5) measured at the top of the slope and the bottom of the slope.

2.3.7: Land Use System models

The Land Use System (LUS) modeling methodology was used to compare the economic value of the cassava cropping systems (Kragten et al., 2001). The LUS model is a multi-year analysis of an agricultural system on one plot of land to evaluate the agronomic and economic performance (Kragten et al., 2001). The LUS model requires a specific context, production method, system inputs and outputs, and prices to assess economic returns, estimate environmental and sociocultural effects, highlight adoption implications, and compare to other production systems. LUS models can give rise to policy initiatives to improve the economic performance the evaluated systems (Vosti et al., 2002).

The two LUS models in our research included all inputs, outputs, and prices over 12 years for a monocrop system compared to a grass strip system. The 12- year system was chosen due to the length of time the grass strip cassava system has been practiced in the region. Both systems began with forest land in year 1, thus forest clearing was the first activity for both LUSs. The LUS models are based on a one-hectare plot, as one hectare was the median plot size within the three communes. The LUS models were created using a combination of soil data, socio-economic survey data, and literature to generate each of the scenarios. The economic profitability was determined based on the household surveys to measure the economic costs and benefits of each system. The profits derived from the annual costs and revenues were discounted (10% discount rate) to calculate the net present value (NPV) of each system over 12 years allowing the comparison of the economic performance of the systems. NPV provided the present- day value of the system with the equation,

$$NPV = \sum_{i=0}^{n} \frac{B_t - C_t}{(1+i)^t}$$

where B_t represents the revenues, C_t represents the annual and investment costs, t represents each year of the system, i is the discount rate, and n is the total number of years of the system (Goodall, 1987). To understand the labor opportunity cost for each system, we calculated the family returns to labor by,

$$\frac{NPV}{L_t}$$

where the NPV is the net present value, as shown above, and L_t is the total labor (person-days) for the entire system (Kragten et al., 2001). Appendix 2 provides a detailed list of LUS assumptions.

The three yield scenarios were created by adjusting values for yield and labor to make a low yield scenario, a mean yield scenario, and high yield scenario. The mean yield scenario used the mean values for labor and yields from the surveys. The low yield scenario included yield subtracted by the standard error with labor remaining constant. In the high yield scenario, the standard error was added to the yield with the labor remaining constant. These scenarios were repeated for both the monocrop and the grass strip systems. In addition, worst case and best case scenarios were created. In the worst case scenario, yields represented the yields in the low yield scenario, with labor as the mean plus the labor standard error. In the best case scenario, yields represented the yield in the high yield scenario with labor as the mean subtracted by the standard error of the labor values.

2.3.8 Prices for system value and Land Use System models

Prices for all inputs and outputs were calculated based on 2015 values reported by the survey participants. Using the annual inflation for the last 12 years, prices for seeds, farmyard manure, and start up inputs were calculated (Bank, 2017). Fertilizer prices were determined using historical data for urea prices as both input prices closely track the price of natural gas (Mundi, 2016). The difference between the urea prices observed and the historical urea prices were determined. The price difference between the corrected urea prices and the local price for NPK were used to determine NPK prices for the last 12 years. Current labor prices were determined with the reported average market price for agricultural labor for the three communes, $6.08 USD/person day. Historical rural wage data collected by the Overseas Development Institute for the agricultural sector in Vietnam was used to build a linear model to predict wages for the last 12 years (Wiggins and Keats, 2014). These wages were $2.16 USD/person day in 2002, $3.92 USD/person day in 2007, $4.69 USD/person day in 2010 and $5.26 USD/person day in 2012 (Wiggins and Keats, 2014). Cassava prices were based on historical farmgate cassava prices for the last 12 years (FAOSTAT, 2016) and forage prices were determined by farmgate maize prices (D Hare et al., 2009; FAOSTAT, 2016).

2.3.9: Statistical analysis

Soil physical and chemical properties from the 45 households were analyzed with ANOVA comparisons of means and linear models with the cultivation treatment commune as fixed variables due to the significant differences between soils in different communes. P-values were adjusted based on the Tukey method (Tukey, 1977).

Linear mixed effects models were used to determine the relationship between the difference of available phosphorus between the two slope positions and the cultivation method, using cultivation method as fixed a variable and the commune as the random variable. In addition, a mixed effects model was used to determine the relationship between yields and cultivation method. Estimates for yields and phosphorus were adjusted using the Tukey method for multiple comparisons. These models were chosen through model reduction. Input (fertilizer, manure, seed) amounts, soil parameters, and slope variables were tested and were not significant in the model. The mean yield from this model was used to calculate revenue for the three treatments.

The total revenue for the 2015 season was calculated using the 2015 prices and the 2015 yields for cassava and forage. To determine the significance of differences between the cropping treatments, the proportional errors associated with the cassava and forage yields were applied to the revenue. The proportion of the error to the cassava yield was used for the monocrop system. The proportions of the errors to the estimates for the cassava and forage yields were used for the grass strip 5 -7 year system and the grass strip 10-12 year system. Significant differences between treatments were determined using Welch's T- test.

Prior to statistical analysis of the system performance, all inputs, outputs, and yields were converted to a 1- hectare system to account for the difference in field size among the households. Covariate regression analysis was used to evaluate the differences in purchased inputs, labor inputs, and income between the cropping systems. Analyses were conducted using the lmerTest and emmeans packages in the R environment for building and summarizing models (R Core Team, 2015). Differences at the $P \leq 0.05$ were considered significant for all statistical tests.

2.4 Results

2.4.1 Soil characterization

Soil properties and chemistry were analyzed as a function of cultivation treatment for each commune. Organic carbon, total nitrogen, sodium, and available phosphorus were not affected by cultivation method or commune. Bulk density, calcium, potassium, pH and magnesium had significant differences between communes; however, were not significantly different between cultivation treatments (Table 2, Appendix 3.1).

Soil Variable	Monocrop	Grass Strip 5-7 years	Grass Strip 10-12 years
Mậu Đông Commune			
Texture	Sandy Clay	Sandy Clay	Sandy Clay
pH	4.23 ± 0.24 ab	4.19 ± 0.22 a	4.32 ± 0.20 ab
Bulk Density (g/cm^3)	1.21 ± 0.04 ab	1.20 ± 0.04 ab	1.20 ± 0.04 ab
Organic Carbon (%)	1.43 ± 0.10	1.22 ± 0.09	1.42 ± 0.08
N (%)	0.13 ± 0.01	0.11 ± 0.01	0.12 ± 0.01
Ca^{+2} meq/100g	2.71 ± 2.19 ab	1.18 ± 0.20 a	2.67 ± 1.79 ab
Mg^{+2} meq/100g	0.05 ± 0.73 a	0.37 ± 0.66 a	0.69 ± 0.60 a
Na^{+} meq/100g	0.12 ± 0.01	0.13 ± 0.02	0.11 ± 0.01
K^{+} meq/100g	0.19 ± 0.06 ab	0.23 ± 0.05 ab	0.19 ± 0.06 a
P (mg P_2O_5/100g) Top	2.39 ± 2.57	3.37 ± 2.30	4.26 ± 2.10
P (mg P_2O_5/100g) Bottom	7.91 ± 3.41	1.54 ± 3.05	2.98 ± 2.79
Đông Cuông Commune			
Texture	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam
pH	5.14 ± 0.20 bc	4.87 ± 0.20 abc	5.68 ± 0.28 c

Bulk Density (g/cm^3)	1.33 ± 0.04 b	1.27 ± 0.04 ab	1.33 ± 0.05 ab
Organic Carbon (%)	1.50 ± 0.08	1.29 ± 0.08	1.12 ± 0.11
N (%)	0.11 ± 0.01	0.12 ± 0.01	0.10 ± 0.01
Ca^{+2} meq/100g	6.21 ± 1.79 ab	6.82 ± 1.79 ab	7.12 ± 2.53 abc
Mg^{+2} meq/100g	1.49 ± 0.60 a	2.26 ± 0.60 ab	1.88 ± 0.85 ab
Na^{+} meq/100g	0.11 ± 0.02	0.07 ± 0.01	0.09 ± 0.01
K^{+} meq/100g	0.37 ± 0.06 ab	0.43 ± 0.05 b	0.32 ± 0.07 ab
P (mg P_2O_5/100g) Top	6.71 ± 2.3	3.21 ± 2.10	12.45 ± 2.97
P (mg P_2O_5/100g) Bottom	9.68 ± 3.05	4.76 ± 2.79	10.62 ± 3.94
An Bình Commune			
Texture	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam
pH	5.01 ± 0.24 abc	5.33 ± 0.24 bc	4.97 ± 0.19 abc
Bulk Density (g/cm^3)	1.28 ± 0.04 ab	1.22 ± 0.04 ab	1.15 ± 0.03 a
Organic Carbon (%)	1.16 ± 0.10	1.16 ± 0.04	1.22 ± 0.07
N (%)	0.11 ± 0.01	0.13 ± 0.01	0.12 ± 0.01
Ca^{+2} meq/100g	7.74 ± 2.19 abc	16.04 ± 2.19 bc	10.00 ± 1.65 c
Mg^{+2} meq/100g	2.146 ± 0.73 ab	4.85 ± 0.73 b	3.05 ± 0.56 ab
Na^{+} meq/100g	0.12 ± 0.01	0.15 ± 0.05	0.12 ± 0.02
K^{+} meq/100g	0.16 ± 0.06 a	0.34 ± 0.06 ab	0.18 ± 0.05 a
P (mg P_2O_5/100g) Top	6.45 ± 2.57	2.97 ± 2.57	3.69 ± 1.94
P (mg P_2O_5/100g) Bottom	10.26 ± 3.41	3.04 ± 3.41	2.20 ± 2.58

Table 2: Mean soil parameters by commune and treatment with standard error. Significance at the $p \leq 0.05$ level is indicated with the letters; a, b, c. Parameters with the same letters or without letters were not significantly different.

2.4.2 Soil erosion/ Phosphorus (P) Erosion Index

The degree of soil erosion was estimated using the P Erosion Index. The mean P Erosion Indices for the monocrop, 5 – 7 years in grass strip production, and 10 – 12 years in grass strip production were -4.01, 0.03, and 1.48 respectively (table provided in Appendix 3.2). The negative P Erosion Index value indicates greater phosphorus levels on the bottom of the slope. The cultivation of grass strips for 10 -12 years had a significant positive effect on the difference in available P between the top and the bottom of the slope compared to monocrops (Figure 4). The lack of significant difference between the grass strip 5 - 7 year system and the monocrop system may have been due to the high variation in available P values (Appendix 3.1).

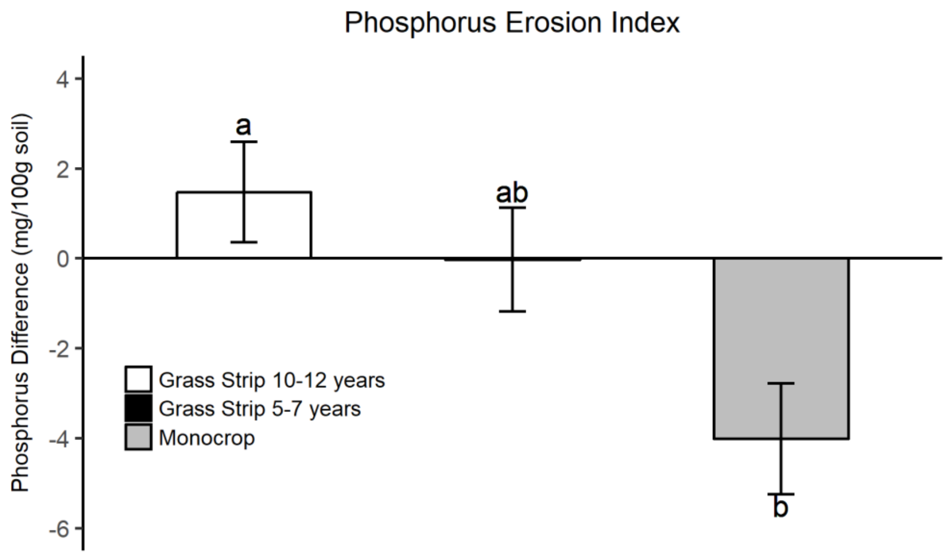

Figure 4: The mean P Erosion Index values for the three cultivation treatments. The letters a and b indicate statistical significance at the $p \leq 0.05$ level.

2.4.3 System agronomic performance

Cassava yields were 22,125 kg/ha for monocrop cassava, 19,611 kg/ha for plots in 5 – 7 years of grass strip and cassava production, and 18,995 kg/ha for plots in 10 -12 years of grass strip and cassava production (Figure 5). These means were not significantly different among the three cultivation treatments on one hectare of cultivation (Appendix 3.3). This result suggests that there was no yield penalty for taking land out of cassava production and placing it in grass strip production. The *Paspalum atratum* forage yields between the two grass strip cultivation methods were not significantly different; however, the reported forage yields were quite variable due to estimation by survey participants (Appendix 3.3).

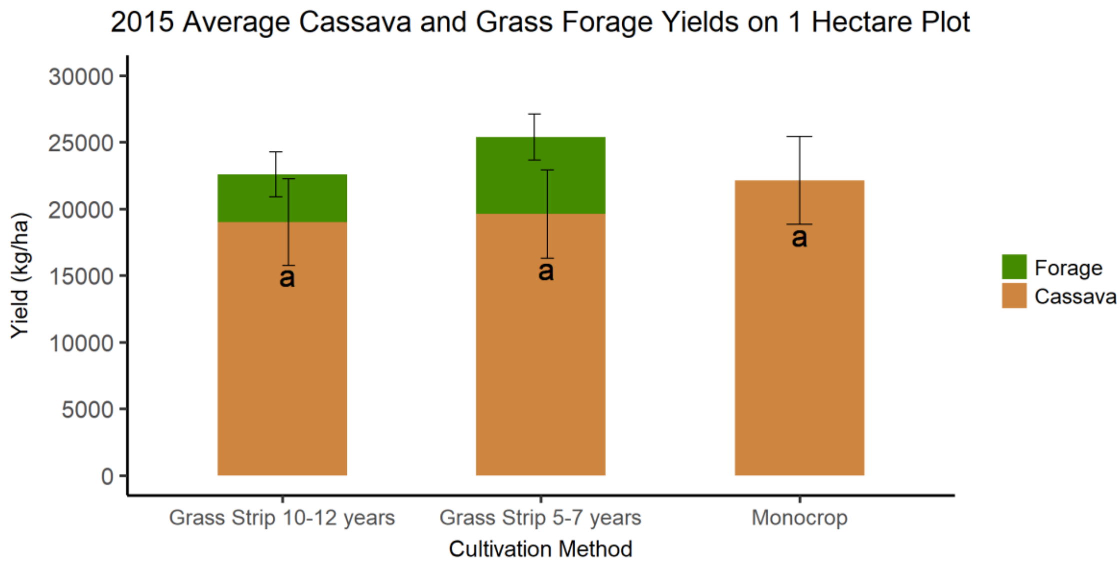

Figure 5: The annual grass and cassava yields in kg/ha as reported by participants. Each bar indicates the average total yield per hectare for each treatment. The black error bars indicate the standard error around the mean for the yield. The letter "a" indicates there was no statistical significance at the $p \leq 0.05$ level for the cassava yields.

2.4.4 2015 economic performance of the systems

Total revenue, cassava revenue, and forage revenue were calculated using the reported prices and the mean yields for cassava and grass for 2015 to compare the economical values of the systems. The total revenue represents the sum of revenue from the cassava for the monocrop system and the revenues of the cassava and estimated revenue from the forage in both grass strip cultivation treatments. The total revenues were $1,203 USD/ha for the monocrop system, $1,435 USD/ha for the 5 – 7 year grass strip system, and $1,262 USD/ha for the grass strip 10 – 12 year system. We found, there were no significant differences between the total revenues received from the different systems (Appendix 3.4).

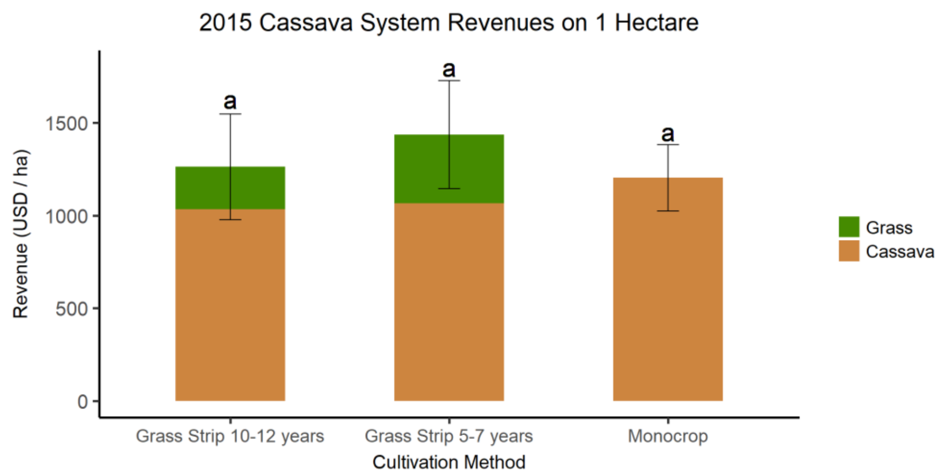

Figure 6: The value of the three treatments based on the mean yields for each cultivation treatment. The black bars represent the error and the letter "a" indicates there were no significant differences between the revenues.

2.4.5 System inputs

Cassava cropping system inputs included NPK, urea, farmyard manure, cassava stalks, and *Paspalum atratum* seeds, for the grass strip systems. Cultivation method had no significant effect on the amounts of each input. The mean NPK values were 949 kg/ha, 810 kg/ha, and 767 kg/ha for the monocrop, grass strip 5 – 7 year, and grass strip 10 – 12 year systems respectively. Based on survey results, urea was applied at an average rate of 9 kg/ha in the monocrop system, 3 kg/ha in the grass strip 10 – 12 year system and was not applied on any of the grass strip 5 – 7 year systems (Table 3). Farmyard manure was collected from the household buffalo or cow in cases when the household owned livestock. According to the survey participants, households with extra manure would typically share manure with households without livestock.

Cultivation Method	NPK (kg)	Urea (kg)	Manure (kg)	Cassava Stalks
Monocrop	949 ± 123	9 ± 4	1732 ± 745	9537 ± 767
Grass Strip 5-7 years	810 ± 123	-	1968 ± 832	9666 ± 871
Grass Strip 10-12 years	767 ± 119	3 ± 4	1408 ± 750	9500 ± 728

Table 3: Cassava system inputs on a per hectare basis for each treatment with standard errors. There are no significant differences between the inputs for the three treatments.

Cultivation method had no significant effect on amount of annual labor in the production system. The mean labor requirements measured in person-days for cassava production for the monocrop, grass strip 5 – 7 year, and grass strip 10 – 12 year treatments were 165, 250 and 164 person days and were not significantly different (Table 7; P = 0.1593) The labor for the cassava production for the monocrop included land preparation, planting, fertilizer and manure application, weeding, and harvest. The labor for the grass strip cassava production included the activities associated with the monocrop system, in addition to land prep, and planting of the grass strips. The livestock labor requirements in the grass strip production systems include grazing management and harvesting the grass. All households with grass strip systems had a ruminant for grass consumption (n = 30), only the households with ruminants (n = 6) were included in the livestock labor analysis for the monocrop system. The annual labor dedicated to livestock for the monocrop, grass strip 5 – 7 year, and grass strip 10 – 12 year systems required 136, 142, and 127 person-days and were not significantly different (Table 4; P = 0.8392). The lack of significant difference suggested there was no labor tradeoff between the two systems. These labor means were used in the land use system models, assuming labor inputs do not change significantly on an annual basis.

Cultivation Method	Cassava System Labor	Livestock Labor
Monocrop	165 ± 35	136 ± 24
Grass Strip 5-7 years	250 ± 36	142 ± 17
Grass Strip 10-12 years	164 ± 35	127 ± 18
P - Value	0.1593	0.8292

Table 4: The means and standard errors of labor inputs (person day/ ha) for each system. The cassava system labor included all labor associated with the 1-hectare plots of cassava or of cassava and grass in the grass strip system.

2.4.6 Land Use System analysis

The LUS models were used to compare the long-term benefits of the cassava monocrop and grass strip systems on 1 hectare of production. The economic performances of the cassava systems were calculated using the LUS model to measure the impacts of each of the cassava systems on the net present value, average returns to land, and returns to family labor over 12 years (Appendix 2 for full LUS models). Multiple yield and labor scenarios were created in the LUS models to compare the grass strip and monocrop cassava systems (Table 5).

Scenario	Cultivation Method	Net Present Value (USD)	Avg. Annual Returns to Land	Returns to Family Labor
Worst Case				
	Monocrop	2,060	172	0.35
	Grass Strip	4,056	338	0.86
Low Yield				
	Monocrop	4,608	384	1.04
	Grass Strip	5,051	504	1.50
Mean Yield				
	Monocrop	7,278	607	1.65
	Grass Strip	6,991	583	1.73
High Yield				
	Monocrop	9,460	788	2.14
	Grass Strip	10,982	908	2.69
Best Case				
	Monocrop	10,886	906	3.00
	Grass Strip	12,521	1,043	3.81

Table 5: The net present values, average annual return to land (USD/ha), and returns to family labor (USD/person day) for the monocrop and grass strip systems under five different yield and labor scenarios.

The mean cassava yields and labor inputs from the surveys were used to calculate the mean yield scenario mean. This was the only scenario in which the monocrop had a higher net present value at $7,278 USD/ha with an average return to land of $607 USD/ha compared to $6,991 USD/ha for the grass strip system with an average return to land of $583 USD/ha (Table 8). To determine the significance of the differences in the net present values, and to determine the sensitivity of the system to yield differences the low yield and high yield scenarios were calculated. The yield subtracted by the standard error for the cassava yields with the mean labor inputs were used to calculate the low yield scenario. In this scenario the net present value for the monocrop was $4,608 USD/ha with an average return to land of $384 USD/ha, which was lower than the net present value of $5,051 USD/ha and average return to land of $504 for the grass strip system. The high yield scenario was calculated using the standard error added to the yield with labor input remaining the same. This scenario also lead to a higher net present value and average return to land in the grass strip system, $9,460 USD/ha for the monocrop compared to $10,892 US/ha in the grass strip system. These results suggest that due to the variation in yields (Appendix 3.3), there was no significant difference between the net present value of the systems.

To determine the sensitivity of each cassava system to changes in labor inputs the worst case and best case scenarios were created. In the worst case scenario, the cassava yields were calculated with the means subtracted by the standard error and the labor inputs were the standard errors of the labor added to the mean labor inputs to reflect a scenario with the lowest yields and highest labor inputs possible using the data collected. The increase in labor had a larger impact on the monocrop system than the grass strip system, as shown by the $2,548 USD/ha reduction in net present value between the low yield scenario and the worst case scenario, compared to the grass strip system that had a $995 USD/ha reduction in net present value. The best case scenario simulated a scenario with high yields and low labor inputs. In this case, the labor had a larger impact on the grass strip system compared to the monocrop system, as shown by the $1,426 USD/ha increase in the net present value for the monocrop system between the high yield scenario and the best case scenario, compared to the $1,629 USD/ha increase for the grass strip system. In all economic performance scenarios, the returns to family labor were lower than the average daily wage for on-farm employment in the region, $6.19 USD/PD, suggesting that both cassava systems have a high opportunity cost, as these systems do not provide sufficient income to compete with employment on another farm.

2.5 Discussion

2.5.1 Impact of cassava production system on soil erosion

Soil erosion is an issue in this region due to the steep slopes, clay sandy loam soils, and lack of sufficient ground cover during the rainy season (Andersson, 2002). Cassava is planted in January or February and does not supply sufficient ground cover until August when the canopy becomes robust and the cassava leaves begin to fall providing soil surface coverage. The rainy season begins in April, leading to daily major rain events that can easily break down soil aggregates and carry those particles down the slopes. The process of erosion typically removes the topsoil, which is full of organic matter and nutrients applied via compost, chemical fertilizers, and accumulation of plant residues. This nutrient rich topsoil includes organic nitrogen, phosphorus, sulfur, microorganisms and organic matter that all contribute to the cation exchange capacity and ability for plants to uptake nutrients (Kuhn, 2007; Montgomery, 2007). Increased soil erosion in these regions, leads to soil nutrient loss and over time will leave the soils depleted. The annual loss of nutrients to soil erosion is problematic in this region due to the highly weathered and acidic soils (Table 2), which results in low availability of nutrients. Soil erosion and leaching of base cations due to high rainfall will continue to acidify these soils, making the annually applied nutrients less available for cassava uptake.

The monocrop system showed significantly greater soil erosion as indicated by the P erosion index compared to 10 – 12 year grass strip system; however no significant difference was observed compared to the 5 – 7 year grass strip system (Table 3). The monocrop system had a P erosion index of -4.01 mg P_2O_5/100 g soil, suggesting that soil erosion occurred. The grass strip system in production for 5 – 7 years had a mean phosphorus difference of -0.03 mg P_2O_5/100 g soil, indicating no occurrence of soil erosion. The grass strip production for 10 – 12 years has a mean phosphorus difference of 1.48 mg P_2O_5/100 g soil, which suggests there was slight accumulation of phosphorus on the top of the slope.

Phosphorus in the soil is in the form of phosphates and these can react with other cations, such as aluminum, iron, and calcium depending on the soil pH. These associations with divalent or trivalent cations lead to immobilization of phosphorus in the soil, thus, phosphorus can be used as a proxy to estimate soil erosion (Cox and Hendricks, 2000). The binding properties of phosphorus and the differences in the phosphorus levels at the two slope positions allow us to infer that the plots with monocrop cassava production showed higher sediment runoff compared to the plots in grass strip cassava production. Planting grass strips across the plot creates a barrier preventing soil erosion in the period between the start of the rainy season and the cassava canopy growth (Valentin et al., 2008). Our results are consistent with those found in studies measuring soil erosion via catchment plots in sloped regions of Northern Vietnam (Phan Ha et al., 2012; Valentin et al., 2008), that show a decrease in soil erosion with grass strip barriers perpendicular to the slope. Our phosphorus erosion index method for estimating soil erosion has limitations. Phosphorus can be leached and can runoff in solution. However, the fate of phosphorus relies heavily on soil texture. Phosphorus strongly adsorbs to clay soil particles and due to the high clay content of our soils, 32%, we can assume that most of the phosphorus is sediment bound (Cox and Hendricks, 2000). In addition, we only have one year of soils data. This prevents the understanding of plot level changes in soil parameters through time. This data could be used as baseline data to track soil erosion and changes in soil through time in future research.

Similar studies on sloped cassava fields in Colombia on sandy clay loams showed an annual loss of dry soil of 5.2 tons per hectare in the monocrop cassava system compared to 2.7 tons per hectare in the cassava with grass hedgerow system with a greater loss of phosphorus by1.06 kg/ha in the monocrop system (Ruppenthal et al., 1997). This high loss of soil leads to unproductive soils. In the resource-poor regions of Văn Yên, growers do not have access to lime or other alkalization methods and cannot increase their fertilization rates due to the high cost. The loss of nutrient rich top soil in the traditional monocrop system requires the annual application of compost, manure, and chemical fertilizers to keep up with nutrient loss and maintain yields.

2.5.2 System impacts on cassava yields

The yields for the monocrop cassava system and both grass strip production systems were not significantly different for the reported 2015 yields, suggesting, there was no yield penalty associated with the grass strip system (Table 4). Although we saw no significant difference in yields, lower yields in monocrop systems than intercropped systems have been observed in previous studies on grass hedgerows in sloped cassava systems (Howeler, 2014; Howeler and Aye, 2014). Studies in Northern and Southern Vietnam on sloped cassava fields, found higher yields in systems with grass hedgerows. In Southern Vietnam, the grass hedgerow system resulted in a higher yield of 4.42 ton/ha in the 16th consecutive cropping system compared to a monocrop system. In Northern Vietnam, the grass hedgerow system resulted in a higher yield than the monocrop system by 4.54 tons/ha in a study conducted in the 3rd year of the cropping system (Howeler, 2014). Preventing annual soil erosion and loss of nutrients provide a more productive environment for cassava to reach maximum yield potential. Our 1 year of yield data limits our understanding on the long-term on-farm yield benefits; however, our data indicates that there is no yield penalty associated with taking land out of cassava production to grow grass hedgerows.

Another benefit of the grass strip system is the additional output of the *Paspalum atratum*, thus creating a diversified cropping system. All growers who implemented the grass strip system had at least one cow or buffalo. The grass strips provided feed for the livestock and allowed the grower to reallocate time initially required to manage grazing to other activities. Growers cultivated the *Paspalum atratum* for a cut and carry system, feeding the livestock through the grass harvest and supplementing with grazing through the village. On average, annual *Paspalum atratum* yields for one hectare in production were 5,767 kg wet yield and 1,153 kg dry yield in the 5 – 7 year system, and 3,590 kg wet yield and 718 kg dry yield in the 10 – 12 year system (dry yields reported at 12% moisture content). The mean grass yields reported in our surveys are lower than *Paspalum atratum* yields in Southeast Asia (1,698 kg dry yield) in controlled research studies (D Hare et al., 2009). These differences in yields may be due participant yield estimation in our surveys, the growers not replanting the grass due to cost of seed or labor investment, and the lack of fertilization on the grass strips.

2.5.3 System impact on economic performance

LUS models were used analyze the two cassava systems to provide an understanding of economic implications of adoption from the perspective of the smallholder farmer at the plot level (Kragten et al., 2001). The LUS model, in our study was used to address the question: if a smallholder grower has 1 hectare of sloped land dedicated to cassava and needs to decide to monocrop or to intercrop, which system will give the highest economic returns? To effectively compare the two cassava systems, the net present value, average annual returns to land, and returns to family labor are calculated for each system. The net present value provides the present value of the implemented system with the future benefits discounted to determine if the system will be profitable (Goodall, 1987). The average annual returns to land provides the annual return of investment on one hectare of production. The returns to family labor calculates the economic benefits per person day spent throughout the system lifecycle. To compare these systems, multiple scenarios were created to determine if these systems perform differently.

In the mean yield scenario, the monocrop system economically performed better than the grass strip production system over the 12 years in production, however, in the low yield and high yield scenarios, the grass strip production system performed better than the monocrop system (Table 5). As expected, due to the lack of significant differences between the yields and labor requirements for the two systems, there was also no significant difference between the net present value of the two systems. In both the best case and worst case scenarios, the net present values for the grass strip production were higher than the monocrop system. This suggests that the grass strip system may be more resilient to a low cassava yield due to the production of the grass strips that can either provide food for the household ruminant or be sold to another household for extra income. Our results indicate that the grass strip system does not require additional labor (Table 4), additional fertilizer inputs (Table 3), or high initial start-up costs, illustrating that there are minimal barriers to entry for smallholder cassava growers. In addition, because we found no difference in the long-term economic performance between the two systems and found agronomic benefits of soil and nutrient retention in the grass strip system, we conclude the grass strip system performed better than the monocrop system overall.

2.5.4 Adoption and system implications

During the initial intervention, the three communes in this study, Mậu Đông, Đông Cuông, and An Bình were provided with *Paspalum atratum* seeds by the Vietnam Ministry of Agriculture to growers willing to adopt the practice. In some cases, extension representatives from the government planted the grass strips for the growers to reduce barriers to adoption. During the time of grass strip establishment, growers were hesitant to reallocate cassava land to grass that has very little market value dissuading growers from adopting. Those growers continuing with monocrop systems gave several reasons for not adopting the grass strips, including: i) not having a need for the grass as forage due to the lack of ruminants, ii) being unwilling to take land out of cassava production which is their only source of income, and iii) the perception of high labor requirements for maintenance of the grass strips. Out of the interviewed growers currently practicing the monocrop system, only two were early adopters who returned to monocrop production. One grower sold their ruminant and had no need for the strips, and the other grower reported that the grass strips died one hot summer and never replaced them due to the lack of seed. Commonly with soil conservation strategies, the initial investment can require increased inputs or monetary investment, and the benefits are not immediate; therefore, adoption rates tend to be low (Bui Dung, 2003).

Based on our research, there are several policy initiatives to be considered to promote this intervention. Just as occurred during the initial interventions, the Ministry of Agriculture can subsidize the implementation of the grass strip cassava production system by providing *Paspalum atratum* seeds, labor for planting, and technical support to those growers willing to adopt. In addition, providing details on the economic returns over time can show growers that taking approximately 20% of land out of cassava production will be beneficial in the long-term decrease in soil erosion and increase in soil nutrient retention and have no penalty on cassava yields (Howeler and Aye, 2014). The input subsidy needs to incorporate an educational component aimed at teaching growers the negative impacts of soil erosion and nutrient loss. This intervention can limit barriers to adoption of the intercrop system.

Growers without a ruminant and growers who have opted to remain in a monocrop system may still not adopt. Providing alternative crops for hedgerows other than *Paspalum atratum*, can increase adoption rates in the region. Tephrosia and peanut crops have been studied in cassava systems to reduce soil erosion and fix atmospheric nitrogen in the soil (Howeler, 2014). Tephrosia is a perennial tree crop that fixes nitrogen and the leaves can be harvested to incorporate into the soil to increase organic matter (Howeler, 2014; Munthali et al., 2015). Tephrosia leaves could be used as an animal feed, provide nitrogen for the surrounding cassava crop, and be grown for seed to sell to other growers in the region. Peanut can be intercropped with cassava in the region. Peanut is not as effective as grass strip hedgerows in minimizing soil erosion, 37.79 tons per hectare soil loss in monocrop, 29.46 tons per hectare soil loss in a peanut intercrop system, and 12.25 tons per hectare soil loss in a grass strip system; however, peanut provides soil coverage, fixes nitrogen in the soil, and can be sold as a cash crop (Howeler, 2014). These alternative intercrops provide growers with options to minimize soil erosion, increase nutrient retention, and improve cassava yields.

2.6 Conclusion

Addressing soil erosion in the sloped regions of Vietnam is crucial for long term agricultural sustainability. This research shows that planting *Paspalum atratum* grass strips along man made contour lines in cassava field provides soil surface coverage and a barrier to prevent soil erosion. The ability to retain topsoil, nutrients, and organic matter in these low input systems can prevent major declines in cassava yields and may lead to yield improvements over time. In addition to the biophysical benefits, we found no yield penalty associated with reallocating approximately 20% of land from cassava production to grass strip production, thus, overall farm productivity does not decrease. Based on the long-term economic performance analysis, our findings demonstrate that the initial investment in the *Paspalum atratum* grass strip production is worthwhile both biophysically and economically.

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Appendix 1: Household Survey

FARM HOUSHOLD SURVEY: COSTS AND BENEFITS OF CLIMATE SMART AGRICULTURE PRACTICES, VĂN YÊN DISTRICT

Researcher Name: Leah Puro
Interpreter Name: Lệ Quyên Bùi

I. General information

1.1. Name of respondent	
1.2. Age	
1.3. Sex	
1.4. Household head	1. Yes 2. No
1.5. Occupation	
1.6. Phone number	
Commune	

Household composition

Number of household members**:**

Position in Household	Age	Gender	on farm activities	Off farm activities	Off-farm income '000 VND/year	Education (years)	Farming experience (years)	notes

II. Land uses

2.1. Total area of agriculture and forestry land (ha)?..

2.2. Total cultivated area in 2015?

Crop	Area (ha)	Ownership	Water source	Distance from home to land	Soil quality (color)	Land slope

2.3. Cropping system

Crop	Area/ha	Cultivation method (1. Cassava Monocrop; 2. Cassava/grass strips 5-7 yrs; 3. Cassava/grass strips 12-14 yrs)	Season	Yield (kg)	Total output (Kg)/year	Total sold (kg)	Price (‘000 VND)

2.4. Annual crop yield

Plot	Crop	Season	Yield				
			Current	2015	2014	2013	2012
		Cause					
		Cause					

III. Cost and benefit of crops and livestock

3.1 Annual crops

Costs					
Seedling					
Crop	Name of crop				
Seed Type	Name of seed 1				
Seed Quantity	Kg				
Did you save the seedling from previous season?	1.yes 2.no				
Purchased seed quantity	Kg				
Seed Price	‘000 VND/kg				
Fertilizer					

1. NPK	-Volume	Kg				
	-Price	'000 VND/kg				
	-When did you pay?	Immediately=1 After buying=2				
2. Urea	-Volume	Kg				
	-Price	'000 VND/kg				
	-When did you pay?	Immediately=1 After buying=2				
3. ***Potassium (kali)***	-Volume	Kg				
	-Price	'000 VND/kg				
	-When did you pay?	Immediately=1 After buying=2				
4. Phosphate	-Volume	Kg				
	-Price	'000 VND/kg				
	-When did you pay?	Immediately=1 After buying=2				
5.Organic fertilizer	-Volume	Kg				
	- % bought					
	- % home-made					
	- Price					
Herbicide Quantity Applied		kg				
Herbicide cost		'000 VND				
Pesticide Quantity Applied		Kg				
Pesticide cost		'000 VND				
Year Purchased Sprayer		Year				
Cost of Sprayer		('000 VND)				

3.2 Labor

			Month				
Land Preparation	Household labor	Man-day					

	Hired Labor	Man-day						
Planting	Household labor	Man-day						
	Hired Labor							
Weeding	Household labor	Man-day						
	Hired labor							
Fertilizer Application	Household labor	Man-day						
	Hired labor							
Herbicide Application	Household labor	Man-day						
	Hired labor							
Pesticide application	Household labor	Man-day						
	Hired labor							
Harvesting	Household labor	Man-day						
	Hired labor							
Processing	Household Labor	Man-Day						
	Hired labor							
Marketing	Household labor	Man-day						
	Hired labor							
Input Collection	Household Labor	Man-day						
	Hired Labor							

3.3 Annual Production Costs

Crop					
Cost of hired labor	‘000 VND/man-day				
Type of Hired Machinery/ equipment					
Total cost for hired machinery/equipment	‘000 VND				
Type of Purchased Machinery					
Year Purchased	Year				

Cost of Purchased Machinery	‘000 VND				
Annual Maintenance Costs	‘000 VND				
Cost of rented land	‘000 VND/season				
Total cost for transport of crops grown?	‘000 VND				
Did you get a loan?	Yes or no				
Amount of interest on the loan	‘000 VND				

3.4 Annual Production By- Products

Crop					
By Product	Name				
Quantity harvested	Unit				
Quantity used for home consumption	Unit				
Quantity by product sold	Unit				
Selling price of by product	(‘000 VND/unit)				
Total Revenue from by product	(‘000 VND)				

3.5 Perennial crops

Information	**Unit**			
Establishment period (within the first three years)				
Seedling				
Date Planted	year			
Number of trees	Number			
Cost of seedlings	‘000 VND			
Price of harvest	‘000 VND/kg			
Lifespan of tree	years			
Fertilizer				
Type 1 of fertilizer	name			
+ Volume	l			
+ Price	‘000 VND/kg			

Type 2 of fertilizer	name			
+ Volume	l			
+ Price	‘000 VND/kg			
Herbicide amount				
Herbicide cost	‘000 VND/			
Pesticide amount				
Pesticide cost	‘000 VND/			
Cost of sprayer for herbicide	‘000 VND			
Labor				
-Land Preparation Household	Man-day			
+ Land Preparation Hired	Man-day			
+ Planting household	Man-day			
+ Planting hired	Man-day			
+ Weeding household	Man-day			
+ Weeding hired	Man-day			
+ Others household	Man-day			
+ Others Hired	Man-day			
Cost of Hired labor	‘000 VND/man-day			
Other establishment costs	‘000 VND			
Operating cost (since 4^{th} year)				
How often do you maintain (weeding, fertilizer application, pruning…)	Time/year			
Household labor	Man-day			
Hired Labor	Man-day			
Cost of hired labor	‘000 VND			
Other maintenance costs	‘000 VND			
Harvesting				
Household Labor	Man-day			
Hired Labor	Man-day			
Cost of hired labor	‘000VND/man-day			

Income from main products		'000 VND/kg			
Month/year income earned					
1. Firewood	Total harvested quantity	kg			
	Quantity sold	Kg			
	Average selling price	'000VND/kg			
Fire wood Purchase	Type				
	Total purchased quantity	kg			
	Cost	'000 VND/kg			

3.6 Livestock

	Livestock 1:		Livestock 2:		Livestock 3:	
Total number						
Main products						
By-products						
Purpose of use (1. Home consumption; 2. Sale)						
Amount Main Products sold						
Price main products ('000 VND)						
Amount By-Products sold						
Price by-products ('000 VND)						
1. Purchase						
Year						
Amount						
Price						

2. Forages						
Amount (kg)						
- Produced on Farm (kg)						
Total value (‘000VND/kg)						
Cost of production (‘000 VND)						
- Forage purchased (kg)						
Price (‘000 VND/kg)						
3. Veterinary						
Times/year						
Price						
4. Electricity & fuel cost						
5. Labor						
Household labor (man-day)						
Hired labor(man-day)						
Cost hired labor (‘000 VND/man-day)						
6. Infrastructure for livestock						
Cost of infrastructure (‘000 VND)						
Household Labor						
Hired Labor						
Cost hired labor (‘000 VND/man-day)						
7. Other cost						

General Cultivation Method

Cultivation method (1. Monocropping; 2. Grass/cassava 5-7 years 3. Grass/cassava 12-14 years

Date Started cultivation method:

Why did you choose this method?

What are the biggest challenges with your cultivation method now?

Notice any soil erosion?

Notice any differences in soil from year to year?

Appendix 2: Land Use System Models

Appendix 2.1: Mean Yield Land Use System Model for Monocrop

Context and Assumptions for LUS Analysis of the Monocrop System

Conversions	Item	Value	Units	Notes
	VND to USD	0.000045		*for August 2016

Policy Setting	Item	Value	Units	Notes
	Discount Rate	0.1		Based on loan interest rates

Agroecosystem Setting	Item	Value	Units	Notes
	Plot Size	1	ha	
	Cropping System	Cassava		
	Production management	Monocrop		

Production System	Item	Value	Units	Notes
	Land Quality			
	Spatial scale of LUS operations	1	ha	
	Timeframe of LUS operation	12	years	
	Casava Spacing	1	meter	
	Seedlings/ha	10,000	stalks	
	Number of grass strips	0	num	
	Amount of land in grass strips	0	%	

Variety & Expected yield	Item	Value	Units	Notes
	Cassava Yield	22855	kg/ha	Year 12 yields based on data collected in 2016, 2015 yields
	Cassava Yield	23491	kg/ha	Year 11 yields based on data collected in 2016, 2014 yields
	Cassava Yield	24226	kg/ha	Year 10 yields based on data collected in 2016, 2013 yields
	Cassava Yield	24306	kg/ha	Year 9 yields based on data collected in 2016, 2012 yields
	Cassava Yield	24306	kg/ha	Year 1-8 yields based on data collected in 2016, 2012 yields

Socioeconomic Context	Item	Value	Units	Notes
	Land Tenure		Owned	
	Market access		Yes	* all cassava is sold to the factory in Van Yen District
	Technology availability		Low	* all planting, weeding, harvesting done manually with the help of buffalo
	Contracts		No	

Labor Price (2016)	Item	Value	Units	Notes
	Houshold Labor (opp cost)	6.19	PD/ha	*initial labor price/PD is based on HH_surveys, linear regression to data from

Inputs (2016)	Item	Value	Units	Notes
	Cassava Stalks	10,000	stalk	* all inputs are averages from 2016 data collection
	NPK Fertilizer	948	kg	*average from hh survey
	Urea	9	kg	*average from hh_surveys
	Farmyard Manure	1248	kg	*average of all households in monocrop system that apply manure

Input Prices 2016 (USD/kg)	Item	Value	Units	Notes
	Cassava Stalks	0.0027	USD/stalk	* this price is based on the full stalk cut into 5 pieces before being planted
	NPK Fertilizer	0.45	USD/kg	*this is the NPK price in central highlands, non subsidized from HH surveys in 2016
	NPK Fettilizer	0.19	USD/kg	*this price is for subsidized NPK, the gov't provides assistance for cassava growers
	Urea	0.4	USD/kg	
	Farmyard Manure	0.019	USD/kg	

Output Price (USD/kg)	Item	Value	Units	Notes
	Cassava Root (fresh)	0.05	USD/kg	*based on price in 2016 and FAO historical prices
	Cassava Stalks	0.0135	USD/stalk	
	Grass (paspalum)	0	USD/kg	

Start-up Inputs	Item	Value	Units	Notes
	Shovel	12.89	unit	*based on surveys, all in 2016 prices converted from VND to USD
	Wheelbarrow	28.37	unit	
	Sprayer	51.6	unit	
	Cart	10.31	unit	
	Motorbike	515.98	unit	
	Tarps	0.5	unit	

Monocrop: Cassava

Inputs/Outputs (I/O), by Year

	Units	Year 1	2	3	4	5	6	7	8	9	10	11	12	
LUS Inputs														
Labor														
Land Preparation														
Shrub and tree removal/Seed bed prep														
Unskilled Labor - family	manday/ha	184	0	0	0	0	0	0	0	0	0	0	0	184
Bed Preparation														
Unskilled Labor - family	manday/ha	25	25	25	25	25	25	25	25	25	25	25	25	300
Planting (Cassava)														
Planting/sowing														
Unskilled labor - family	manday/ha	27	27	27	27	27	27	27	27	27	27	27	27	324
Cassava Management														
Input Transport														
Unskilled labor - family	manday/ha	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6
Weeding														
Unskilled labor - family	manday/ha	53	53	53	53	53	53	53	53	53	53	53	53	636
Fertilizer/Manure application														
Unskilled labor - family	manday/ha	4.0	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4	50
Manure application														
Unskilled labor - family	manday/ha	1	1	1	1	1	1	1	1	1	1	1	1	12
Other application (herbicide, insecticide)														
Unskilled labor - family	manday/ha	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	2
Harvest (Cassava)														
Unskilled labor - family	manday/ha	42	42	42	42	42	42	42	42	42	42	42	42	504
Marketing														
Unskilled labor - family	manday/ha	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2
Farm Management														
Unskilled labor - family	manday/ha													0
Livestock														
Grazing														
Unskilled labor - family	manday/ha	200	200	200	200	200	200	200	200	200	200	200	200	2400
Other maintenance														
Unskilled labor - family	manday/ha													0
Start-up Inputs														
Shovel	units	2	0	0	0	2	0	0	0	0	2	0	0	
Wheelbarrow	units	1	0	0	0	0	0	0	0	0	1	0	0	
Sprayer	units	1	0	0	0	0	0	0	0	0	0	0	0	
Cart	units	1	0	0	0	0	0	0	0	0	1	0	0	
Motorbike	units	1	0	0	0	0	0	0	0	0	0	0	0	
Tarps	units	2	0	0	0	2	0	0	0	0	2	0	0	
Annual Inputs														
Cassava Stalks	num/ha	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	120000
NPK Fertilizer	kg/ha	948	948	948	948	948	948	948	948	948	948	948	948	11376
Urea	kg/ha	9	9	9	9	9	9	9	9	9	9	9	9	108
Farmyard manure	kg/ha	1248	1248	1248	1248	1248	1248	1248	1248	1248	1248	1248	1248	14976
LUS Outputs														
Cassava	kg/ha	24306	24306	24306	24306	24306	24306	24306	24306	24306	24226	23491	22855	289326
Stalks	kg/ha	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	120000
Total Labor														
Total Unskilled Labor - Family	manday/ha	537	353	353	353	353	353	353	353	353	353	353	353	4421
Total Labor	manday/ha	537	353	353	353	353	353	353	353	353	353	353	353	4421

Monocrop Cassava

Inputs/Output Prices

	Units	Year 1	2	3	4	5	6	7	8	9	10	11	12
LUS Inputs													
Labor													
Land Preparation													
Shrub and tree removal/Seed bed prep													
Unskilled Labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Bed Preparation													
Unskilled Labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Planting (Cassava)													
Planting/sowing													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Cassava Management													
Input Transport													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Weeding													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Fertilizer application													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Manure application													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Other application (herbicide, insecticide)													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Harvest (Cassava)													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Marketing													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Farm Management													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Livestock													
Grazing													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Other maintenance													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Start-up Inputs													
Shovel	USD/unit	5.16	5.54	6.00	7.39	7.05	8.62	10.23	11.16	11.89	12.38	12.48	12.89
Wheelbarrow	USD/unit	11.36	12.20	13.22	16.27	15.52	18.96	22.50	24.55	26.17	27.24	27.48	28.37
Sprayer	USD/unit	20.67	22.20	24.04	29.59	28.23	34.49	40.93	44.65	47.60	49.54	49.98	51.60
Cart	USD/unit	4.13	4.43	4.80	5.91	5.64	6.89	8.18	8.92	9.51	9.90	9.99	10.31
Motorbike	USD/unit	206.68	221.94	240.37	295.94	282.33	344.89	409.31	446.53	475.97	495.41	499.77	515.98
Tarps	USD/unit	0.20	0.22	0.23	0.29	0.27	0.33	0.40	0.43	0.46	0.48	0.48	0.50
Annual Inputs													
Cassava Stalks	usd/stalk	0.0011	0.0012	0.0013	0.0015	0.0015	0.0018	0.0021	0.0023	0.0025	0.0026	0.0026	0.0027
NPK Fertilizer	usd/kg	0.21	0.21	0.27	0.40	0.23	0.25	0.35	0.34	0.30	0.28	0.25	0.19
Urea	usd/kg	0.43	0.44	0.57	0.85	0.48	0.54	0.74	0.71	0.62	0.59	0.51	0.40
Farmyard manure/org fert	usd/kg	0.008	0.008	0.009	0.011	0.010	0.013	0.015	0.016	0.017	0.018	0.018	0.019
LUS Outputs													
Cassava	usd/kg	0.07	0.06	0.07	0.14	0.09	0.11	0.12	0.12	0.13	0.14	0.13	0.05
Stalks	usd/kg	0.0009	0.0009	0.0010	0.0011	0.0012	0.0013	0.0015	0.0015	0.0018	0.0021	0.0023	0.0027

Monocrop Cassava

Inputs/Output Prices

	Units	Year 1	2	3	4	5	6	7	8	9	10	11	12
LUS Inputs													
Labor													
Land Preparation													
Shrub and tree removal/Seed bed prep													
Unskilled Labor - family	USD/year	162.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bed Preparation													
Unskilled Labor - family	USD/year	22.11	34.17	46.22	58.28	70.33	82.39	94.44	106.50	118.55	130.61	142.66	154.72
Planting (Cassava)													
Planting/sowing													
Unskilled labor - family	USD/year	23.88	36.90	49.92	62.94	75.96	88.98	102.00	115.02	128.04	141.06	154.08	167.10
Cassava Management													
Input Transport													
Unskilled labor - family	USD/year	0.44	0.68	0.92	1.17	1.41	1.65	1.89	2.13	2.37	2.61	2.85	3.09
Weeding													
Unskilled labor - family	USD/year	46.88	72.43	97.99	123.55	149.10	174.66	200.22	225.77	251.33	276.89	302.44	328.00
Fertilizer application													
Unskilled labor - family	USD/year	3.54	5.74	7.77	9.79	11.82	13.84	15.87	17.89	19.92	21.94	23.97	24.75
Manure application													
Unskilled labor - family	USD/year	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Other application (herbicide, insecticide)													
Unskilled labor - family	USD/year	0.18	0.27	0.37	0.47	0.56	0.66	0.76	0.85	0.95	1.04	1.14	1.24
Harvest (Cassava)													
Unskilled labor - family	USD/year	37.15	57.40	77.65	97.90	118.16	138.41	158.66	178.92	199.17	219.42	239.67	259.93
Marketing													
Unskilled labor - family	USD/year	0.18	0.27	0.37	0.47	0.56	0.66	0.76	0.85	0.95	1.04	1.14	1.24
Farm Management													
Unskilled labor - family	USD/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Livestock													
Grazing													
Unskilled labor - family	USD/year	176.89	273.33	369.77	466.21	562.65	659.10	755.54	851.98	948.42	1044.86	1141.30	1237.74
Other maintenance													
Unskilled labor - family	USD/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Start-up Inputs													
Shovel	USD	10.33	0.00	0.00	0.00	14.11	0.00	0.00	0.00	0.00	24.75	0.00	0.00
Wheelbarrow	USD	11.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.24	0.00	0.00
Sprayer	USD	20.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cart	USD	4.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.90	0.00	0.00
Motorbike	USD	206.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tarps	USD	0.40	0.00	0.00	0.00	0.55	0.00	0.00	0.00	0.00	0.96	0.00	0.00
Annual Inputs													
Cassava Stalks	USD	10.82	11.61	12.58	15.49	14.77	18.05	21.42	23.37	24.91	25.92	26.15	27.00
NPK Fertilizer	USD	199.08	199.08	255.96	379.20	218.04	237.00	331.80	322.32	284.40	265.44	237.00	180.12
Urea	USD	3.87	3.96	5.13	7.65	4.32	4.86	6.66	6.39	5.58	5.31	4.59	3.60
Farmyard manure/org fert	USD	9.36	10.06	10.89	13.41	12.79	15.63	18.54	20.23	21.56	22.45	22.64	23.38
LUS Outputs													
Cassava	USD	1701.42	1458.36	1701.42	3402.84	2187.54	2673.66	2916.72	2916.72	3159.78	3391.64	3053.83	1142.75
Stalks	USD	8.98	9.27	9.99	10.82	11.61	12.58	15.49	14.77	18.05	21.42	23.37	27.00
Total Annual Costs	USD	952	707	937	1,239	1,258	1,439	1,712	1,876	2,011	2,227	2,305	2,418
Total Annual Revenues	USD	1,710	1,468	1,711	3,414	2,199	2,686	2,932	2,931	3,178	3,413	3,077	1,170
Annual Net Income	USD	759	760	774	2,175	941	1,247	1,220	1,055	1,167	1,186	772	-1,248
Annual Discounted Net Benefits (10%	USD	759	691	640	1,634	643	774	689	541	544	503	298	-438
Economic Indicators (USD)													
Net Present Value of LUS (1.0 ha)	USD/Total LUS /	7,278											
Returns to Land	USD/ha	7,278											
Average Annual Returns to Land	USD/ha/yr	606.54											
Returns to Family Labor	USD/manday	2											
ıs to Family Labor/Market Wage Rate	USD	0.47											

Appendix 2.2 Mean Yield Land Use System for the Grass Strip cropping system

Context and Assumptions for LUS Analysis of the Monocrop System

Conversions	Item	Value	Units	Notes
	VND to USD	0.000045		*for August 2016

Policy Setting	Item	Value	Units	Notes
	Discount Rate	0.1		Based on loan interest rates

Agroecosystem Setting	Item	Value	Units	Notes
	Plot Size	1	ha	
	Cropping System	Cassava		
	Production management	Grass Strip		

Production System	Item	Value	Units	Notes
	Spatial scale of LUS operations	1	ha	
	Timeframe of LUS operation	12	years	
	Casava Spacing	1	meter	
	Seedlings/ha	8,000	stalks	
	Number of grass strips	3	num	
	Amount of land in grass strips	20	%	

Variety & Expected yield	Item	Value	Units	Notes
	Cassava Yield	17410	kg/ha	Year 12 yields based on data collected in 2016, 2015 yields
	Cassava Yield	19544	kg/ha	Year 11 yields based on data collected in 2016, 2014 yields
	Cassava Yield	19844	kg/ha	Year 10 yields based on data collected in 2016, 2013 yields
	Cassava Yield	20211	kg/ha	Year 9 yields based on data collected in 2016, 2012 yields
	Cassava Yield	20211	kg/ha	Year 1-8 yields based on data collected in 2016, 2012 yields - in the 10-12 system
	Grass (*paspalum*) Yield	927	kg/ha	Based on averages from HH_surveys, assumes a 60% moisture content, reported at 12% mo
	Grass (*paspalum*) Yield	1698	kg/ha	Based on literature: tropical grasslands paper 2009
	Cassava Stalks	8000	num	*based on the amount planting

Socioeconomic Context	Item	Value	Units	Notes
	Land Tenure		Owned	
	Market access		Yes	* all cassava is sold to the factory in Van Yen District
	Technology availability		Low	* all planting, weeding, harvesting done manually with the help of buffalo
	Contracts		No	

Labor Price (2016)	Item	Value	Units	Notes
	Houshold Labor (opp cost)	6.19	PD/ha	*initial labor price/PD is based on HH_surveys, linear regression to data from

Inputs (2016)	Item	Value	Units	Notes
	Cassava Stalks	8,000	stalk	* all inputs are averages from 2016 data collection
	NPK Fertilizer	788	kg	*average from hh survey
	Urea	0	kg	*average from hh_surveys
	Farmyard Manure	3031	kg	*average of all households in combined grass strip system due to very high variation
	Paspalum Seed	0.5	kg	*HH surveys

Input Prices 2016 (USD/k	Item	Value	Units	Notes
	Cassava Stalks	0.0027	USD/stalk	* this price is based on the full stalk cut into 5 pieces before being planted
	NPK Fettilizer	0.19	USD/kg	*this price is for subsidized NPK, the gov't provides assistance for cassava growers
	Urea	0.4	USD/kg	
	Farmyard Manure	0.019	USD/kg	
	Paspalum Seed	8.32	USD/kg	*HH_survey

Output Price (USD/kg)	Item	Value	Units	Notes
	Cassava Root (fresh)	0.05	USD/kg	*based on price in 2016 and FAO historical prices
	Cassava Stalks	0.0135	USD/stalk	
	Grass (paspalum)	0.32	USD/kg	*based on dry maize prices, substitute for feed and has similar crude protein/dry weight ratio

Start-up Inputs	Item	Value	Units	Notes
	Shovel	12.89	unit	*based on surveys, all in 2016 prices converted from VND to USD
	Wheelbarrow	28.37	unit	
	Sprayer	51.6	unit	
	Cart	10.31	unit	
	Motorbike	515.98	unit	
	Tarps	0.5	unit	

Monocrop: Cassava

Inputs/Outputs (I/O), by Year

	Units	Year 1	2	3	4	5	6	7	8	9	10	11	12	Total
LUS Inputs														
Labor														
Land Preparation														
Shrub and tree removal/Seed bed prep														
Unskilled Labor - family	manday/ha	184	0	0	0	0	0	0	0	0	0	0	0	184
Bed Preparation														
Unskilled Labor - family	manday/ha	32	32	32	32	32	32	32	32	32	32	32	32	384
Planting (Cassava)														
Planting/sowing														
Unskilled labor - family	manday/ha	30	30	30	30	30	30	30	30	30	30	30	30	360
Cassava Management														
Input Transport														
Unskilled labor - family	manday/ha	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2
Weeding														
Unskilled labor - family	manday/ha	69	69	69	69	69	69	69	69	69	69	69	69	828
Fertilizer application														
Unskilled labor - family	manday/ha	4	4	4	4	4	4	4	4	4	4	4	4	48
Manure application														
Unskilled labor - family	mandy/ha	1	1	1	1	1	1	1	1	1	1	1	1	12
Other application (herbicide, insecticide)														
Unskilled labor - family	manday/ha	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	4
Harvest (Cassava)														
Unskilled labor - family	manday/ha	46	46	46	46	46	46	46	46	46	46	46	46	552
Grass Strip Management														
Land Preparation														
Unskilled labor - family	manday/ha	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	3
Planting														
Unskilled labor - family	manday/ha	2	0	0	0	2	0	0	0	2	0	0	0	6
Fertilizer/Manure application														
Unskilled labor - family	manday/ha	1	1	1	1	1	1	1	1	1	1	1	1	12
Harvest (Grass)														
Unskilled labor - family	manday/ha	47	47	47	47	47	47	47	47	47	47	47	47	564
Marketing														
Unskilled labor - family	manday/ha	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	7
Farm Management														
Unskilled labor - family	manday/ha													0
Livestock														
Grazing														
Unskilled labor - family	manday/ha	91	91	91	91	91	91	91	91	91	91	91	91	1092
Other maintenance														
Unskilled labor - family	manday/ha													
Start-up Inputs														
Shovel	units	2	0	0	0	2	0	0	0	0	2	0	0	
Wheelbarrow	units	1	0	0	0	0	0	0	0	0	1	0	0	
Sprayer	units	1	0	0	0	0	0	0	0	0	0	0	0	
Cart	units	1	0	0	0	0	0	0	0	0	1	0	0	
Motorbike	units	1	0	0	0	0	0	0	0	0	0	0	0	
Tarps	units	2	0	0	0	2	0	0	0	0	2	0	0	
Annual Inputs														
Cassava Stalks	num/ha	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	96000
NPK Fertilizer	kg/ha	788	788	788	788	788	788	788	788	788	788	788	788	9456
Urea	kg/ha	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	86
Farmyard manure	kg/ha	3031	3031	3031	3031	3031	3031	3031	3031	3031	3031	3031	3031	36372
Paspalum Seed	kg/ha	0.50	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.50	0.00	0.00	0.00	2
LUS Outputs														
Cassava	kg/ha	20211	20211	20211	20211	20211	20211	20211	20211	20211	19844	19544	17410	238697
Stalks	kg/ha	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	96000
Forage	kg/ha	927	927	927	927	927	927	927	927	927	927	927	927	11124
Total Labor														
Total Unskilled Labor - Family	manday/ha	508	321	321	321	324	321	321	321	324	321	321	321	4046
Total Labor	manday/ha	508	321	321	321	324	321	321	321	324	321	321	321	4046

Grass Strip Cassava

Inputs/Output Prices

	Units	Year 1	2	3	4	5	6	7	8	9	10	11	12
LUS Inputs													
Labor													
Land Preparation													
Shrub and tree removal/Seed bed prep													
Unskilled Labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Bed Preparation													
Unskilled Labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Planting (Cassava)													
Planting/sowing													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Cassava Management													
Input Transport													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Weeding													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Fertilizer application													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Manure application													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Other application (herbicide, insecticide)													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Harvest (Cassava)													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Grass Strip Management													
Land Preparation													
Unskilled labor - family	manday/ha	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Planting													
Unskilled labor - family	manday/ha	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Fertilizer/Manure application													
Unskilled labor - family	manday/ha	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Harvest (Grass)													
Unskilled labor - family	manday/ha	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Marketing													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Farm Management													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Livestock													
Grazing													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Other maintenance													
Unskilled labor - family	USD/manday	0.88	1.37	1.85	2.33	2.81	3.30	3.78	4.26	4.74	5.22	5.71	6.19
Start-up Inputs													
Shovel	USD/unit	5.16	5.54	6.00	7.39	7.05	8.62	10.23	11.16	11.89	12.38	12.48	12.89
Wheelbarrow	USD/unit	11.36	12.20	13.22	16.27	15.52	18.96	22.50	24.55	26.17	27.24	27.48	28.37
Sprayer	USD/unit	20.67	22.20	24.04	29.59	28.23	34.49	40.93	44.65	47.60	49.54	49.98	51.60
Cart	USD/unit	4.13	4.43	4.80	5.91	5.64	6.89	8.18	8.92	9.51	9.90	9.99	10.31
Motorbike	USD/unit	206.68	221.94	240.37	295.94	282.33	344.89	409.31	446.53	475.97	495.41	499.77	515.98
Tarps	USD/unit	0.20	0.22	0.23	0.29	0.27	0.33	0.40	0.43	0.46	0.48	0.48	0.50
Annual Inputs													
Cassava Stalks	USD/kg	0.0009	0.0009	0.0009	0.0010	0.0011	0.0012	0.0013	0.0015	0.0015	0.0018	0.0021	0.0027
NPK Fertilizer	USD/kg	0.21	0.21	0.27	0.40	0.23	0.25	0.35	0.34	0.30	0.28	0.25	0.19
Urea	USD/kg	0.43	0.44	0.57	0.85	0.48	0.54	0.74	0.71	0.62	0.59	0.51	0.40
Farmyard manure	USD/kg	0.008	0.008	0.009	0.011	0.010	0.013	0.015	0.016	0.017	0.018	0.018	0.019
Paspalum Seed	USD/kg	3.33	3.58	3.88	4.77	4.55	5.56	6.60	7.20	7.67	7.99	8.06	8.32
LUS Outputs													
Cassava	USD/kg	0.07	0.06	0.07	0.14	0.09	0.11	0.12	0.12	0.13	0.14	0.13	0.05
Stalks	USD/kg	0.0043	0.0045	0.0046	0.0050	0.0054	0.0058	0.0063	0.0077	0.0074	0.0090	0.0107	0.0135
Forage	USD/kg	0.13	0.16	0.14	0.2	0.25	0.24	0.27	0.3	0.32	0.33	0.34	0.32

Grass Strip System: Cassava Van Yen, Vietnam

Economic Performance

	Units	Year 1	2	3	4	5	6	7	8	9	10	11	12
LUS Inputs													
Labor													
Land Preparation													
Shrub and tree removal/Seed bed prep													
Unskilled Labor - family	USD/ha	163	0	0	0	0	0	0	0	0	0	0	0
Bed Preparation													
Unskilled Labor - family	USD/ha	28	44	59	75	90	105	121	136	152	167	183	198
Planting (Cassava)													
Planting/sowing													
Unskilled labor - family	USD/ha	27	41	55	70	84	99	113	128	142	157	171	186
Cassava Management													
Input Transport													
Unskilled labor - family	USD/ha	0	0	0	0	1	1	1	1	1	1	1	1
Weeding													
Unskilled labor - family	USD/ha	61	94	128	161	194	227	261	294	327	360	394	427
Fertilizer application													
Unskilled labor - family	USD/ha	4	5	7	9	11	13	15	17	19	21	23	25
Manure application													
Unskilled labor - family	USD/ha	1	1	2	2	3	3	4	4	5	5	6	6
Other application (herbicide, insecticide)													
Unskilled labor - family	USD/ha	0	0	1	1	1	1	1	1	1	2	2	2
Harvest (Cassava)													
Unskilled labor - family	USD/ha	41	63	85	107	129	152	174	196	218	240	262	285
Grass Strip Management													
Land Preparation													
Unskilled labor - family	USD/ha	1	0	0	0	3	0	0	0	5	0	0	0
Planting													
Unskilled labor - family	USD/ha	2	0	0	0	6	0	0	0	9	0	0	0
Fertilizer/Manure application													
Unskilled labor - family	USD/ha	1	1	2	2	3	3	4	4	5	5	6	6
Harvest (Grass)													
Unskilled labor - family	USD/ha	42	64	87	110	132	155	178	200	223	246	268	291
Marketing													
Unskilled labor - family	USD/ha	1	1	1	1	2	2	2	3	3	3	3	4
Farm Management													
Unskilled labor - family	USD/ha	0	0	0	0	0	0	0	0	0	0	0	0
Livestock		0											
Grazing													
Unskilled labor - family	USD/ha	80	124	168	212	256	300	344	388	432	475	519	563
Other maintenance													
Unskilled labor - family	USD/ha	0	0	0	0	0	0	0	0	0	0	0	0
Start-up Inputs													
Shovel	USD	10	0	0	0	14	0	0	0	0	25	0	0
Wheelbarrow	USD	11	0	0	0	0	0	0	0	0	27	0	0
Sprayer	USD	21	0	0	0	0	0	0	0	0	0	0	0
Cart	USD	4	0	0	0	0	0	0	0	0	10	0	0
Motorbike	USD	207	0	0	0	0	0	0	0	0	0	0	0
Tarps	USD	0	0	0	0	1	0	0	0	0	1	0	0
Annual Inputs													
Cassava Stalks	USD	7	7	7	8	9	9	10	12	12	14	17	22
NPK Fertilizer	USD	165	165	213	315	181	197	276	268	236	221	197	150
Urea	USD	3	3	4	6	3	4	5	5	4	4	4	3
Farmyard manure	USD	23	24	26	33	31	38	45	49	52	55	55	57
Paspalum Seed	USD	2	0	0	0	2	0	0	0	4	0	0	0
LUS Outputs													
Cassava	USD	1415	1213	1415	2830	1819	2223	2425	2425	2627	2778	2541	871
Stalks	USD	35	36	37	40	43	46	50	62	59	72	86	108
Forage	USD	120.51	148.32	129.78	185.4	231.75	222.48	250.29	278.1	296.64	305.91	315.18	296.64
Total Annual Costs	USD	904	640	846	1,113	1,156	1,310	1,553	1,707	1,851	2,039	2,111	2,224
Total Annual Revenues	USD	1,570	1,397	1,582	3,055	2,094	2,492	2,726	2,765	2,983	3,156	2,942	1,275
Annual Net Income	USD	666	756	735	1,942	938	1,183	1,173	1,059	1,133	1,117	831	-949
Annual Discounted Net Benefits (10% DR)	USD	666	688	608	1,459	641	734	662	543	528	474	320	-333
Economic Indicators (USD)													
Net Present Value of LUS (1.0 ha)	USD/Total LUS Area	6,991											
Returns to Land	USD/ha	6,991											
Average Annual Returns to Land	USD/ha/yr	582.56											
Returns to Family Labor	USD/manday	2											
turns to Family Labor/Market Wage Rate	USD	0.49											

Appendix 3: Supplementary Tables

3.1 Soil parameter ANOVA tables for soil parameters with significant differences at the $p \leq 0.05$ level by commune and/or cultivation method.

Source	Degrees of freedom	Sum of Squares	MSE	F	P - value
pH					
Cultivation method	2	0.16	0.08	0.16	0.8
Commune	2	14.8	7.39	15.55	1.92e-06
Interaction*	4	3.04	0.76	1.59	0.18
Residuals	81	38.52	0.48		
Bulk Density g/cm^3					
Cultivation method	2	0.09	0.05	3.19	0.05
Commune	2	0.16	0.08	5.14	0.007
Interaction	4	0.07	0.02	1.21	0.31
Residuals	81	1.23	0.02		
Ca^{+2} meq/100g					
Cultivation method	2	22.89	22.44	0.59	0.56
Commune	2	1185.22	592.61	15.46	2.05e-06
Interaction	4	258.87	64.72	1.68	0.16
Residuals	81	3104.81	38.33		
Mg^{+2} meq/100g					
Cultivation method	2	9.80	4.90	1.14	0.33
Commune	2	122.97	61.49	14.29	4.83e-06
Interaction	4	17.20	4.30	0.99	0.41
Residuals	81	348.50	4.30		
K^+ meq/100g					
Cultivation method	2	0.22	0.11	3.62	0.03
Commune	2	0.51	0.25	8.11	6.14e-04
Interaction	4	0.05	0.01	0.46	0.73
Residuals	81	2.56	0.03		

* Interaction is the cultivation method and commune interaction term in the model.
Results considered significant at the $p \leq 0.05$ level.

3.2 Mean P Erosion Index for each cropping treatment. The group indicates statistical significance at the $p \leq 0.05$ level.

Cultivation Method	P (mg P_2O_5/100g)	Group
Monocrop	-2.01 ± 1.24	a
Grass Strip 5 – 7 years	-0.03 ± 1.15	ab
Grass Strip 10 – 12 years	1.48 ± 1.12	b

3.3 Cassava and forage mean yields with standard error. Means reflect one hectare of the system in production. Results considered significance at the $p \leq 0.05$ level.

Cultivation Method	**Cassava Yield (kg)**	**Forage Yield (kg)**
Monocrop	22125 ± 3310	-
Grass Strip 5 – 7 years	19611 ± 3310	5767 ± 1693
Grass Strip 10 – 12 years	18995 ± 3250	3590 ± 1693
P – value	0.6521	0.1695

3.3 Cassava and forage revenues, in USD for 1 hectare of the system, for 2015 with standard error (a). Revenues reflect the mean yield for each cultivation treatment and the mean cassava price for 2015 based on the household surveys. Results from Welch's t-test considered significance at the $p \leq 0.05$ level for the total revenue comparisons by cultivation treatment (b).

a.

Cultivation Method	Total Revenue	Cassava Revenue	Forage Revenue
Monocrop	1203 ± 180	1203 ± 180	-
Grass Strip 5-7 years	1435 ± 291	1066 ± 180	369 ± 111
Grass Strip 10-12 years	1263 ± 285	1032 ± 177	230 ± 108

b.

Test	Cultivation Method	P - value
1	Monocrop Grass Strip 5-7 years	0.50
2	Monocrop Grass Strip 10-12 years	0.86
3	Grass Strip 5-7 years Grass Strip 10-12 years	0.67