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'Pioneer Farmers': Joint Exploration of Crop Diversity and Agroecosystem Function in Waslala, Nicaragua

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Abbreviations

ADDAC: Association for Diversification and Communal Agricultural Development
ADDS: Agroecosystem Dietary Diversity Score
AFS: Agroforestry Systems
AMFVGW: Association of Mothers from Families who are Victims of War in Waslala
APROMUWAS: Association for the Promotion of Women, Waslala
CATIE: The Tropical Agricultural Research and Higher Education Centre
CGIAR: Consultative Group on International Agricultural Research
CIAT: International Centre for Tropical Agriculture
FAO: Food and Agriculture Organisation of the United Nations
FIS: Food Insecurity Score
FUMAT: Mother Earth Foundation
HDDS: Household Dietary Diversity Score
INTA: Nicaraguan Institute of Agricultural Technology
INTEWAS: Technical Education Institute of Waslala
RTB: Roots, Tubers and Bananas

Abstract

Exploring the role of crop diversity on the functioning of agroecosystems has significant implications for agriculture. ‘Pioneer farmers’, on Nicaragua’s agricultural frontier are adapting their cropping systems to new agroecological conditions including steep slopes, heavy rainfall and market inaccessibility which characterise the region. Farmers report that integration of a greater diversity of crops has regenerated previously degraded land and improved performance of their agroecosystems. Working in partnership with Bioversity International and local NGOs in Waslala, the role of crop diversity on agroecosystem function was explored together with farmers in their fields, using a participatory joint learning approach. Results show that farmers in Waslala are managing highly diverse systems which enable year-around dietary diversity, food security and income stability. Farmers are using agroecological diversification practices which contribute to key agroecosystem functions such as pest and disease suppression, microclimate regulation and reducing soil erosion. Supporting theories from ecology, farmer’s experiences in Waslala suggest a link between agroecosystem diversity, productivity, stability and resilience. Opportunities to further enhance the use of crop diversity to overcome current and future challenges were also explored with farmers and local stakeholder and potential interventions identified. However, it is important to note that these interactions can be difficult to manage at a farm scale and negative interactions must be traded off with benefits. Diversification is not a solution to all problems for all farmers and some are seeking other strategies. Through joint exploration this study has shed new light on the link between crop diversity and agroecosystem function and led to the co-production of new knowledge. Reflection on this process highlights important considerations for future development of more engaged research processes. As farmers in other parts of the world are facing increasing challenges, experiences in Waslala suggest that agroecological diversification could be a viable option to increase productivity, stability and resilience in the face of change.

Pioneer farmer Doña Elba harvesting beans growing in Taiwan (Napier) grass in Caños los Martinez, Waslala

Introduction

Agriculture is at a crossroads. Small-holder farmers are facing increasing challenges including climatic variability (Altieri, 2015; Lin 2011); land degradation and reduced fertility (McIntyre et al, 2009); market shocks (Tucker et al, 2010) and increasing pressure on land (Meyer et al, 1992). Many scholars suggest that climate change will affect both biotic (pest and disease) and abiotic (water availability, temperature, light) factors in agroecosystems which will threaten productivity and stability (Lin, 2011). There is therefore an urgent need to learn how to make agroecosystems more resilient in order to protect farm livelihoods.

Some suggest the use of strategies such as biotechnology, increase of chemical inputs and crop insurance to intensify small-holder agriculture in the face of such challenges (e.g. McGloughin, 1999). However, there are concerns that the tendency for crop specialization and system simplification in these approaches will lead to further production instability and vulnerability (Godfray et al, 2010, Lin, 2011, Soliel-Turmel et al, 2016). As such diverse agroecosystems which host a range of crops with differing traits and functions may be better able to perform under changing environmental and economic conditions (Altieri, 2015; Lin, 2011; Matson et al. 1997; Altieri 1999).

Agricultural biodiversity "encompasses the variety and variability of animals, plants and microorganisms used directly for food and agriculture" (Mijatovic et al, 2013). This consists of both ‘planned’ and ‘associated’ diversity (Vandermeer, 1998). Crop diversity is planned and managed by farmers at various scales; landscape, farm, species and genetic. Agricultural biodiversity and associated local knowledge play an important role in strengthening ‘socio-ecological resilience’ to economic and environmental risks, largely overlooked by researchers (Mijatovic et al, 2013; Altieri et al, 2015).

Resilience may be defined as the ability of an agroecosystem to sustain functioning and productivity when subjected to stresses and shocks (Mijatovic et al, 2013). It is suggested that management of crop diversity enables farmers to adapt to changing market conditions, buffer against extreme weather events and maintain productivity when subjected to stresses and shocks (Lin et al, 2011). Numerous studies in the field of ecology have demonstrated links between species richness and ecosystem services, providing greater system resilience (Tilman et al, 1997; Nystrom et al, 2000). Yet fewer studies have investigated this ‘diversity – function hypothesis’ in agroecosystems, particularly in farmers' fields.

Vandermeer et al (1998) highlighted three points linking diversity, agroecosystem functional capacity and resilience;

1. Different species perform slightly different functions / have different niches
2. There are more species than there are functions (functional redundancy)
3. Those components which are redundant at one time become more important when some environmental change occurs.

Moreover, as per the ‘insurance hypothesis’ (Yachi and Loreau, 1999), diversity provides a buffer against environmental changes as different species and varieties have different levels of tolerance to different stress factors. Thus even if some species are lost following a perturbation, others will survive, allowing adaptation to changing environmental and economic conditions.

Agroecological diversification refers to the integration of a range of crop species / varieties into agroecosystems over different temporal and spatial scales through practices such as intercropping, agroforestry, crop rotations and varietal mixtures (Vandemeer 1992, Altieri and Nicholls 2010, Leibman and Dyck 1993, Kremen et al, 2012). Kremen and Miles (2012) hypothesise that biological diversification across ecological, spatial and temporal scales maintains and regenerates ecosystem functions that provide critical inputs to agriculture. Increasing crop diversity and managing crop composition of an agroecosystem can enhance ‘supporting’ functions such as nutrient cycling and pollination, ‘regulating’ functions such as management of pest and disease and ‘provisioning’ functions such as production of food, fodder and fibre for household consumption or sale (Bommarco et al, 2013). For example, soil can be improved through agroecological diversification practices which build up organic matter, add nutrients and prevent erosion. A healthy soil makes the system more resilient to extreme climatic events (such as heavy rainfall and landslides), soil erosion and also to outbreaks of soil borne pests (Rai et al, 2011). Weed population density and biomass production can be considerably reduced through use of temporal and spatial crop diversification and use of crops with functional traits for weed suppression (Liebman and Dyck 1993). Farmers may also be able to increase and manipulate plant diversity to manage pests by promoting natural enemy abundance, limiting the density of ‘host' crops and including crops which ‘push' and ‘pull' herbivores away from the main crop (Lin, 2011; Altieri, 1999, Khan et al, 2008). Moreover, studies have shown that agroecosystems with greater diversity and structural complexity, suffered less losses and recovered faster from the impact of extreme events such as hurricanes (Holt-Giménez 2002). As such, intentional management of functional diversity has tremendous potential to contribute to sustainable agriculture (Jackson et al, 2007).

Analysis of functional diversity includes the classification of species into groups based on functional traits. Functional traits are those characteristics which underpin both a species' contribution to ecosystem processes and services as well as their tolerance to environmental stressors and disturbances (Diaz et al, 2013). Functional groups may be defined as ‘a set of species that have similar effects on a specific ecosystem-level biochemical process' (Swift et al, 2004).

Previous studies suggest that agroecosystem diversity also plays a role in dietary diversity of small-holder systems, ensuring that families have access to a range of crops from key nutritional functional groups (Remans et al, 2011). Moreover, diverse agroecosystems may include traditional and underutilized species which could help to improve nutrition and food security of farming families (Hunter and Fanzo, 2013). Design of future ‘nutrition sensitive' agroecosystems which incorporate nutrition objectives and ensure dietary diversity could be key to ensuring food security and resilience in an uncertain future.

Traditional multiple cropping systems are estimated to provide 15–20% of the world's food supply (Altieri, 1999). These systems are managed with low external inputs through "a practical application of ecological principles based on biodiversity, plant interactions and other natural regulation mechanisms" (Malezieux et al 2009). In Mesoamerica, smallholder systems with cacao (Theobroma cacao) in association with crops and trees under a shade canopy, date back to pre-Colombian era (Vaast and Somarriba, 2014). Such systems integrate a diverse range of species producing multiple products and services. It is suggested that agroecosystem diversity in these systems enhances resilience to shocks, both biophysical (such as pest and diseases outbreaks; Bentley et al. 2004; Cerda et al. 2014; Duguma et al. 2001) and socio-economic (such as fluctuating cocoa prices in international markets).

Innovative management of agrobiodiversity could offer a means to further intensify production with limited resources, make more efficient use of labour, diversify diets and enhance food security, increase incomes, minimize risk and reduce the incidence of pest and disease problems. This may be considered as a form of Agroecological Intensification or "intensification in the use of the natural functionalities that ecosystems offer" (Chavassus and Griffon, 2008) which "considers the use of biological regulation to manage agroecosystems, at field, farm and landscape scales" (Dore et al, 2011). Such approaches seek to enhance ecological processes and interactions between system components, including social and economic elements.

Whilst the Green Revolution was input intensive, agroecology is knowledge intensive. Seeking to maximize the potential of these diverse, multi-functional systems requires a deep understanding of the processes and interactions which take place within them. As such, farmers' knowledge is ever changing as they continue learning from observations, experiments and exchange with other farmers in the actualization of agroecology. The intersection of such local knowledge and modern ecology, could result in the generation of valuable new insight for participatory design of more resilient and productive agroecosystems (Vandemeer and Perfecto, 2013; Altieri, 2004).

There is therefore a need to develop participatory research methods which seek to bring together different types of knowledge to facilitate co-learning for action. Tools to enable joint analysis of these agroecosystems between scientists and farmers could help to deepen understanding of the role of crop diversity on agroecosystem function and resilience, and to identify opportunities for system optimization at a whole farm scale (Altieri, 2004; Mijatovic et al, 2013). Using the farmers brain to model these complicated systems enables a qualitative assessment of the tradeoffs, creates a space for co-learning and can have a direct impact on the decisions they make in their farming systems. Such methods need to take into account the different nature of local and scientific knowledge (Argawal, 1995). Farmers knowledge may be considered as ‘tacit’; and is mostly embedded in routines, skills and practical experience. Farmers knowledge may therefore be better captured by observing what farmers ‘do’ and the decisions they make (Richards 1989; Van Krogh et al, 2000). Moreover, there is a role for researchers to reflect and learn through this knowledge co-production process to provide insight for future collaborative endeavors.

Research objectives

- To develop and test a new methodology which facilitates joint analysis of agroecosystem diversity between farmers and agroecologists
- Participatory classification of crop species into groups based on contribution to key agroecosystem functions and response to stress
- To identify opportunities for agroecosystem optimization based on crop diversity
- To identify potential interventions to support farmers
- To create a space for learning and positive change

Research questions

General RQ: What are the current and potential roles of crop diversity in enhancing agroecosystem function and resilience identified through the co-production of knowledge between farmers and scientists?

RQ 1.
How do farmers manage crop diversity for agroecosystem function in their farming systems?
Sub Research Questions

a) What are the main drivers for maintaining high levels of crop diversity?
b) How do farmers manage crop diversity for dietary diversity, income, soil quality, climate resilience and pest control?
c) What role does crop diversity play in enhancing resilience and stability?

RQ 2.
What are the opportunities to optimize farming systems using crop diversity?
Sub Research Questions

a) Which crop species / agroecological diversification practices offer potential to optimize farming systems for the future?
b) What are the limitations and barriers?
c) What interventions may support farmers to optimize their systems with crop diversity?

RQ 3.
What was the experience of the ‘co-production of knowledge’ and how did it contribute to learning?

a) What did we learn in the process to enhance and develop the methodology?
b) How did the process contribute to the co-production of new knowledge?
c) What lessons does this give about doing engaged research?

Context

Located on the ‚agricultural frontier' in the remote forested mountains of the Autonomous Region of the North Atlantic (RAAN), the ever-green municipality of Waslala hosts a humid tropical climate. With high annual rainfall (2298 mm), average temperature of 23.8 °C (range from 15.5 to 33.9 °C) and average 84.7% relative humidity over the year (CATIE, 2014: Waslala substation data). Altitude varies from 250 to 1267m asl providing a wide range of potential agroecological zones (Waslala Municipality, 2014). Most of the population lives in rural areas, however Waslala town is a growing "mountain port": an important commercial hub in an otherwise very rural municipality. Located only 118km from Matagalpa, due to poor road conditions the journey takes over 6 hours in public bus, Waslala is relatively isolated from most of the population.

Map of Northern Nicaragua (Source: CGIAR Humid Tropics)

The favorable agroclimatic conditions have attracted a wave of migrants from across the country since the end of the Nicaraguan Revolution in 1990. Many of these ‚pioneer farmers' come from the drier North and West Nicaragua, areas which have experienced extended drought in recent years. Although not the first to live in the area, early migrants describe how forest was cleared and burned to make way for maize, beans and livestock systems, using practices similar to those in their homelands. Initially experiencing high soil fertility, subsequent years of continuous cropping and burning, exacerbated by erosion on steep hillsides resulted in a rapid decline in fertility (Jose Ramon, ADDAC, Pers. Comm). Wasala's lush green hillsides have also attracted large scale livestock operations, commercial logging and gold mining (which date back to 19th Century). Local data suggests that 60,945 hectares of forest has been cleared since 1987, with 22,130 hectares remaining in 2010, reducing by 50% from 2005 to 2010 (Waslala Municipality, 2014). Local people describe the period from 1995 – 2005 as a period of rampant exploitation and deforestation, causing large scale soil erosion, changes in the microclimate (particularly increased temperature) and drying up of water sources.

Bean field on a steep slope in Caños los Martinez.

Farming on the frontier also comes with other challenges, not least adapting farming systems to new agroecological conditions: including high rainfall, steep slopes and new pests and diseases. The mountainous terrain and ‚incomodo' hillsides (slopes of up to 70% on some farms, see bean field in Caños Los Martinez left) pose a serious risk to soil erosion and many farmers explained that their soils have been "decapped". The geography also poses a serious challenge to transport, communications and access to basic services. Making access to market for sale and purchase of goods difficult. Beyond the few unpaved roads, the only option is to walk and many farmers walk for long distances every day to reach their farms.

Moreover, 71.7% of the population of Waslala are classified as living in "extreme poverty", with a further 18.5% in "poverty" (Waslala Municipality, 2014) with limited resources to invest in their farming systems. As the population increases with new migrants (doubled from 32,924 in 1995 to 62,822 in 2010, (Waslala Municipality, 2014), farms are divided by new generations and demand for land for extensive livestock operations - there is increasing pressure on land. Farmers explained that land speculation is pushing up land prices, making it harder to access and pushing people further into the mountains. Much of the municipality now lies in the Bosawas Biosphere Reserve, which also applied heavy restrictions on the extraction of timber (Waslala Municipality, 2014).

A recent Nicaragua-wide climate study conducted by CIAT/CATIE, identified Waslala as a zone of high vulnerability to climate change impacts in the agricultural sector, predicting an increase in temperatures and reduction in rainfall / frequency of temporal droughts (Bouroncle et al, 2014.) Based on access to basic services, information and other resources to invest, the report also classified Waslala with the lowest adaptive capacity. Beans and coffee were identified as the crops most sensitive to these changes.

In response to some of these challenges, and with encouragement from local organisations such as ADDAC (Association for Diversification and Communal Agricultural Development) small-scale farmers began reforesting the hillsides and diversifying their farming systems in the late 1990s. Farmers have been experimenting with new crops and practices, adapting their seeds and integrating trees into cropping systems. This has created a mosaic landscape of land-uses including *patio* (homegardens), basic grains, agroforestry, pasture, *rastrojo* (fallow) and *montaña* (natural areas). The agroforestry systems are usually based around cash crops of cacao (*Theobroma cacao*) and coffee (*Coffea arabica*) with shade and fruit trees. Grains systems are based on maize (*Zea mays*) and beans (*Phaseolus vulgaris*) sown in annual cycles – *primera* (May), *postrera* (September) and *apante* (December). Patio, pigs and poultry are also important for household subsistence (Silva, 2013). The increase in crop diversity may be considered a response to the multiple challenges of climate, food security and land pressure.

Mosaic landscape: pasture, grains and agroforestry in Santa Rosa Dudu

Waslala is one of the sites of the CGIAR Humid Tropics NicaNorte Learning Alliance: which brings together multiple stakeholders (including farmers, farmers organisations, NGOs, Government bodies and Research Institutes including CATIE, CIAT, Bioversity International and Wageningen University). Overall the objective is to enhance farm productivity, income and environmental services through collaboration between researchers, farmers and local organizations. In 2014, the Alliance carried out workshops to identify key areas for research interventions. Farmers, local experts, organizations and researchers agreed that the exploration of viable options for agro-ecological diversification to minimize risk in the uncertain economic and climatic conditions is a priority (Humid Tropics, 2015a). This is therefore the objective of this study.

Methodology

1. Research philosophy: Research in Action

New understanding and solutions can only arise with wide public and scientific participation (Pretty, 1995). This study sought to follow an "engaged research" approach; "..a praxis where researchers actively engage in problem solving and reflection in a social field, and combine this with the scientific knowledge generation process" (Levin and Ravn, 2007, p1). Working in the field with Bioversity International and collaborating with local organisations, I aimed to gain a deeper understanding of the knowledge and perspectives of farmers by learning and reflecting along with them and those who seek to support them. The intention was that the process may contribute to positive change by discussing findings on the way and exploring issues that arose as part of the process. A trans-disciplinary, systems approach integrated natural and social sciences, seeking to explore functional crop diversity at a farm systems scale. Using a ‚Farmer First' philosophy (Chambers et al, 1989) the intention was to work together with farmer scientists to explore the functional role of crops in their agroecosystems based on their knowledge and participate in developing solutions. Analysis was based at the farm-system level as this is the scale at which farmers operate. In partnership with Bioversity International[1], one of the objectives of this study was to develop a new methodology for participatory analysis of agrobiodiversity and agroecological diversification options.

2. Research set up and process

Phase 1: Consultation with Bioversity International, review of project documents, previous research and data collection tools. Development of proposal and research objectives (Wageningen, Netherlands)
Phase 2: Initial development of methods and consultation with researchers (CATIE, Costa Rica)
Phase 3: Consultation with local organizations and farmers. Workshops with technicians to test and adjust the methods, verify seasonal data and define functional groups. (Waslala, Nicaragua)
Phase 4: Data collection and reflection: participatory agroecosystem analysis (Waslala, Nicaragua)
Phase 5: Data analysis and report writing (CATIE Costa Rica / United Kingdom)

3. Sample and selection

Working in partnership with local organisations engaged in the Humid Tropics Innovation Platform; FUMAT, APROMUWAS and AMFVGW one community per organization were selected, all of whom participate with the Humid Tropics Cacao Alliance. These three communities are located at varying distances to Waslala: Caños los Martinez (4km, 20 mins, regular transport), El Chile (12km, 70 mins, 2 trucks daily) and Santa Rosa Dudu (22km, 150 mins, infrequent transport plus 40-minute walk from roadside). All communities had similar agrocological conditions, although Canos Los Martinez extended to higher altitudes, more favorable conditions for coffee, and was charachterised by the steepest slopes.

A random sample of 30 small and medium producers were self-selected at a community meeting in which all community members were invited to participate. Aiming for 10 for each community. only 8 farms were visited in El Chile due to safety concerns and 12 in Caños los Martinez. These farms have an average of land area of 17.9 manzanas (mz) (mode 10mz, 1mz = 0.7ha), the smallest 1mz (0.7ha) and largest 81mz (56.7ha). In most cases multiple household members were consulted, the main respondent being male on 12 farms, female in 8 and both male and female in 10. 10 farms were certified organic (cacao) and an additional 16 farms did not use agrichemicals in cacao but were not certified. As most farms used chemicals in basic grains, only 5 farms were not using any agrichemicals on the whole farm.

4. Data collection tools

The approach combined quantitative and qualitative methods to paint a rich picture of the situation.

a. Community Meetings / workshops

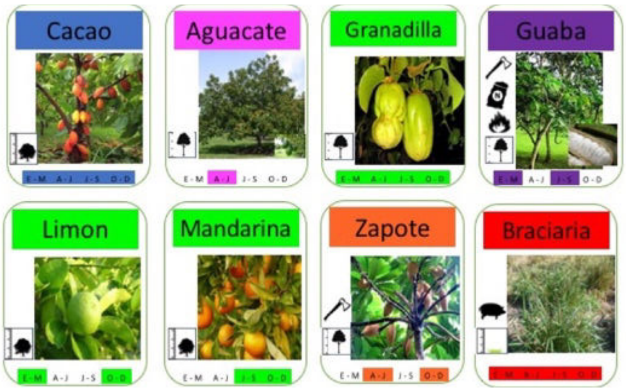
Working in partnership with local organisations, meetings were held in each community, to introduce the study the concept of agrobiodiversity and invite farming families to participate, reflecting on the goals of the research and how it could be beneficial to the participants. To encourage a spirit of local-scientific

[1] Bioversity International is a global research-for-development organization which delivers scientific evidence, management practices and policy options to use and safeguard agricultural and tree biodiversity to attain sustainable global food and nutrition.

knowledge dialogue results of a previous study were shared and discussed. A semi-structured workshop went on to discuss limiting factors to production, reasons for maintaining crop diversity and scenarios / priorities for the future. Farmers identified the key benefits of crop diversity and supported the identification of the main agroecosystem functions of interest to their systems – diet and food security, soil quality, pest and disease, income and climate resilience.

b. Farm Diversity Mapping tool

In collaboration with Bioversity International, a new tool was developed which builds on their existing methods for agrobiodiversity analysis. The intention was to create a participatory analytical tool that would enable farmers (in collaboration with me the "agroecologist") to explore the current and potential use of crop diversity, to enhance agroecosystem function, incomes and diets. The tool survey both as a crop diversity survey – to document the species in each farming system and their key functions / roles, as well as a participatory mapping exercise to understand how crop diversity is managed spatially. Semi-structured questions provide a space to discuss the motivations, barriers and potential future scenarios. Originally intended to be used in workshops, the method was adapted to work with farming families at a farm systems level. The tool was intended to facilitate the co-production of agroecological diversification strategies between farmers and researchers based on both local and scientific knowledge.



The ‘diversity tool' is centered on the use of 115 crop cards based on species identified in a previous ‘Four-cell analysis' study in the same communities (Guitterez, 2015). Each card shows the crop name, is colour coded by food group, has symbols indicating growth form/structure and harvest season. Each card includes a photo both of the harvestable crop and the structure of the plant in order to aid visualization of interactions between crops. Additional coloured cards were also available to make cards of any additional species.

The farmers first drew a rough map of the different land-uses on farm – namely pasture, basic grains, agroforestry, homegarden and patio. They then used the cards to map out crop species composition by land-use for this year. A series of semi-structured questions guides the process to analyse current and potential management of agrobiodiversity - loosely following the process of ‘Describe; Explain; Explore; Design' (Giller et al, 2008). Identifying those crops which are planted in association, the key interactions between them and classifiying them by agroecosystem functionality. Focusing on soil quality, control of weeds, pests and disease and climate resilience (3 of the 12 ecosystem services identified by Kremen and Miles, 2012) identified as areas of interest in community meetings. Dietary diversity, food supply and livelihoods were also discussed and crops ranked by contribution to diets and incomes. Based on this joint analysis, potential future farm designs and crop diversity compositions were explored in a qualitative form of ‘participatory modelling', addressing issues of interest to the farming family including climate resilience, dietary diversity and enhancing incomes. The final step was for farmers to decide what changes would be necessary to create these systems – both on farm and externally.

Using the diversity tool with a farming family in Santa Rosa Dudu

The cards also acted as a visual prompt for more informal discussion around their experiences and opinions of agroecological diversification on the farm. Effort was made to engage all members of the family of different ages and gender. Species compositions were documented by photos. Discussions were recorded and summaries of each farm written up after each visit. Farmers knowledge, current and potential use of crops with key agroecological functions were also documented in a record table. Compared to previous methods used by Bioversity International, the method added a spatial element and analysis of potential actions.

c. Farm Observation tool and transect walk

A transect walk with farmers complimented the diversity mapping tool with observation and analysis of the structure and function of crop diversity in different land-uses of the farming system. Deepening understanding of "what farmers do", how and why they are experimenting in their systems. Observing and documenting agroecological diversification practices and crop species and combinations with key agroecological functions. Key biophysical parameters – such as slope angle, shade, soil cover and pest and disease incidence were also observed and documented.

Harvesting beans with Doña Elba in Caños los Martinez

Walking the farm also presented an opportunity for informal discussion with farmers in their fields. Exploring farmer's perceptions of the role of diversity in their systems. Why and how are they innovating with diversity? What are the key interactions in multi-species systems? Where possible these discussions were also recorded.

Where time permitted, I also worked with the farmers in their fields – particularly during the early part of the study when farmers were harvesting beans. This gave an opportunity for closer observation of the systems and more relaxed discussions, as well as being respectful to farmer's time.

d. Household survey

A survey of 12 questions, collected basic quantitative data including farm size, agrochemical use, yield / income and sources of knowledge with all 30 farming households. Where possible this data was collected during discussions in the diversity tool and farm transect walk to enable a more fluid interaction with participants.

e. Informal interviews and reflection

Regular informal discussions with key individuals from local organisations (in particular FUMAT, ADDAC and Fundacion Madres) provided a richer picture of the context but also made way for joint reflection and learning. Sharing findings, observations and thoughts and reflecting together with them. In particular, discussing the barriers and opportunities farmers highlighted and how they may be able to support in the future. This also enabled me to refocus some elements of the study – for example the focus on local seed systems. Other key stakeholders, such as technicians, fruit and vegetable sellers, agriculture students, seed and agrochemical retailers and grain buyers were also informally consulted in order to build a richer picture of the situation. These discussions were recorded and transcribed where possible.

f. Scientific exploration of findings

Based on discussions with farmers, issues and practices they highlighted, I also explored the 'scientific' relevance of these findings in the academic literature and functions of key crops, in particular using the FAO ecocrop database (http://ecocrop.fao.org/ecocrop/srv/en/home), seeking further insight to share with farmers. Findings were also discussed with fellow researchers at CIAT and Bioversity International.

g. Reflections with farmers and final workshop

As understanding of the situation deepened, this enabled reflection with farmers on some of the key issues arising. A final workshop brought together all the farmers from each community to do some analysis as a group – including the classification of the crop species into 'vulnerable' and 'tolerant' and 'caliente' 'fresca'. But most importantly, this was an opportunity to share and reflect on some of the findings, what farmers had learned from the process and to enable exchange of knowledge and ideas between farmers. Locally produced seed of pigeon pea and macuna were shared to thank farmers for participating.

Classifying 'caliente' and 'fresca' species in Santa Rosa Dudu

h. Field journal

Key insights, observations and reflections were noted in a field journal. In particular, observations in the field, the use of the methods and tensions between different types of knowledge. Reflecting on my own actions and actions of others.

5. Data analysis

a. Analysis with local stakeholders

The initial stage of analysis was conducted with farmers in the field. The visual nature of the cards in the crop diversity tool enabled analysis of seasonal availability, dietary diversity and agroecological functional diversity. Reflection with farmers and local stakeholders also facilitated a deeper understanding of the data and implications for action.

b. Grounded typology construction

Based on qualitative and quantitative data collected, consultation with local stakeholders, farmers were grouped into five typologies based on farm configuration and strategy (Alvarez et al, 2014).

c. Quantitative data analysis

Crop species composition data was taken from photos of farmer's configurations in the diversity tool, coded and input to Microsoft Excel. The presence of each crop species was indicated, classified by land-use, ranked by importance for diet and income, and categorized based on its current and potential use for specific agroecological functions according to farmer knowledge. Basic statistics, calculations and figures on species richness were produced using Excel. More advanced statistics, including correlation coefficients were calculated using online statistics calculators (www.socscistatistics.com). Analysis of crop species by function, dietary diversity and seasonal availability (Figures 1 and 6) were produced using R Studio. Data for the 30 household surveys and from the farm observation tool was input into Excel and analysed using Excel package and online statistics calculators.

d. Qualitative data analysis

Recordings of diversity tool exercise and interviews with farmers were transcribed and filed with field notes and photos documenting agroecosystem structure and relevant practices for each farm. Notes from communty meetings and interviews with other key stakeholders were also documented.

Thematic content analysis was used to identify commonalities, anomalies and patterns in the data. Quotes and case studies were also selected to seek to represent key themes and also heterogeneity. This information complimented quantitative data to seek to paint a richer picture of the true reality. Based on the synthesis of discussions with farmers and quantitative data on species use, summary tables were compiled to classify the key crop species for each agroecological function.

This rich mix of information and data from the various methodologies was combined to seek to build a deeper understanding of the role of crop diversity on agroecosystem function in Waslala.

Results

Results are presented in three sections in accordance to the research questions;

A. Current management and local knowledge of crop diversity
B. Future scenarios: opportunities, barriers and potential interventions
C. Co-production of knowledge and joint learning

Section A: Current management and local knowledge of crop diversity

This section presents quantitative and qualitative data collected in collaboration with farmers on the current use of crop diversity and its role in agroecosystem function, seeking to answer;

RQ1: How and why do farmers manage crop diversity for agroecosystem function in their farming systems?

First wider patterns of species richness, farm configurations and key drivers will be explored, then results on the role of crop diversity on five key functions: diet, income, climate, soil, pest and disease.

Figure 1: Frequency of crop species use for key functions

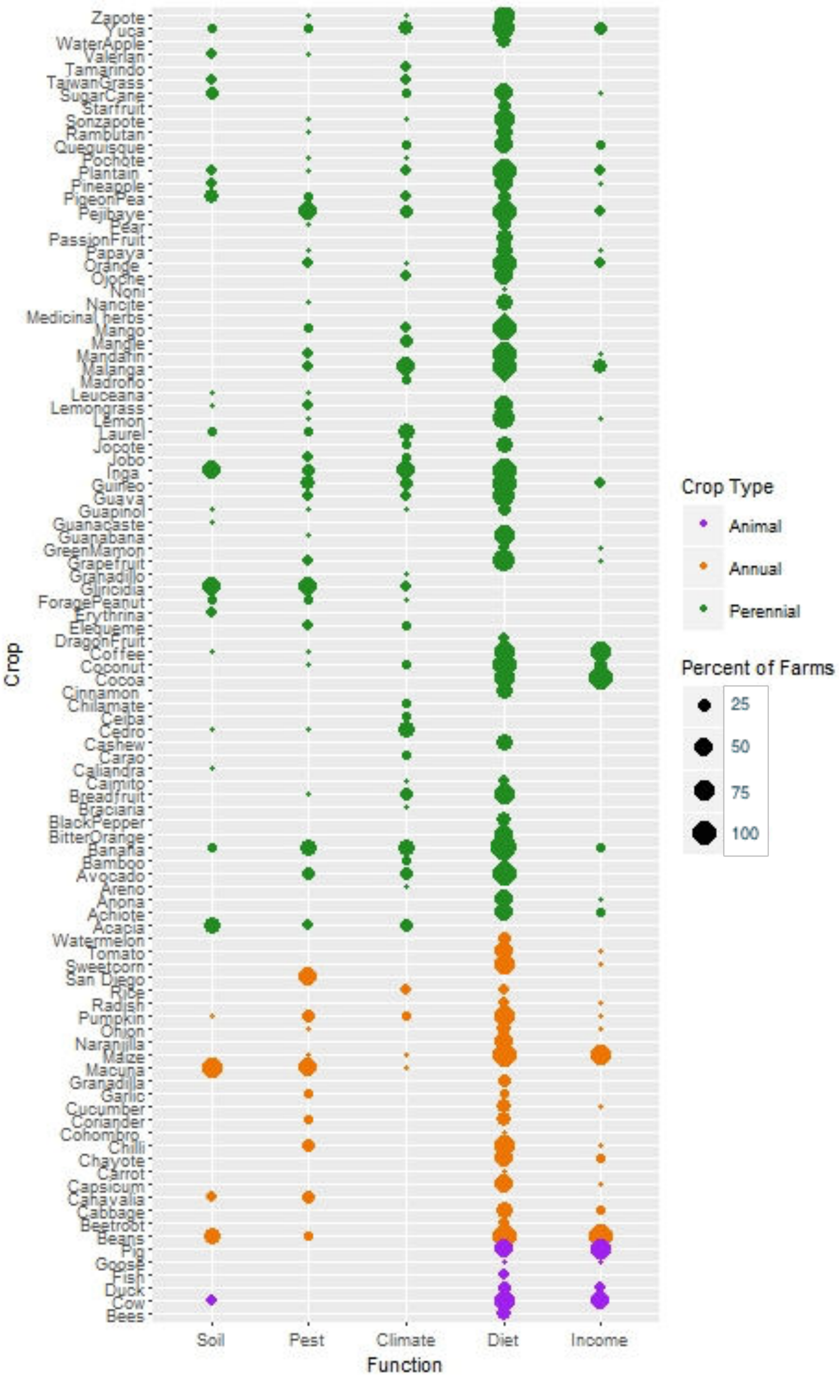


Fig. 1 outlines all the crop species documented on the 30 farms in the diversity tool (see appendix for list of latin names). The size of the circle represents the percentage of farmers who reported using that species for five main functions: soil quality, pest and disease control, climate resilience, diet and income. It shows that most of the species are consumed as part of the diet, with some providing additional functions.

It illustrates that diet is the key function of the most of the species. It also shows the multifunctionality of many of the species, for example *inga* is a nitrogen fixing shade tree, used for timber, with edible seed pods, also alternative food for cacao pests. Farmers explained how they manage a diversity of species for their different roles in their systems, suggesting that it is not just about species richness, but the selection of species and their multifunctionality which is important

> "*I am always looking for a double use and so look for crops that will have other benefits*" Don Santos, Innovative farmer, El Chile

Fig. 1 also shows that 70% of the species are perennial. Farmer classification of crops in workshops shows that 76% of the species considered 'tolerant' to pest, disease and climate shocks are perennial and 82% of the species considered 'vulnerable' are annuals, thus they often rely on perennials in the case of crop failure.

This data is summarized from the more detailed information collected in the diversity tool in which the specific role of each crop for key functions was described (for example preventing soil erosion, adding nutrients and building soil organic matter were some of the groups farmers identified for soil). These specific roles and practices will be described in more detail in the following pages.

Species richness

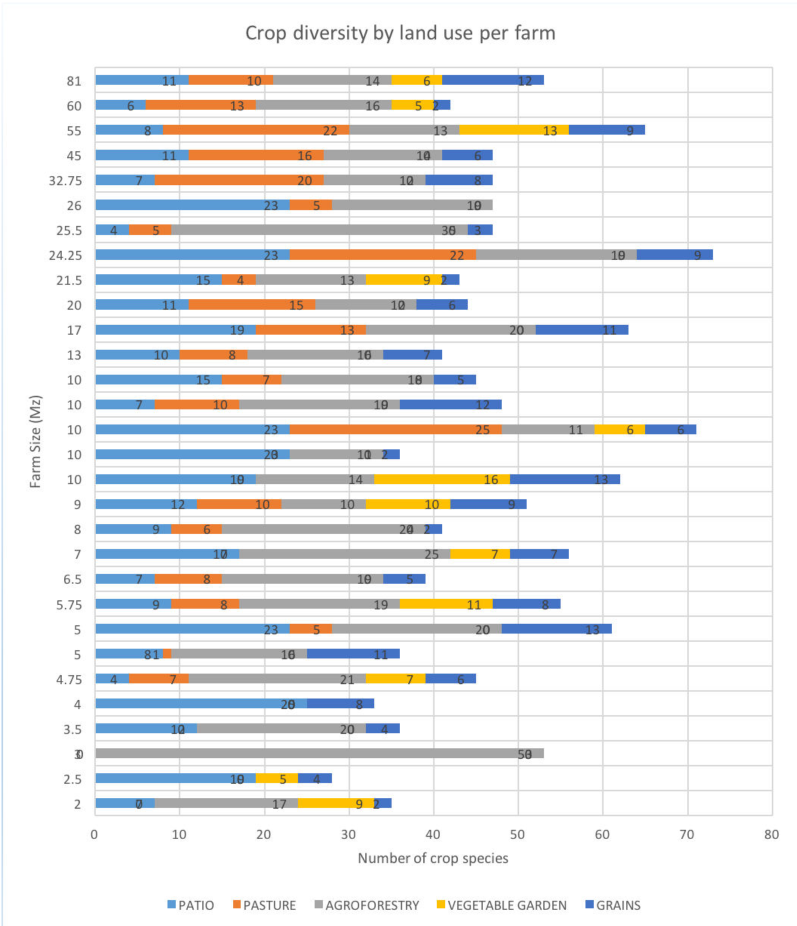
Results show that most agroecosystems in the study are highly diversified with a large range of food, timber and animal crops. Species richness was calculated from the total number of crop species documented per farm in the diversity tool exercise. The average number of total species per farm is 48, ranging from the lowest at 35 and highest at 67. A considerable percentage of these are edible (see fig. 1) and the unique number of food crops consumed is on average 31 species, with a minimum of 21 and a maximum of 46. The closest comparable data was found in Mexico in June 1999, in which the unique number of foods consumed was an average of 17, with a maximum of 35 (Hoddinott and Yohannes, 2002)

Crop diversity, land use and agroecological intensification

Agricultural landscapes in Waslala consist of a mosaic of land-uses. Local classification systems divide this by pasture, agroforestry, patio (or ‚homegarden'), vegetable garden and basic grains. Farmers explained this range of land uses enabled the fitting of different crops to exploit a range of agroecological niches on the farm – for example grains were mostly located in higher, drier areas that received more sunlight; agroforestry systems on steeper slopes and more humid areas in low points and valleys. This often means that fields belonging to the same farm are spatially segregated which could reduce the transfer of pest and disease across the farm and make the system as a whole more resilient to climate shocks and pest and disease. To the contrary, it was also observed that this leads to the clustering of crops at a landscape scale, in particular the basic grains. As such this creates localized monocultures, which may be more prone to the rapid spread of commonly mentioned pests such as slugs and fungal diseases.

In the crop diversity tool farmers arranged crop species cards by land-use. Results show that some land-use types are characterized by greater crop diversity than others.

Figure 2: Number of crop species per farm by land use



This is demonstrated in figure 2 which shows the number of crops by land use type per farm and ranked by farm size. Overall it shows that patio and agroforestry systems tend to be most diverse.

It also shows that those farmers with a smaller land area, manage to maintain relatively large amounts of diversity by focusing on agroforestry systems and patio. The advantage of this seems to be a greater capacity to intensify land use through the use of polycultures.

> "*the field is small and so we have to take advantage of the land… the crops grow together because they are different sizes and look after each other*" (Diversified farmer, Caños)

This suggests that smaller farms are more intensive, meanwhile, larger farms contain larger species diversity in pasture systems – often integrating a wide range of fruit and trees into a silvopastoral system and grains. Farmers accounts suggest many are using crop diversity to facilitate land use intensification. There is a weak positive correlation between farm size (total land holding this year, including rented land) and species diversity, however it is not statistically significant (r =0.23, R^2 = 0.053). In fact, many farmers talk about crop diversity as a strategy for intensifying land use by planting together crops which have complimentary and facilitative associations.

Figure 3: Correlation between farm size and species richness

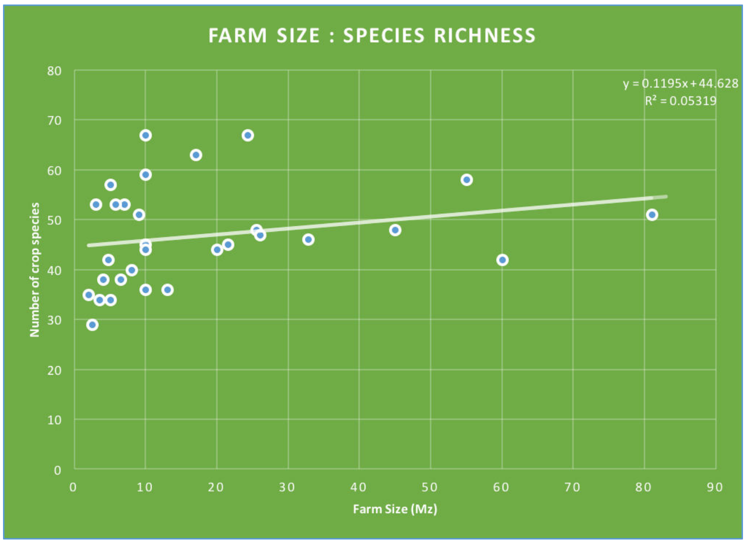
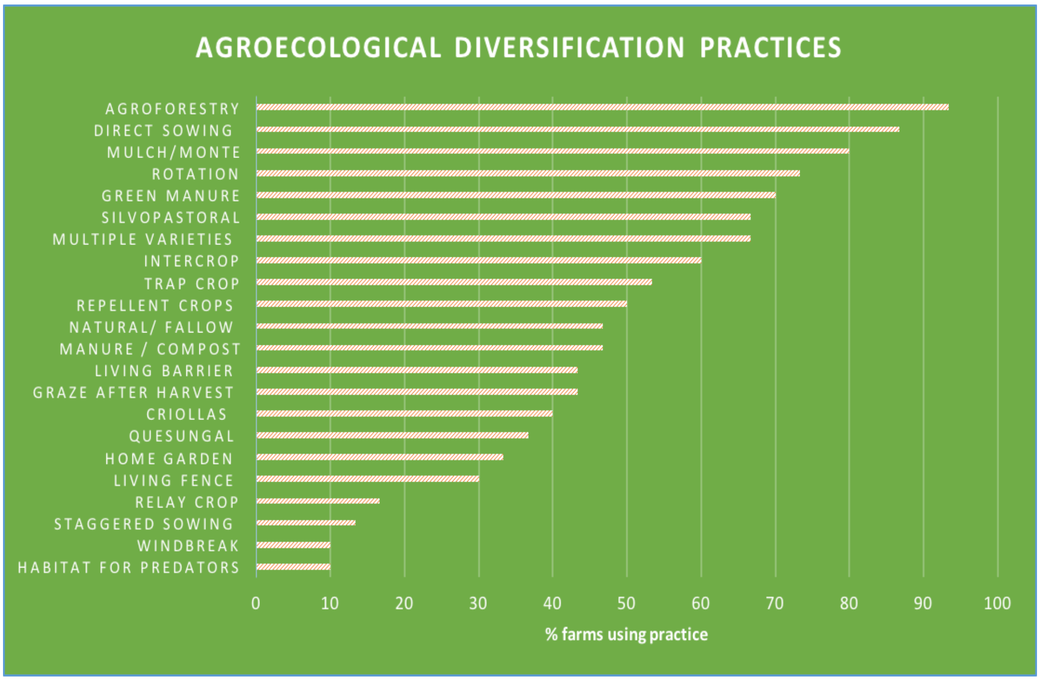


Figure 3 shows that some farmers with small farm sizes, manage high levels of crop diversity. Farm observations suggest that this is namely by using multiple strata systems such as agroforestry and patio (see also fig 3). In fact, the farm with the highest diversity in the sample is farming only 10 mz (7ha) and has 68 different crop species. The figure also suggests that there is an optimum, with farms between 5 and 25Mz with the highest diversity and larger farm seem to prefer smaller species numbers. For example, Margarito, has 81mz (56.7ha), and manages 51 species. He has a more commercial strategy, with a larger area in coffee and cacao agroforestry. He explained that he noted the benefits of crop diversity for shade, pest and disease control, but also that a degree of focus was necessary to manage the farm well. It is clear that farmers take different strategies regardless of farm size and that diversity can be a tool for land use intensification.

Agroecological diversification practices

In addition to increasing species richness, it is clear farmers are also consciously managing the species selection and composition through the use of agroecological diversification practices).

Figure 4: Use of agroecological diversification practices



Household surveys show that farmers are using 22 agroecological diversification practices, with an average of 12 per farm[2]. Most common are agroforestry systems, direct sowing, mulching / use of weeds and rotation. Farmers explained how these practices enhanced the structure (e.g. crops spread across different land use types, polycultures, use of multiple stratas and crop rotations) and function (e.g. diverse food groups, inclusion of crops with different agroecological functions, multiple income sources).

[2] Practices were defined based on those used by Kremen and Miles, 2012 adapted to local practice with support from local technicians

The use of these practices suggests that farmers are consciously managing crop diversity for specific functions. Based on interviews with farmers and technicians, the crop diversity tool and observations of systems below is a summary of the key agroecological diversification practices used in Waslala, discussed in more detail in the following sections.

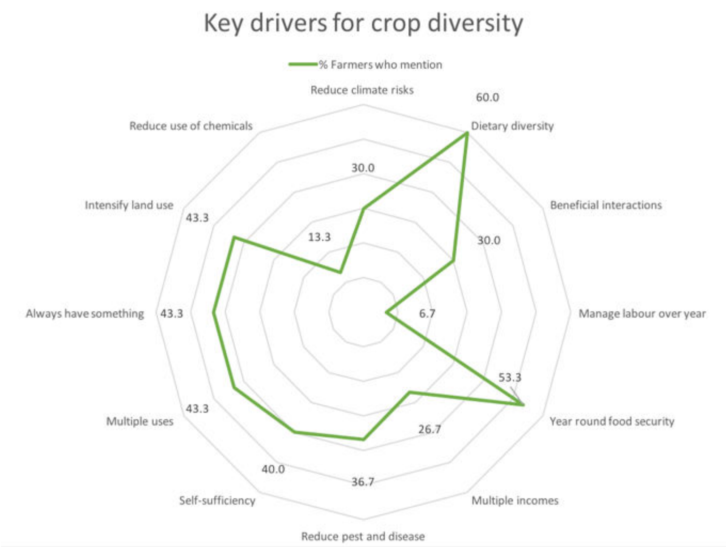
Table 1: Overview of key agroecological diversification practices used in Waslala

Practice	Description / definition	Typical species	Benefits / functions
Agroforestry	Integrating crops and trees	Cacao, coffee, fruit and shade trees	Pest control, soil quality, microclimate
Direct sowing	Sowing grains into a mulch of crop residues / weeds / cover crops	Beans, maize	Soil quality
Mulch / monte	Leaving chopped crop / weed residues on the surface to create a cover	Beans, maize	Soil quality
Crop rotation	Successive planting of different crops on the same land	Beans, maize, macuna	Pest control, soil quality
Green manure	Crop species which enhance fertility when incorporated into the soil or cut residues left as a mulch	Macuna, canavalia, pigeon pea	Soil and water quality
Silvopastoral	Integrating trees in pastoral systems	Acacia, cedro, guayaba, jobo, inga	Microclimate management , soil, forage
Multiple Varieties	Using more than one variety at a field or farm sale	Beans, maize, bananas	Pest control, climate resilience
Intercrop	Mixing of crop species (not including agroforestry)	Maize and pumpkin,	Pest control, soil, complimentary resource use
Trap crop	Crops which distract pests from the main crop	Pejibaye, bananas,	Pest control
Repellent crops	Crops which repel pests from the main crop	San Diego, gliricidia, chile, garlic	Pest control
Living barriers	Crops planted along contour lines to intercept down flowing water and soil	Pineapple, sugar cane, bananas	Soil and water quality
Graze after harvest	Grazing livestock on crop residues following harvest	Cows, maize, beans, rice	Soil, off-season forage
Criollas	Local varieties and ‚landraces' which have been adapted to the zone	Maize, beans, bananas	Pest control, climate resilience
Quesungal	Planting and pruning trees together with grains in a ‚slash and mulch' system	Maize, beans, laurel, leuceana, macuna	Soil and water quality
Living fence	Trees planted as fence to retain livestock or mark boundaries	Gliricidia, mango,	Pest control, microclimate, forage

Why diversity?

The household survey also identified the key three drivers for managing crop diversity and mixed species systems per farm. The reasons commonly mentioned were dietary diversity, year around food security, ensuring there is always something to eat, multiple use (food, income, timber) and intensifying land use (see fig 5). Beneficial interactions, reducing chemical use and controlling pests were also mentioned.

Figure 5: Key drivers for crop diversity



One of the main themes of discussion in workshops and in the diversity tool was the idea of "*siempre hay algo*" or "there is always something" – that growing multiple crop species which perform the same function (for diet, income or agroecological process) provides insurance in the case of crop loss, particularly as they may have differing vulnerabilities to pest, disease and abiotic stress.

> "*If we have more crops, if one is lost because of bad weather or slugs, then there is something else*". El Chile community meeting.

It is important to note that there are trade-offs and synergies in regards to diversification. These were discussed with farmers throughout the process and are highlighted in the following sections.

Farm typologies

Despite overall high levels of diversity and identification of common patterns, it is also important to recognize the heterogeneity in the data. Basic typologies were developed based on farm configuration information from the household survey, diversity tool and farm observations. ‚*Resource poor farmers'* are those with a small land area, with low incomes, limited labour availability and high food insecurity. ‚*Part-time farmers'* are those farms where the majority of income comes from off farm (teaching and village shop). ‚*Agroecologically intensified farmers'* are those which despite a small land area (<5Mz) are using agroecological diversification practices to increase species richness, self-sufficiency and farm income, ‚*Diversified farmers'* are those farmers that have a land holding higher than 5mz, have high species diversity across 4-5 different land-use types and are innovating with agroecological diversification practices. With a focus on both home consumption and some cash crops. ‚*Business farmers'* are those which have a larger land holding (over 30Mz), with a greater focus on production of cash crops in addition to home consumption. Table 2 below is a summary of the averages of some of the key indicators by farm typology. These indicators will be explained and discussed in more detail in the following pages.

Table 2: Averages of key indicators per farm typology

	No. of farmers in sample	Farm size (Mz)	Income (Cordoba /Mz/yr)	Species richness	Food Insecurity score	Agroecosystem Dietary Diversity Score	No. of Agroeco diversification practices
Resource poor farmers	2	1.75	660	33	9.5	11	4.5
Part-time farmers	2	5.6	5400	40	1	9	8.5
Agroecologically intensified farmers	7	4.6	7382	45	3.7	9.6	10
Diversified farmers	15	19.6	4574	48	2.2	11.2	13.5
Business farmers	4	46.6	6820	56	1.5	11	15.3

Two surprising outcomes are that the ‚business farmers' maintain the highest species richness and use of agroecological diversification practices, contrary to assumptions that they may be more specialized on a few cash crops. Secondly, ‚Agroecologically intensified' farmers are generating more income per mz/yr than the ‚business farmers'.

To better understand variability between communities, table 3 below highlights the averages by all three locations of the study.

Table 3: Averages of key indicators per community

	Number of farms in sample	Farm size (Mz)	Access to Waslala (Mins)	Income (Cordoba)	Species Richness	Food insecurity score	Agroecosystem Dietary Diversity Score	No. Agroeco diversification practices
Caños los Martinez	12	20.0	58	6198.3	44	4.0	10.1	11
Santa Rosa Dudu	10	11.9	190	2883.2	48	2.5	10.7	11
El Chile	8	22.2	73	7061.7	49	1.9	11.4	16

The following sections will expand on these results, exploring the role of crop diversity on 1) Household food supply and dietary diversity, 2) Income diversity and stability, 3) Climate resilience 4) Soil quality, 5) Pest and disease control.

1. Household Food Supply and Dietary Diversity

How do farmers manage crop diversity to secure household food supply and dietary diversity?

Factors relating to the provision of food for home consumption were the most important drivers for crop diversity (figure 5) including dietary diversity (60% of farmers), year around food security (53.3%), minimise purchase of food (40%) and to ensure that there is always something (43%). In discussions farmers also mentioned other reasons such as being able to grow tastier, healthier, safer, fresher food, without chemicals (Community meeting, Caños los martinez). As shown in figure 1, the vast majority of crops grown contribute to the diet. Farmers discussed multiple strategies of managing crop diversity to ensure a varied diet and a secure food supply which are outlined below. Most farms show moderate to high dietary diversity and availability of different food groups through the year.

The farms studied are mostly self-sufficient: 72% of farmers in the study produce the "majority" (80-99%) of the food they eat on the farm and the remaining 18% produced a "considerable" (60-79%) amount. The additional amount is exchanged between households and bought (commonly rice, oil, sugar and occasionally meat), however the majority of households (26 out of 30) buy less than 10% of their food. This dependency on food self-sufficiency, is a key reason for producing a diverse range of crops.

a. Seasonal availability and food security

One of the most important drivers for crop diversity in Waslala is to ensure the year around availability of food; "Siempre hay algo" (there is always something!). The crop cards in the diversity tool included data on the harvest seasons of each crop. This enabled analysis with farmers on the availability of food across the year on their farm. Waslala experiences a short hot, dry season from February to April, with the remainder of the year experiencing consistent rainfall and lower temperatures. Farmers explained the ‘scarce season’ extends between when bean and maize supplies finish at the end of the dry season in June and awaiting the harvest of the ‘primera’ in August[3].

Crops which bridge this gap and that are reliable in the case of crop failure are therefore considered of critical importance to food security to many households. These "emergency foods" are indigenous carbohydrate rich crops which are more tolerant to stresses and available during this season.

Farmers accounts suggest that these crops are the critical keystone crops of these farming systems to ensure food security. In particular, roots, tubers and bananas (malanga, yuca, banana) and pejibaye[4] are consumed by over 75% of households during this period. Other crops which provide this function include

Box 1: ‘Emergency foods'

Josefa is an ‘agroecologically intensive farmer' in Santa Rosa Dudu.

An older widow living with her daughter, they produce a wide range of crops on 5Mz (3.5ha), on which they rely for the majority of their food. She explained that they integrate crops which are more tolerant to drought, pest and disease and provide a reliable source of food all year around.

"*We make the decision to cultivate so much diversity because some species are not for all of the year…. This season (June to August) is more ‘palmada' (impoverished), but there is pejibaye, malanga, yuca, banana, ojoche…… we use Ojoche seeds as a flour to make tortillas or boil them – they taste like potatoes!…,..*"

Left to right: Pigeon Pea (Cajanus Caja), ojoche (Bromisum alicastrum), malanga (Xanthosoma sagittifolium), breadfruit (Artocarpus atilis) and pejibaye (Bactris gaesipaes)

Others explain how these crops are shared with those with less resources;

"*Some families come and ask to collect breadfruit and pejibaye from our farms when they don't have anything else to eat*" Marbeliz, Diversified farmer, El Chile

3 Note that seasonal availability data used in the study were verified with local stakeholders based on previous research in the same communities (Guitterez, 2015), as such unfortunately it was not possible to highlight crop availability specifically over the scarce season from June to August. Future research could investigate crop availability over this period.

4 See appendix for index of latin names for key species mentioned in this text

quequisque, ojoche and breadfruit seeds (approx. 25% of households). These crops grow within the agroforestry requiring little inputs or maintenance, providing an important safety net. Although most farmers maintain some of these crops, some farmers explained that the cultivation of some of these crops is declining. This appears to be in part due to the associations of these crops with poverty and cultural preference for rice, beans and maize. Encouraging the production of these ‚emergency crops' may be a way of increasing resilience to climate variability.

Figure 6: Contribution of crop species to dietary diversity over the year

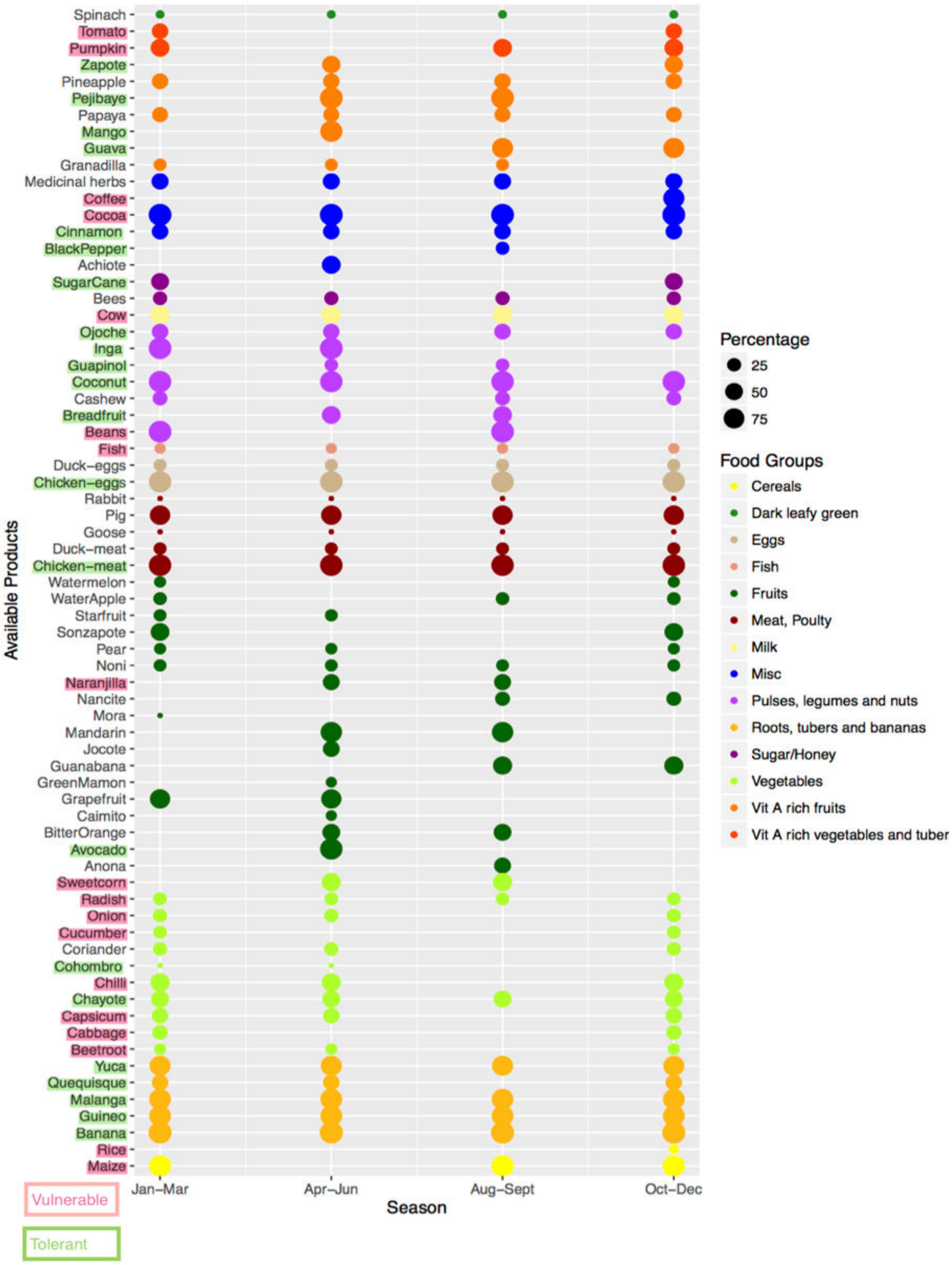


Figure 6 shows crop species data collected from all 30 farms in the diversity tool, colour coded by food group (as used by Remans et al, 2011) to indicate nutritional diversity. The four columns indicate the availability of each crop per season (i.e. ready for harvest), the size of the circle represents the % of farmers who produce that species. This indicates that despite distinct seasonal changes in climate, availability of a diverse range of food is relatively consistent over the year.

Analysis also shows that agroecosystems often contain multiple crops from the same food group throughout the seasons, in particular fruit. Therefore, buffering the impact of crop loss and ensuring availability and dietary diversity throughout the year, despite potential stresses and shocks.

Fruits are the food group with the most species diversity and dark leafy greens, milk, sugar / honey and cereals with the least - despite the heavy dependence on cereals for food security. Oil crops are not produced and farmers explained this was one of the few products purchased.

The majority of households had chickens or ducks, only 32% of households had cattle (namely ‚diversified farmers' and ‚business farmers'), as such only 25% of farms produce milk. Historically diets in the region have been characterized by low vegetable consumption, however this has been promoted by a number of local organisations and many farmers expressed interest in increasing vegetable production. Only one dark leafy green crop was identified (spinach) and was produced by a few households, however others mentioned eating leaves of yuca, squash. Some farmers had lower diversity of food groups at certain times of the year, for example many farmers were lacking Vitamin A rich crops from January to March. Filling these gaps was therefore discussed in regards to system redesign (section B).

The figure also highlights farmer classifications of crops in farmer workshops as tolerant and vulnerable to abiotic and biotic stresses. Those highlighted green are considered to be more tolerant to shocks and have stable yields year to year. This group includes many of the ‚emergency foods' that farmers mention. Those highlighted pink are considered to be more vulnerable and have unstable yields. This includes the staple grains and new horticultural crops. Although it does not highlight the scarce season specifically, the figure also provides some verification of the role of some of these crops in bridging to the first harvest of grains in August.

b. Dietary Diversity

The Household Dietary Diversity Score (HDDS) was developed as a simple indicator of household food access and the number of unique food groups consumed by household members (Swindale and Bilinsky, 2006). The HDDS was adapted for this study to enable rapid assessment of dietary diversity of the agroecosystem using the crops species cards and is here called the Agroecosystem Dietary Diversity Score (ADDS). Therefore, analysis was based on the crops included in the agroecosystem rather than a 24-hour recall of foods consumed as in HDDS. Moreover, in order to highlight more specific nutritional gaps dark leafy green vegetables and crops which are rich in Vitamin A were also included, as used by Remans et al (2011) to make a maximum score of 15. These groups are outlined in figure 6. Crop cards in the diversity tool were colour coded by the food groups, which enabled co-analysis with farmers to highlight nutritional and seasonal gaps. The outcome was that the majority of agroecosystems provide a diverse diet throughout the year, as shown by the integration of a range of crops from 14 key food groups in fig 6.

The ADDS scores ranged from 6 to 14 out of 15, with a mean of 11. This further supports farmers accounts that diversified systems provide diverse diets. The only group not represented were ‚Oils and fats', which are purchased. Compared to data collected elsewhere this is relatively high, supporting the hypothesis that agroecosystems in Wasala provide a high level of dietary diversity. (e.g. Remans et al, 2011, found an HDDS range of 2 - 9 in African villages, including food that was bought and exchanged, however this based on 24-hour recall of food consumed).

c. Dietary diversity and farm typology

As shown in table 2, the ‚diversified farmers' had the highest average ADDS score of 11.2 and the part-time farmers had the lowest at 9. Jesus, an ‚agroecologically intensive' farmer has all his land in agroforestry, and despite a high level of species richness (53) has the lowest ADDS score (6 - see outlier on figure 7). In this case food was exchanged with families on other farms for beans, maize and milk. However, in addition to the lower average ADDS score for the ‚Agroecologically intensive' farmers (9.6) this suggests that a range of land uses may be beneficial for dietary diversity.

Interestingly, many smaller farms manage to have nearly the same dietary diversity as larger farms and there is no significant correlation between ADDS and farm size (r=0.24). As farm size is also independent to the amount of food purchased, this suggests that farmers are able to produce a sufficient and diverse range of produce on a smaller area of land. Discussions with farmers and observations show that smaller farmers are intensifying land use by using polycultures, multiple strata, biointensive vegetable gardens and crops in association. Through careful crop choice they are able to maintain high dietary diversity.

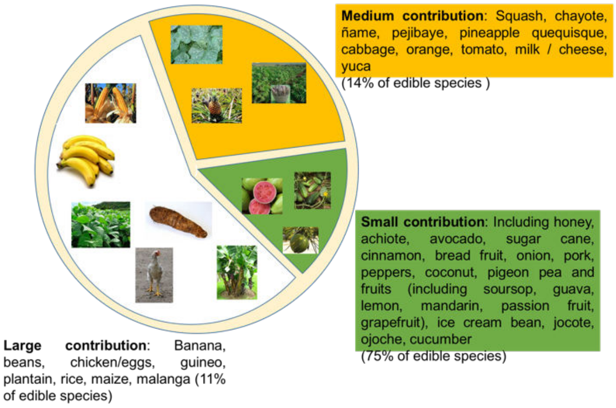
d. Contribution to diet

Despite the high dietary diversity of the agroecosystems, it is important to also consider the composition of the crops consumed. Eating with families it was observed that much of the food consumed was based on a much smaller range of crops namely maize, beans, bananas and fruits.

Typical ‚*campesino*' meal

In the diversity tool, farming families ranked the different crop species by those which they felt provided a large, medium and small contribution to their household diet over the year (those which they ate more and less). Figure 7 below groups the crops by most common responses. It demonstrated that the majority of families actually depend on only 11% of total species (8 crops) for the majority of their diet whilst 75% of the crops only provide a small contribution.

Figure 7: Contribution of crop species to diet



Through the diversity tool we discovered that some crops considered most important for the diet are also considered most vulnerable to climate, pest and disease shocks and suffer from instable yields (maize, rice and beans, see figure 6). This suggests that despite high levels of crop diversity, cropping systems are still quite vulnerable due to high dependence on these species. Many farmers explained that integration of more resistant species, characterised by more stable yields makes the system more resilient.

In order to deeper understand the relationship between agroecosystem diversity and dietary diversity, future studies could consider using a 24-hour recall method (see Remans et al, 2011).

Figure 8: Relationship between species richness and dietary diversity

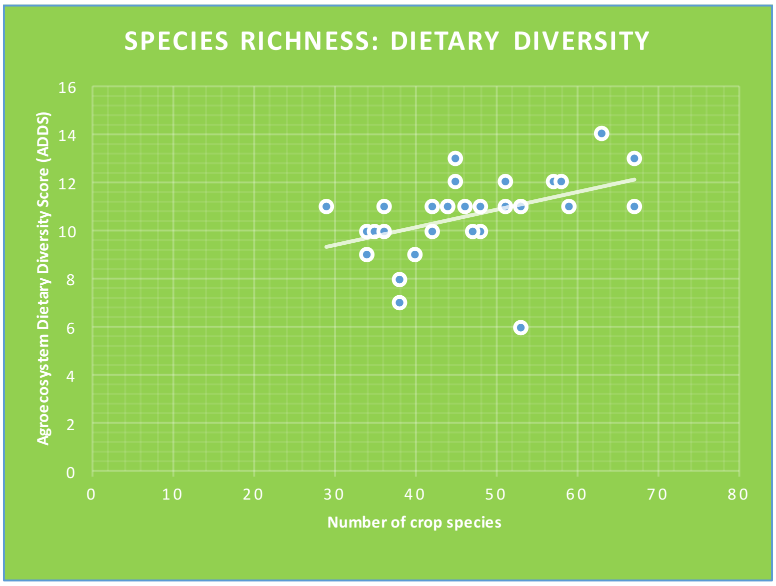


Figure 8 shows the positive correlation between species richness and ADDS per farm. The relationship is statistically significant to $p<0.05$ with a Pearsons Correlation Coefficient r value of 0.45, suggesting that increased crop diversity has an impact on dietary diversity and thus household nutrition.

It is also interesting to note that average ADDS was highest in El Chile (11.4), where ADDAC have a strong presence and lowest in Caños los Martinez (10.1) with the easiest access into Waslala.

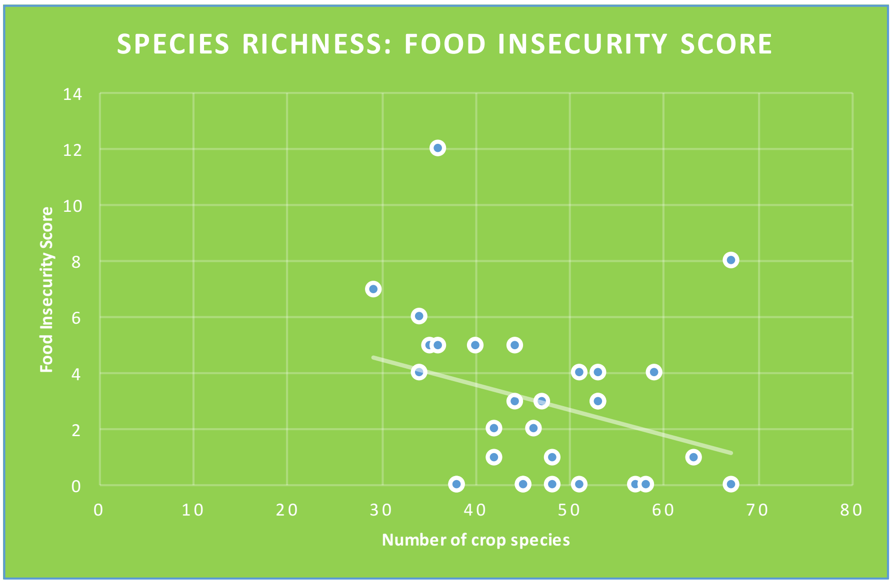
e. Food Insecurity Score

A simplified Food Insecurity Score was adapted from the Household Food Insecurity and Access Score (HFIAS, Coates, Swindale and Bilinsky, 2007). Farmers rated the frequency of occurrence of three scenarios, each relating to one of the ‚domains' of food access: 1. anxiety and uncertainty over food access; 2. insufficient quality / diversity and 3. insufficient food intake. A score is calculated per household based on the perceived frequency of each scenario (0 = never, 1 = a few times, 2= sometimes, 3=frequently), both over the last 4 weeks and for the last ‚scarce season' to a maximum score of 18.

The results showed that overall perceived food insecurity is relatively low, varying from scores of 0 to 12 and a mean of 3. Most common was that they or a family member "worry that their household would not have enough food" (77% of households mentioned at least once during the year), less common was that they or a family member "had to eat a limited variety of food due to lack of access to resources" (47% households mentioned) and rarely did farmers comment that they or a family member "had to eat less than they thought was necessary because of lack of access to food" (10% households mentioned). All statements were more common in the scarce season. This suggests that although there is some anxiety regarding access to food, the actual experience is that overall most households feel that they have sufficient quality / variety and quantity of food.

Figure 9: Relationship between species richness and Food Insecurity Score (FIS)

There is a significant negative correlation between Species Richness and Food Insecurity Score(FIS) per farm (r=-0.3, significant to p<0.10). Figure 9 shows that as species richness increases, Food Insecurity Score decreases. This suggests that there is a relationship between agroecosystem diversity and food security. This is also echoed by farmer's comments. It is clear however that these are sensitive questions and there is a chance that some did not give honest answers, but overall most seemed very confident of their household's food security status.



f. Community level diversity and social safety nets

An important observation during time in the communities, was the culture of reciprocal gifting of food. It is common practice for family members and neighbours to knock on each other's doors and request produce which may be surplus. 28 out of 30 households described using this practice, mainly exchanging on a small quantity of produce. This is often crops such as roots, tubers and fruits, but expands to almost all available species. Discussing with farmers it seems that this is a way of further diversifying diets at a ‚community' scale, to have access to crops they do not farm, filling shortfalls and to try new crops before investing in planting them. Thus it is likely that household dietary diversity is considerably higher than the agroecosystem dietary diversity.

Moreover, this food exchange system provides an additional social safety net, increasing diversity at a landscape scale making the community more resilient to biophysical and economic shocks.

> "*…if we have extra then we share it and if they do (family/neighbours) they share it too!…We just call at the house and ask for something if we need it…*" Guillermina, ‚Diversified farmer' Caños los Martinez

g. Income as security

The farm typology with the highest FIS score was the ‚resource poor' farmers, an average of 9.5, and the lowest the ‚part-time farmers' with an average of 1 and ‚business farmers' with an average of 1.5. This suggests that income plays a key role food security. When asked about food insecurity, many laughed at the idea of not having enough to eat and explained that they ensure there is always money available to buy food (particularly beans and maize) if there is a shortfall.

Piggy bank!

It seems that crop diversity may play a role in this. Livestock, in particular pigs, are used as a kind of ‚piggy bank'. I observed how villagers hurriedly bought young animals straight after harvest of major seasonal cash crops (such as beans, maize, coffee) in order to bridge any potential food shortages. The role of crop diversity on income is continued in the following section. Although most households buy "little" of their food (less than 10%), there was no significant relationship between those that are buying more of their food and farm size or species richness.

> "*Cacao has fruit all year around, so there is money on the tree to buy food if we need it!*" Faustino, ‚Diversified farmer', Caños los Martinez.

2. Income diversity and stability

How do farmers manage crop diversity to for income diversity and stability?

Income is another key driver of diversification. Farmers accounts suggest that agroecological diversification has increased the number of crops they sell and enhanced net incomes. Farmers explained that access to cash is critical to pay for medicine, childrens school and buy food they cannot grow (oil, sugar, salt) and have security in the case of failure of a staple crop. It seems that farmers manage crop diversity for income in a number of ways: productivity (amount of income), stability (over the year) and resilience to market / biophysical shocks (buffer effect).

a. Diverse income sources

All farms produce multiple crops which provide an income. Across the 30 agroecosystems, there is an average of 6 crops per farm which provide an income, with a minimum of 2 and maximum of 14. 67% of the families reported that the amount of produce sold was "small" (1-25% of total production) and 30% (mostly ‹business farmers' and ‹diversified farmers') sold a "considerable" amount (25-50%).

Cinnamon processing

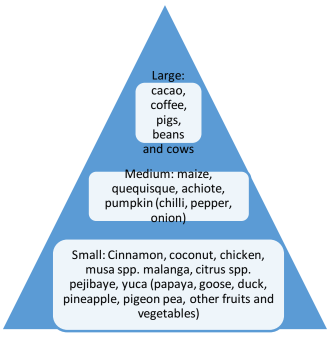
Farmers accounts suggest that maintaining multiple income crops helps to distribute income through the year and also acts as a buffer to both biophysical (heavy rains, pest and disease, seasonal drought) and economic (market price variability and demand) risks, thus stabilizing incomes. Therefore, although income for each crop may not be stable year on year, the stability of income at a farm scale is stabilized. Figure 1 demonstrates the 34 crop species which provide an income across the 30 farms; most common species include beans, bananas, malanga, less common higher value crops include pigeon pea (for seed), chilli (for a local exporter) and achiote. Farmers say fruits such as orange, avocado and mango ‹almost have no value' in the market and so they do not grow commercially.

Achiote seed: a popular spice which farmers say has a good price

b. Contribution to income

In the diversity tool, farming families ranked crop species by those which provided a small, medium and large contribution to income. The most common responses are illustrated in fig 10 below. This highlighted that many households are dependent on a small range of crops for a large proportion of their income.

Figure 10: Contribution of crops to income



When this is cross-referenced to figure 6 – we note that some crops which are more important for income, are also those which are considered more vulnerable, particularly to pest and disease – such as beans and coffee. The combination of these factors could be placing farming households in a vulnerable position in the face of biotic and abiotic stresses. Those products which provide a large / medium contribution to income are commonly sold to commercial buyers in Waslala. Those which provide a small income are commonly sold within the community. This diversity of markets may be an additional resilience measure.

d. Income per Manzana

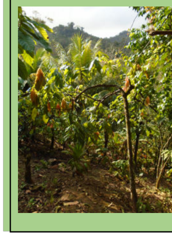
Rough calculations of farm income for were made with farmers[5]. When calculated by manzana a large difference was noted between farm types. ‹Resource poor' farmers had an average income of $23/yr/Mz, ‹business farmers' $237/yr/Mz, the highest being ‹agroecologically intensive' farmers $257/yr/Mz, demonstrating that this strategy can increase income per Mz.

However, statistical analysis shows that income is independent from species richness, with no significant relationship (r=0.054), an indication that crop diversity has little impact on the amount of income.

> "*…if you have a cow you can sell it if you need money..for medicine, the house or to buy food*" Angelina, ‹Diversified farmer, Santa Rosa

Box 2: Agroecological intensification strategy

Vilma is an ‹agroecologically intensive' farmer on only 3.5Mz she has 35 different species, mainly edible. She achieves high cacao yields, which she partially attributes to high levels of diversity, particularly bananas which enhance humidity, pigeon peas and canavalia to improve soil quality and reduce pest pressure from moles. Moreover, in areas of developing cacao she also has a ‹nurse crop' of beans / maize in order to maximize the use of space. By using these multiple agroecological diversification strategies, Vilma is able to generate a relatively high income of $400USD per manzana / year.



c. Seasonality / stability of income over the year

The use of the cards in the diversity tool enabled analysis of the seasonality of income crops. Although there were gaps, particularly during the scarce season, as a whole it was clear that farming families were managing diversity to maintain a fairly stable income over the year. Some income crops are distinctively seasonal – such as coffee, beans and achiote, whereas cacao produces pods year around (with two peaks of production over the year), making it key in income stability. Livestock is another source of income year round, although milk production declines during the dry season, the potential sale of the whole animal is a possibility all year around, offering an essential function as a bank account / insurance in times of crisis. Some crops were also used to provide income in the scarce season, for example pigs, some fruits, pejibaye and roots, tubers and bananas, however farmers explained prices were low.

Box 3: Using waste produce

Faustino, a ‹diversified farmer' in Caños los Martinez, explained that the crops are diversified, but the markets are not. Walking in his farm there were grapefruits and oranges on the floor.

"*..I have a lot of produce I could sell like mangoes, avocadoes and yuca, but often it is wasted… the transport to Waslala is expensive, the crop sometimes damages and they don't give good prices in the market….*"

Instead, Faustino feeds excess produce to fatten pigs which have a better price and more economical to transport to market. He also sells and exchanges a small volume of produce within the community.

e. Distance / access to market

As farms are very dispersed, some over 2 hours walk from the village centre, distance to market was calculated on the time it takes to reach Waslala from the farm. No significant relationship was identified between distance to market and species richness. Even in villages closer to Waslala, farmers explained that selling fruit and vegetables was not profitable due to very low prices, thus the diversity of crops farmer can sell is limited. This finding is contrary to Bioversity International studies in Vietnam which found that that crop diversity was greater in towns closer to market, namely due to market opportunities.

The cost of transport and low prices in the market were frequently mentioned as the key reasons for not commercializing more producets, some of which is wasted (box 3).

5 This process was challenging as income tends to come in small amounts over the year, thus calculations were mainly based on farmers estimates of income per crop for last year. Calculating by manzana is to enable comparison per farm, but perhaps not a fair measure as some farms have large areas of forest. Amount is in USD as per exchange rate on 12.8.16, xe.com.

f. Experimentation with new crops and markets

Another explanation for diversity is to experiment with and establish new crops. For example, Pablo planted maize and beans in a field of establishing cacao. He described how this both functions to provide an income until the cacao starts producing, reduce pest pressure and to some degree offer a little shade to the small cacao plants. Others mentioned that the combination of annuals (grains, vegetables) with perennials (fruit trees, cacao, coffee, nuts and spices) is a way to manage the time it takes to get returns. Moreover, cacao agroforestry systems present an opportunity to integrate and ‚trial' new crops – such as spices (cinnamon, cardomon) and fruits (rambutan and starfruit) with minimal risk. In this sense it is clear that the land use in many farmer's fields is in fact more dynamic and adaptable than what we see in a single snap shot visit, with many land uses in ‚transition' from one land use to another.

g. Crop diversity and labour

Figure 11: Relationship between labour and species richness

A weak positive relationship was identified between on-farm labour availability (number of daily workers) and species diversity, which was not statistically significant (r=0.136). It is important to note that labour is more fluid than this calculation suggests, as additional workers (family members and contracted) are available to help with peak labour demands for harvest, sowing and "chapeando". Farm households who have off farm income (in the form of casual farm labour, village shops or remittances from children living in town) tend to have lower crop diversity. This relationship is statistically significant r=-0.4. It is assumed that these households are also generally buying more food and thus are less dependent on agroecosystem diversity. More families seem to be taking this strategy as Waslala grows.

Farmers had different opinions in regards to the impact of agroecological diversification on labour demand. Some felt that increasing crop diversity was a way of spreading labour demand across the year, as the peak for different crops are at different times. Others felt that increasing diversity, demanded more labour in order to manage them well, for example pruning in agroforestry systems and for this reason chose to focus more on less species in the future (see box 4). This clearly also depends on the portfolio of crops that the farmers select, for example farmers explained coffee has high labour demands at peaks of the year – normally requiring contracted labour, whereas cacao is harvested all year around and can mainly be managed by the farming family.

Box 4: Is managing crop diversity more work?

Less Work: Chispa, Diversified farmer, El Chile
Walking through his cacao, Chispa explained that diverse systems did not require more work, especially due to focus on perennial crops which needed less attention. He also showed me how interactions between some crops limited the need for labour, in particular weeding in agroforestry systems. "*The weeds always stay small where there is shade and so there is less work to do*"

More Work: Juan Antonio, Diversified farmer, Santa Rosa
Juan Antonio has a young family and manages much of the farm on his own. He felt he did not have enough time and was intending to reduce diversity to focus on those crops which generated income. He had removed most of his shade trees in cacao (partially due to an accident in which he fell when pruning) and is planning to move more land pasture, energy banks for forage crops and cabbage and peppers for home consumption and sale. He was also considering to move beans and maize into cacao production as it is a more stable crop.

3. Climate resilience / Microclimate regulation

How do farmers manage crop diversity to enhance resilience to climate variability?

Climate variability, in the form of more irregular rains, uncertainty in the timing of the seasons and more extreme climatic events were frequently mentioned by farmers throughout the study. This has serious implications for the start of the seasonal rains and planting dates, which farmers say have shifted from November to December (and even January) for the ‘apante’. Moreover, unseasonal daily changes, such as heavy rain and then hot sun stress the plants (Technician, FUMAT, pers. comm, May 2016). Although meteorological records for Waslala are only available since 2013, records suggest that precipitation levels in November and December are lower than are required for optimum plant development and inconsistent over the three years (William Muños, CATIE Waslala weather station manager, Pers. Comm, April 2016 / Data: CATIE, 2014).

> "*It should be summer and it's raining – it was well marked before….now you don't know if the (‘primera') rains are coming in May or June*" Alfonso Diversified farmer, El Chile

In the household survey, 68% of farmers reported climate variability as a key constraint to production, 57% unseasonal droughts and 63% unseasonal heavy rains. Increasing unpredictability of climate is complicating cropping system management, and many reported high levels of crop loss in basic grains this year due to unexpected droughts at flowering and heavy rains at harvest (which caused losses of up to 50% due to sprouting of beans). Moreover, farmers reported that deforestation, particularly due to the rapid increase in large scale cattle ranches have also impacted the local micro-climate making it hotter and drier.

Box 5: Agroecosystem manipulation for climate functions

Marbeliz is a ‘diversified farmer' on 10Mz in El Chile. She explained how she is manipulating crop diversity in order to optimise certain climate functions.

Firstly, breadfruit trees on the borders of a low lying area of her cacao which was previously prone to water logging. This ‘*caliente*' tree ‘sucks the water' providing a drainage function, maintaining a drier environment and reducing the incidence disease related to high humidity (monillia and mazorca negra).

Marbeliz explained that other areas of the agroforestry system (AFS) can be prone to drought in the dry season. She chops banana trunks and distributes it through the crop as the ‘leche' (sap) of the plant creates a more humid micro-climate and also pools of water which provide habitat for pollinating midges during the dry season. She also used this method in establishing cocoa in a crop of beans and in her plant nursery. Another method was planting malanga – which likes humid conditions and sun – on the edges of the AFS to ‘aprovechar' (take advantage of) the humidity.



Many farmers reported that they are already seeking to use crop diversity to buffer the effect of climate variability and micro-climate regulation, in particular the ‘diversified farmers'. As reported earlier, in the diversity tool it was apparent that the majority of farming systems included multiple crops which perform the same functions (see figure 1) and that some crops are more tolerant to stress (figure 6). Farmers explained that having a range of crops provides insurance - if one crop was lost due to drought, rain damage or other extreme weather events, it was likely that other crops would survive, particular if the crop portfolio includes crop that are more tolerant to different climate hazards.

> "*Some crops, like beans and maize, don't like too much rain or too little rain. They damage. So that is why we also grow other crops like yams and bananas that are stronger*" Business Farmer, Caños los Martinez

a. Farmers classification of climate resilience / regulation functions

It also became clear that many farmers are manipulating their systems in order to enhance climate resilience - key crop species and practices were identified by farmers. Functional characteristic groups were developed together with technicians in the consultation workshops and modified based on farmer's comments and emerging themes. During the diversity tool exercise, farmers classified crop species in regards to their actual and potential role in climate resilience and microclimate regulation functions. The number of farmers using each species is also highlighted in figure 1.

Table 4 below is a synthesis of farmer's classifications of species by climate function, as documented in the crop diversity tool, discussions and observations with farmers in their fields. These include both the functional traits (the benefits species deliver) and response traits (response to specific conditions). This process demonstrated that many have an acute understanding of the climatic functions of different species and are seeking to manipulate them in their systems.

Table 4: Synthesis of farmer classification of crops by climate functions

Functional characteristic	Species farmers frequently mentioned	Crop combinations / ABD practices	Negative implications / trade offs
Provide shade / cool environment	Coconut, caimito, areno, tamarind, zapote, avocado, jocote, inga, cedro, among many others. Typically "fresco" species	Intercrop with cacao / coffee to reduce temperature / sunlight and maintain humidity Many of these species have fine leaves which allow some infiltration of light and prevent heavy water drops which damage leaves /flowers Most shade trees are also used for timber / fruit / firewood	More shade more disease, trees with large leaves can cause large water droplets and leaf damage, pruning shade trees is a lot of work and can be dangerous Some say inga and tamarind attracts berry borer (insect pest)
	Mango, jobo, gliricidia	Plant in pasture for animal shade, some fruits / forage can also be eaten by animals	
	Granadillo	Granadillo maintains humidity, plant in grains, can help to prevent erosion and protect from heavy rains	Caliente species can have negative effect on grains including allelopathy and water competition
	Laurel	Although it is a caliente spp often planted in cacao/ coffee and grains as good timber	Caliente – allelopathic? But also attrachs lianas which are a big problem in cacao
Drainage / maintain dry environment	Braciaria	Provides root aeration to dry soil?	
	Breadfruit, acacia, eucalyptus	Plant in the area around cacao which Is in low area prone to flood (patanosa) - caliente species "chupa el agua" (suck the water)	Caliente species can have negative effect including allelopathy Breadfruit is quite slow growing
Maintain humid environment	Bamboo, mangali	"Pure water" tree collects water and creates a humid environment "no la chupa, caiga el agua", Plant near water source, café, cacao,	Bamboo can have pervasive growth habits
	Banana, plantain, guineo (musa spp.)	Trunk has a lot of "leche" - cut pieces and leave around young cacao plants to provide moisture	
	Pumpkin, macuna ('compost bean'), taiwan (napier) (napier) grass, monte (weeds)	Undersown in maize helps to retain a moist soil. Create a mulch to retain water Weeds maintain humidity in cacao in summer	Can be too competitive with maize - some say better to undersow after maize is established
	AFS shade trees - Guaba, ceiba, granadillo, chilimata, avocado	Planting vegetables / tubers (malanga / quequisque) on edges of AFS to utilise humidity	Too much humidity encourages fungal diseases such as monillia
Windbreak	Musa spp	Plant on borders / in belts in grains. Interplanted with young cacao	
	Natural forest	Leave selected areas of natural forest to break wind for grains	
	Sorghum, sugarcane, taiwan (napier) (napier), acacia, gliricidia, madrono	Plant in rows perpendicular to prevailing wind	

	Laurel, fruit trees, elequeme, gandul, yuca, mango, areno	Interplanted in grains to reduce wind strength	Trees in grains also compete for light. Many prune trees to reduce impact.

a. Extreme climatic events

Discussing the impact of extreme climatic events, it seems that in the past they suffered more damage from hurricanes and storms. Margarito, a ‚Business farmer' on 81Mz in Caños los Martinez explained how Hurricane Juana in 1988 caused a huge landslide on his farm which took over 8 Mz of land and nearly threatened his home. In response he planted over 4000 trees including pochote, cedro, laurel, pino, caoba and established coffee and cacao in agroforestry systems. He explained that he has not suffered from damage from hurricanes and heavy rains since.

"*It (Hurricane Mitch) didn't affect us much….the crops were not seriously damaged – there was still plenty to eat*". Isabel, Diversified farmer, El Chile

Farmers say that those cropping systems / land uses that are more structurally complex, in particular. agroforestry, are much more able to buffer from climate variation and protect production than those which are less, such as grains. Seasonal droughts as a result of climate variability are also an increasing concern. In recent years most felt that hurricanes have rarely had a major impact in the area. In particular, Hurricane Mitch, which had devastating effects in other parts of Nicaragua (Holt-Gimenez, 2002) was not seen to have much effect in Waslala.

Box 6: Mixing varieties to cope with climate variability

Emelia, a diversified farmer in Caños Los Martinez mixes seven varieties of beans, some which are higher yielding improved varieties, less tolerant to rains and extremes of heat, together with more resistant local varieties. The range of varieties also have different maturation lengths which permits a staggering of planting and harvest dates, reducing risk with increasing uncertainty of the start of the rains. ‚frijol regado' is a long maturing local variety which is suitable for broadcasting into crop residues and mulch, which Emelia says is more resistant to pest and disease.

b. ‚*Caliente*' and ‚*Fresca*'

Like farmers across much of Central America, farmers in Waslala classify plants as hot (‚*caliente*') and cool (‚*fresca*')[6]. This is part of a wider cosmological world view that also includes human pathology and plant medicines. Farmers explained that from a cropping systems perspective, it provides guidance on appropriate crop associations, interactions and micro-climate manipulation.

In farmer workshops and the diversity tool the species cards enabled farmers to classify crops as caliente and fresco and analyse the management and distribution across their farming systems. Table 5 below seeks to synthesize farmer's definitions and the most common classifications of species as discussed in workshops and during the diversity tool exercise.

Table 5 Farmer classification of *caliente* and *fresca* species

	‚Caliente'	**‚Fresca'**
Climate tolerance	Prefer dry, hot environments, more resilient to seasonal drought	Prefer cool, humid environments, with plenty of water, more resilient to heavy rain and water logging.
Microclimate provision	Maintain dry, hot microclimate	Maintain cool, humid microclimate
Shade tolerance	Generally shade intolerant	Generally shade tolerant
Leaf characteristics	Most trees lose leaves during summer. Low leaf density	Most trees maintain leaves during summer. High leaf density,
	Plant components (particularly leaves and stems) have little sap	Plant components (particularly leaves and stems) have a lot of sap - "full of water"
Competitive / negative interactions	Leaves of some species ‚burn': release (alleopathic?) compounds which impact plant growth, strong competition for water and nutrients and ‚take all the strength' of nearby plants	Too much humidity encourages fungal pests; Competition for nutrients.
Facilitative interactions	Create a drier environment, light availability in summer for grain crops	Shade in summer, maintain humidity and lower temperature, capture and spread water
Common location in cropping systems	Crop perimeters, living fences, in waterlogged areas, in open sun / higher fields, grains and pastures. Tend to be segregated.	Intercropped in agroforestry systems, patio and homegardens. Tend to be integrated.

6 Also noted by previous researchers in the region; Westphal (2002) and Staver et al (2011) however this topic is relatively undocumented and warrants further investigation (Charles Staver, Pers. Comm, 2016)

Typical species		
Trees	Acacia, eucalyptus, laurel, madero negro, jocote, guayaba, cedro, pochote, tamarind, teak	Inga spp, bamboo, mangle, green mamon, macueli
Fruit	Citrus spp., jocote, guanabana, pejibaye	Musa spp, papaya, nancite, passionfruit, avocado
Vegetables	Chile	Squash, cabbage, tomato, pepper, chayote,
Grains	Maize	Rice
Roots and tubers	Yuca	Malanga
Other	Braciaria, cinnamon, pepper, breadfruit	Sugar cane, coffee

‘*Caliente*’ plants are more tolerant to high temperatures and drought (Oscar, FUMAT, Pers.Comm, 2016). They tend to be plants which have farmers brought from other regions with drier, hotter climates. Despite drought tolerance, many say they “suck a lot of water” – generally having negative impacts on associated crops, which some speculate is related to root traits (Elisa, CIAT, pers. Comm, 2016).

“‘*Caliente*’ *plants make the soil dry, hard and infertile*” Diversified farmer, 23 Santa Rosa

‘*Fresca*’ plants are those which are more tolerant to high humidity, rain and prefer cooler temperatures. Unlike *caliente* trees, which lose their leaves during the summer, *fresca* species maintain leaves providing essential shade and maintaining a cool, humid environment during the drier summer months.

Interestingly, a small number of species are considered ‘*calido*’ or tepid, such as cacao. As such farmers talk about maintaining agroforestry systems ‘*calido*’, buffering from large fluctuations in temperature and moisture through the use of a combination of *caliente* and fresco species to maintain optimum ‘*calido*’ conditions for cacao growth. As such maintaining a fairly stable environment over the year that is neither to hot and dry during the summer, nor to wet and humid during the winter.

Figure 12: Distribution of caliente and fresca species by land-use

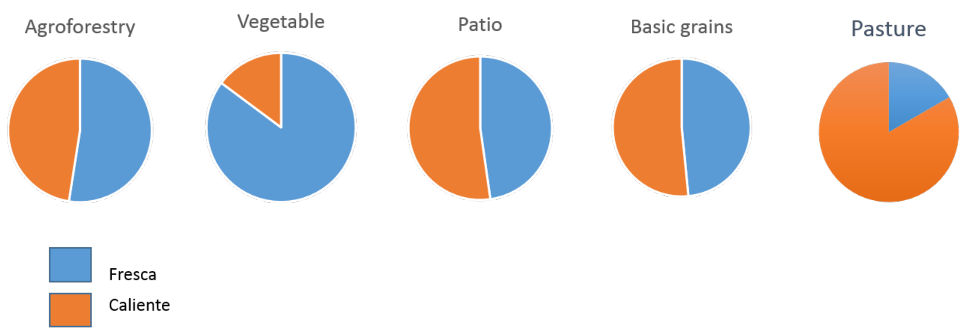


Figure 12 shows the split of species caliente / fresca species by land use type (based on data from all 30 farm). This reflects farmers comments that pasture and grains are generally composed of more ‘caliente’ species, which are more resilient to hot, dry weather and agroforestry systems and vegetable gardens tend to contain more ‘fresco’, species which are more resilient to wet, humid conditions. Farmers explain that more caliente species are integrated in pasture systems as they have less negative interactions (namely competition for water and ‘burning’) and it is easier to keep them apart – usually in ‘living fences’. Many of the species commonly used in living fences, such as gliricidia, acacia and leuceana are multifunctional; nitrogen fixers, forage and timber. Other *caliente* species such as laurel and jocote are scattered within the fields.

Caliente trees in a maize field, Santa Rosa Dudu

Although many say that *caliente* species should not be included in with basic grains (because of negative interactions), they commonly are. Namely species such as Laurel which farmers say are fast growing and provide good timber. This tradeoff is generally managed by heavily pruning these trees and leaving a mulch on the soil surface.

"*… we have to cut the trees if not the grains will stay small… laurel sucks the water before it arrives on the soil and the soil remains dry*" Pablo, diversified farmer, El Chile.

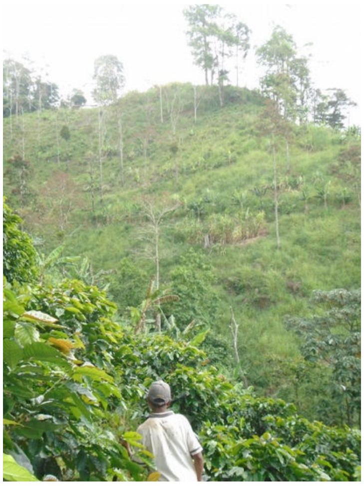
Discussions with farmers and observations of their systems indicate that farmers are consciously manipulate cropping systems with these characteristics in mind, to facilitate beneficial interactions and minimize negative. In particular, farmers select and plant favorable tree species and cut out non-favorable species depending on the land use and microclimate demands. Moreover, as farmers felt that a mixture of *caliente* and *fresca* species in the cropping system is likely to provide greater climate resilience at a farming systems scale. Both in terms of adjusting the microclimate and having species and land uses which are more resistant to different extremes of climate such as seasonal drought, heavy rains and high temperatures.

Some technicians and researchers dismissed this ‹folk science'. However, the *caliente/fresca* system is a practical way of farmers deal with the complexity of crop diversity. More research to explore biophysical characteristics of *caliente* and *fresca* species, such as water demand, rooting depth, water retaining properties and impact on microclimate would be of interest for further studies.

4. Soil Quality

How do farmers manage crop diversity for soil quality and nutrient cycling?

Waslala's tropical forest soils are classified as acrisols, which are typically prone to leaching, low in plant nutrients and highly erodible (FAO Soil map of the World, 2016). Farmers report that management based on the production of livestock and grains in swidden agriculture systems, became less sustainable as population density rose. With slopes of up to 80% observed, many report high levels of soil erosion and catastrophic landslides in 1980s/1990s. As cases of soil erosion became more dramatic, farmers explained it became a wakeup call that their farming systems were unsustainable and many stopped burning and began to diversify their systems, in particular by planting trees – in grains, pasture and establishing agroforestry systems, to seek to protect the soil and water resources.



Some farmers are seeking to reduce erosion on steep slopes by planting trees and living barriers

Remarkably, only 20% of farmers felt erosion was still a limiting factor to production (see figure 15). Farm observations show that evidence of erosion (gullying, exposed roots, and removal of top soil) was low in 53% of cases, medium in 42% and high in 5%, across all land-use types. Evidence of high levels of erosion were mostly identified in grains and pasture systems. However, this study was just a ‹snapshot' during the dry season, and there may be more erosion during the winter. Farmers suggest the reason for low erosion is in part due to the high level of soil cover with an average of less than 10% bare soil across all land uses. In particular, agroforestry systems had very low indication of soil erosion and high soil cover (namely leaf mulch). In grains, farmers suggest cover with crop and weed residues as well as the integration of trees play large role in preventing soil erosion.

"*we know the soil is lacking nutrients but no fertilizer is added as it is too expensive*" – Jacinta, Agroecologically Intensive Farmer, Caños los Martinez

27% of farmers identified declining soil fertility as a major limiting factor. On analysis of the systems in the diversity tool it was apparent that despite high levels of diversity there was limited flow of nutrients from one land use to another, for example in the form of compost or manure. Negative nutrient balances could therefore be the reason for declining soil fertility and yield response. Some farmers are addressing this by with the integration and association of crops to return nutrients to the soil, described below.

a. Farmers classifications of crop species for soil functions

During the diversity tool and farm visits farmers identified crop species in their agroecosystems which have specific functions in enhancing soil processes. These are highlighted by species in Figure 1 and broken down by specific function in the table below;

Table 5: Farmer classification of crops for soil functions

Functional characteristic	Species farmers mentioned	Crop combinations / ABD practices	Negative implications / trade offs
Soil cover / stabilization	Taiwan (napier) grass, papito, braciaria, forage peanut, squash, macuna, weeds, trees	Leave weeds and crop residues in grains to maintain cover. Undersow squash in maize. Quesungal system of planting trees in grains	Weeds compete with crops for nutrients and light
Fix Nitrogen	Beans, macuna, gliricidia, pigeon pea, acacia, canavalia, inga spp.	Macuna undersowed / in rotation with grains. N fixing trees intercropped in AFS and in living fences. N fixing trees pruned and scattered in grains (quesungal)	Macuna can climb up & choke maize (must be sown later). Some N fixing trees are 'caliente' – and take a lot of water
Living barrier / prevent soil erosion	Sugar cane, pineapple, yuca, pigeon pea, dormolina, canavalia, pinuela, musa spp., valeriana, taiwan (napier),	Sow along slope contour line in grains to stabilise slopes and prevent soil erosion	Taiwan (napier) grass is prolific & can take over. Time consuming to plant & maintain Digging up yuca could increase soil erosion by exposing the soil?
Increase SOM / soil condition	Bamboo, coffee, cocoa, pigeon pea, tree leaves and prunings (e.g. inga spp, gliricidia), macuna, zapatillo, weeds, Taiwan (napier) grass	Plant biomass contribute to SOM and mulch. Mulch of weed / crop residue. "paja"	Weeds compete with crops for nutrients and light Mulch may increase slugs
Provide nutrients (non N fixing)	Cows (N,P), musa spp (K), weeds and crop residues(coffee, cocoa, bananas etc) for compost / biofertiliser, worms (vermiculture)	Collect and spread manure, chop banana leaves in agroforestry, Cut and leave crop residues on surface to feed the soil Making compost from crop residues	Time consuming to collect manure as most farmers do not have corrals. Weeds compete with crops for nutrients and light Difficult to buy worms
	Caliandra, pigeon pea	Deep rooting crops which bring up nutrients	Some competition for light in maize – however open canopy minimizes the impact
Loosens compacted soil / grow on damaged land	Macuna, achiote, pigeon pea, bamboo	Remediates damaged soil, Will grow on compacted / damaged soil	Bamboo can become out of control

b. Increasing biomass inputs

The most common response was that agroecological diversification has contributed to improving soil quality by increasing the quantity and quality of biomass inputs. This includes tree prunings, cover crops such as macuna, taiwan (napier grass) and crop / weed residues. Farmers suggested this helped to increase moisture retention, reduce soil erosion and vulnerability to seasonal drought.

c. Working with weeds!

On first sight, the grain fields in all the farms I visited seemed to be overrun with weeds! However, I soon realised that farmers saw them in a different light. They were practicing no till, and direct sowing annual grains into a mulch ('paja') of weeds and crop residues chopped by machete. They did not refer to weeds

" *....the 'monte' in some ways is good. We cut it with machete and leave the roots in the ground and it helps the soil*" Elba, diversified farmer, Caños los Martinez.

Weeds provide a cover to protect the soil and are 'slashed and mulched' to cycle nutrients as ‚hierbas malas' (bad herbs), the typical Spanish word for weeds, but as ‚monte' a word which is used more generally locally to mean ‚wild' or ‚uncultivated'. Indeed, some farmers refer to certain weeds which are seen to have specific functions as ‚buenazas' (a word play meaning good weeds). For example, Taiwan (napier) grass, is a common weed in grain systems, however many value its properties in stabilizing the soil and providing biomass to replenish the organic matter back to the soil. Despite the trade-off between weed competition for light and nutrients and the benefit for soil quality, weeds may thus be seen as ‚unplanned' agrobiodiversity which also offers a function.

d. ‚Quesungual' system

In addition to the management of soil cover, many farmers have trees integrated in their grains (such as laurel, guava and cedro). They explained these trees were both selected and planted in order to support water retention, prevent soil erosion and provide mulch for the soil. Moreover, these trees are a source of fruit, nuts, forage, firewood and timber for construction. However, they also recognized trade-offs – in particular shade and negative impacts of ‚caliente' trees such as laurel which they say no maize plant will grow under. These trees are normally pruned (pollarded) and mulched or in some cases fed to animals.

This combination of practices forms part of a wider production system known as ‚Quesungual' which builds on traditional practices across this area of Central America. The key practices are rotation of maize and beans between dispersed trees, no burn, direct sowing, permanent soil cover, slash and mulch of natural vegetation and selective pruning of trees (Don Santos, Business Farmer, El Chile). Although traditionally from drier areas of the country, this practice is now being promoted in sub-humid areas prone to seasonal drought. Interestingly many farmers see it as a traditional technology that their grandparents were using in other parts of Nicaragua. However, farmers suggest that the modern maize and beans varieties are not as well adapted to these systems as criollo varieties, such as the climbing ‚cinaki' bean.

Pruned trees in basic grains

Box 7: Selection of species for living barriers

Lucia is an ‚agroecologically intensified' farmer on slopes of over 70% in Caños los Martinez. In the past her grain fields suffered from serious erosion. In response, she planted living barriers of sugar cane where now there is a noticeable build-up of soil on the upslope, which she explained was the most productive part of the field. Yuca and pigeon pea bushes were also planted in alleys with the grain crops. Although she had noted a significant reduction in erosion, there were still some signs of gullying, which may be due digging up the yuca and exposing the soil.

e. Living barriers

Other farmers explained how integrating certain crops as living barriers on slope contours has had a significant effect on reducing soil erosion, however farmer experimentation suggests that some crop species are more effective than others.

The multi-functionality of living barriers as both a soil protection method and also a food crop, forage or nitrogen fixer was also considered important in the selection of species. Pigeon pea is a fairly recently introduced species, also fixes nitrogen and is known to pull other nutrients up from deeper in the soil profile (JuanRamon, ADDAC pers. comm). Its deep roots also play a role in stabilizing the soil and minimize competition with the maize crop. Moreover, it is a nutritious drought resistant legume, which can be a replacement for beans, particularly useful during the scarce months from June to August (JuanRamon, ADDAC pers. comm and FAO, 2016b).

f. Soil fertility

All 30 farms included N fixing species in their systems, the most common being beans, inga and gliricidia, a total of 18 species. N fixation is important in these systems as the use of fertilizer and manure is relatively low (8 farms used artificial fertilizer this year (all in grains), 10 farms used manure and 10 used compost (namely AFS and homegarden). In fact, analysis of nitrogen budgets of the cacao agroforestry systems on farms engaged in the learning alliance show that the majority have a net N deficit, and some have a P deficit in their cacao agroforestry systems (Humid Tropics data, 2016). Some farmers chose to graze their livestock in their grain fields after the harvest. However, no farmers collected manure and spread it on the grain land. They explained this was because most livestock is out on the pastures, collecting manure from the fields can be time-consuming and is not considered desirable.

"*…I put the cows onto the field after harvest as it gives them food the pasture has dried up… they also eat the weeds and bring manure*" Leopoldo, diversified farmer, Santa Rosa.

70% of farmers are using green manures (fig. 4) including forage peanuts, canavalia, pigeon pea and Macuna. Macuna is locally known as ‹compost bean' and was traditionally cultivated by the grandparents of many participants. It is used in rotation with maize and beans and sometimes undersown. Many explained the challenge of replicating and maintaining the seed (as it is cut before going to seed).

In summary, many farmers in Waslala are harnessing key crops with particular functional traits, such as deep roots or heavy biomass, and using agroecological diversification practices to enhance soil function. The integration of some of these species and practices, in particular through agroforestry systems has largely reduced the frequency and severity of soil erosion and landslides.

5. Pest, disease and weed control

Perhaps not surprisingly, pest and disease were identified as a key limitation to crop production by 83% of farmers. The incidence of pest and disease is also considered to be increasing, which to some farmers relate to increased rainfall and humidity at key times in the year. A wide range of pest and disease were identified, those thought to cause the most damage being: Cacao: monillia, mazorca negra, gophers, squirrels; Coffee: berry borer, *ojo de gallo;* Maize: birds, *chicharra*, *mancha de asflato*; Beans: slugs; Vegetables: slugs, whitefly, crickets, caterpillars

Slug, Mancha de asflato (phyllacora maydis), monillia, gallina ciega (phyllophaga) image:generacionverde.mx

Overall the grains systems were considered to be the land use with the highest level of pest damage – in particular as it was harvest time all farmers were talking about slug damage in beans. This is also the land use with the least crop diversity (fig 3) and on which farming families are most dependent on for the production of food staples. The dependency on a small number of crops also means that if one suffers from heavy pest and disease attack then there are few other crops to replace them.

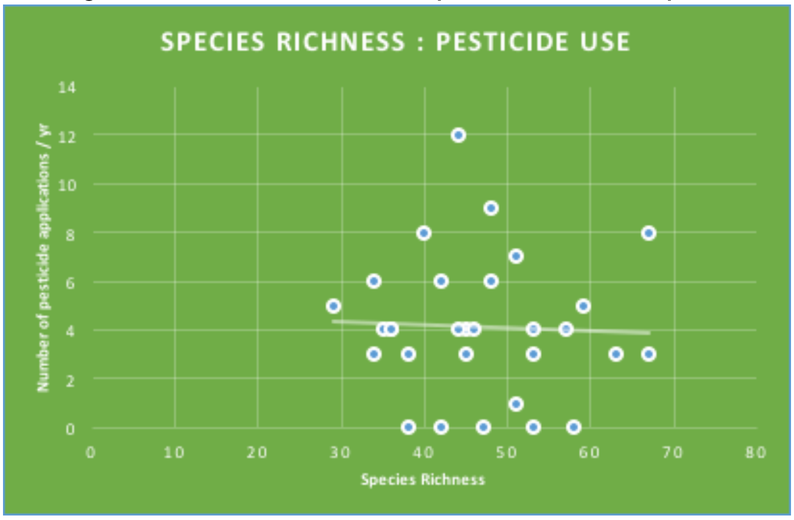
"*Where the crops are mixed it is harder for pest and disease to travel between plants…in cacao that is mixed with other crops monillia spreads less than if it is alone..*" Community meeting, Santa Rosa

Pest control is clearly a complex issue that requires a multi-pronged approach. However, discussions showed that many farmers are consciously using diversity to help mitigate the impact and enhance resistance to pest attack, particularly in agroforestry systems.

a. Species richness and pesticide use

The number of pesticide applications (all herbicides, insecticides and fungicides) per year was collected in the household survey. There is a minor, however not statistically relevant negative correlation between species richness and pesticide use. This suggests that in some cases having more diversity may reduce the need for chemicals. According to farmers there is a trade-off – as a diversity based approach uses more labour than a chemical approach (figure 13).

Figure 13: Correlation between species richness and pesticide use



It is also worth noting that farmers say the use of pesticide has increased since the ban on post-harvest burning. However, chemicals are expensive and farmers need to travel to buy them. There was also serious concern about the impact on health and contamination of drinking water. Many farmers are therefore exploring alternatives mixing ‚traditional' methods with those they have learned from local organisations.

b. Farmers classifications of crops by pest and disease function

The table below synthesizes farmers' classifications of crops by their function in pest and disease control as explored in the crop diversity tool, farm observations and informal discussions. The frequency of use of these species are indicated in figure 1.

Table 6: Farmer classification of species with pest and disease function

Functional characteristic	Species farmers mentioned	Crop combinations / ABD practices	Negative implications / trade offs
Habitat for natural enemies	‚Monte', natural forest, areas of regeneration	Biological corridors for natural enemies such as snakes, birds, frogs and beneficial insects	Less land in production. Need to manage venomous snakes.
	Guayaba, acacia, elequeme, laurel, pochote, gliricidia, cedro, orange, mango, guaba, leuceana	Plant in 'living fences' on borders (particularly pasture fields) – some species also serve to repel / distract pests (see below)	Time to establish living fences
	Shade trees in AFS	Intercrop with cacao/coffee to provide habitat for birds, snakes, insects	Too much shade can bring fungal disease
Repel pests	San diego, lemongrass, chile, garlic, guanabana, onion	Infused in water to make a spray. Some Intercropped in grains and vegetable gardens	Time to make sprays Some would like trainings
	Gliricidia	Make a spray / leave branches on edge of grains to repel rats. Some use as stakes in tomatoes to repel white fly and other pests. Also repels grubs (corhellero)	
	Canavalia	Plant in cacao borders – gophers are repelled by bitter taste and don't eat cacao roots.	
	Grapefruit	Toxic to slugs/weevils. Peelings left in grains.	Time / labour
Trap crops	Bananas	Leave skins / leaves / trunks in borders of grains / in between plants to attract slugs and kill them. Also attract pollinating midges.	
	Orange	Leave peels in borders of grains to attract slugs and then kill them	
	Macuna (frijol abono)	Some say slugs prefer to eat decomposing macuna cover than beans	Others say macuna increases slugs in maize crop
	Guaba, tamarind	Attract coffee berry borer, plant in and around coffee	Some farmers think they increase berry borer pressure on coffee
	Musa spp.	Attract bizote beetle away from maize, put in borders / windbreak	Some say they are too ‚fresca' and bring fungal diseases to grains

	Culantro, beans	In vegetable gardens to distract pests	
	Gandul, Sorghum, maize	Plant in borders around grains	Sorghum is not a crop farmers are familiar with
	Pejibaye, musa spp, mango, orange, avocado, guava, lemon, mammon chino,	Intercropped with cacao to give alternative food to squirrels and birds	Many say they still prefer cacao! Need to make sure there is an alternative all year around
	‚Monte' (weeds)	Some say that weeds provide alternative food for pests, in particular weeds.	Others say weeds increase pest pressure – in particular slugs
Suppress weeds	Macuna (frijol abono), forage peanut	Rapid, thick growth covers soil, in rotation or intercropped with maize. Climb up weeds making it easier to cut with machete. Forage peanut undersown in cacao Some say macuna slows down growth of weeds	Can climb up maize. Including in rotation with beans may increase disease pressure? Forage peanut is hard to establish
	Pumpkin	Undersow in maize - provides a cover to compete with weeds.	
	Cows / chickens	Post-harvest grazing of grain fields keeps weeds down, especially Taiwan (napier) and provides nutrients. Chickens eat weeds / pests in AFS.	Need to control chickens – can't have in vegetable garden
More resistant to pest and disease	Musa spp, pejibaye, coconut, guapinol, maize, malanga, yuca, breadfruit		

The diversity tool and farm observations showed that many farmers are using multiple strategies to manage weeds, pest and disease. However, it was also clear that although some farmers were aware of the functions mentioned above they were not always practicing them. Therefore, many of these options were also explored in section 2 – system optimization.

Diversified farmer Pablo with Canavalia on the border of a cacao / beans intercrop

c. Deterring pests

Over half of the farmers mentioned that they are using certain species which are repellent to pests. Some of these are living crops and some are processed into a spray. For example, some plant san diego integrated or on the borders of vegetable gardens. Living branches of gliricidia are used as climbing poles for tomatoes to deter insects and canvalia in borders of cacao and grains to deter gophers.

d. Distracting pests

A very common practice is the provision of alternative food for pests in cocoa agroforestry systems; fruits trees and pejibaye are included to distract pests such as squirrels from the main crop. Trap crops in other land-use systems were also mentioned, such as bananas in grain crop borders and beans in cabbage and tomatoes. However, this was less common and potential species were identified for future system redesign.

Pejibaye

e. Encouraging natural enemies

A smaller number of farmers reported the awareness and management of natural enemies in their fields and 10% are maintaining natural habitat for snakes, frogs and birds. Some explained that they selectively manage snakes – to kill only the venomous ones and maintain others to eat pests. Don Santos, a particularly innovative ‚business farmer' in El Chile, encouraged boa constrictors to live in natural habitat on his farm and felt that they were very effective in controlling pests, particularly slugs in the basic grains.

"Where there is diversity there are various things that eat pests. I prefer not to use chemicals as pesticides cause more problem with pests…I try to make my farm a good home for snakes, alacran (like scorpion, eats insects), spider, ants, and ‚grillo' crickets" Don Santos, ‚business farmer' El Chile.

f. Genetic diversity

It is common to integrate multiple varieties of the same species such as bananas, maize, cacao and beans (66% of farms), partly motivated by differential resistance to pest and disease. Josefa, a ‹resource poor' farmer in Santa Rosa explained how she had over 10 varieties of bananas which have different cooking functions but also responded differently to disease.

"*…the few people that lived here since the 1970 conserved criolla seeds of maize, beans, rice, cocoa, bananas, citrus and pejibaye. Residents who arrived from other departments brought seeds and adapted them to the zone. For example some varieties of maize such as NB6, Catcama, H5 are now ‹acriolladas' (localized)*" (Jose Ramon, ADDAC)

Variety of musa spp. Josefa's kitchen, Santa Rosa

40% of farmers also use local or "*criollo*" varieties which have been adapted to the agroecological conditions in Waslala, are namely varieties and landraces of maize and beans but also include pumpkins, ‹compost bean' (macuna) and chayote. Farmers say that *criollos* give more stable yields year to year, are more resistant to fungal disease caused by the humid conditions in Waslala and better adapted to the local climate. Farmers often maintain both local ‹*criollo*' varieties (such as *tuza morada / holotillo* (maize) and *vaina roja / guaniceño* (beans) and improved varieties. However, due to increased use of ‹improved' varieties and hybrids, the availability of *criollos* has decreased significantly (Jose-Ramon, ADDAC, pers. comm, June, 2016).

Box 8: Farmer breeders

A few innovative farmers explained how they cross varieties of maize to create ‹populations' which they claim are more resistant to extremes of climate. Don Chispa, a ‹diversified farmer' in El Chile, explained that he sowed mixtures of seeds of *holotillo* (*criollo*) and *maiotillo* (improved) together in the same field.

"*the improved is shorter and has bigger cobs, but the ‹gorgojos' eat it a lot, the criollo is more resistant but taller*"

Chispa explained that they ‹marry' (cross-pollinate) in the field and every year he selects those seeds which give the best yield and disease resistance. This developed a visibly heterogeneous mix of cob colours and sizes. Chispa claims that the yields are more stable year to year and incidence of disease is lower than in *maiotillo*, however the crop is only good for home consumption as the grain buyers need single varieties.

Chispa inspecting the waste maize cobs; heterogeneity in the mix; ‹gorgojo' (*Sitophilus zeamais)* (Image:www.integralhouse.com)

g. Suppressing weeds

Some crops were also included in order to suppress weeds, this includes undersowing pumpkin and macuna in grains and mani forrajero in coffee. Farmers comments also suggest that macuna has some alleopathic qualities which limit weed growth.

"*‹compost bean' (macuna) grow very quickly and make a thick cover, they affect the weeds, they don't like to grown there*" Vidal, diversified farmer, Santa Rosa

h. Negative interactions and trade-offs

It is also important to recognize that there are some trade-offs. For example, increasing shade and fruit trees in cacao may reduce pest pressure on cacao, but may also increase humidity providing optimum conditions for fungal disease such as monilia (Moniliophthora roreri). Similarly, the integration of new crops can also increase pest and disease pressure – for example farmers reported that the increase in the production of tomatoes had increased the amount of ‹*mosca blanca*' (Aleyrodidae) on beans and that inga spp. and mango increase levels of monilia in cacao.

Another observation was that although there is great diversity and field scattering across the farm – at a landscape scale there are localized monocultures of maize and beans as farmers across a community tend to take advantage of key areas of the landscape (higher, drier, lighter) to plant grains. This may therefore have an impact on the transfer of pest and disease, particularly as these fields do not tend to be rotated with other land uses across the farm.

Summary

This section has sought to understand how farmers in Waslala are currently innovating with crop diversity and explore the linkages between crop diversity and agroecosystem benefits from the perspectives of farmers. It highlights the complexity of managing these multispecies systems and the tradeoffs between different elements. In regards to climate, pest and disease resilience this is particularly due to the inclusion of a range of crop species tolerant to different stresses. Other crops were selected and managed for their specific functions such as pest repellency and nitrogen fixation. It is clear that crop diversity also plays a role at a system level in order to increase flexibility and adaptability to changing environmental and climatic conditions. Farmers can adapt annual crop mixes and distribution through the growing season, select and plant new species and remove unwanted species, use planned and associated agrobiodiversity. There are also trade-offs which farmers need to negotiate in their decision making – the resulting crop mix is a ‹performance' (Richards, 1987).

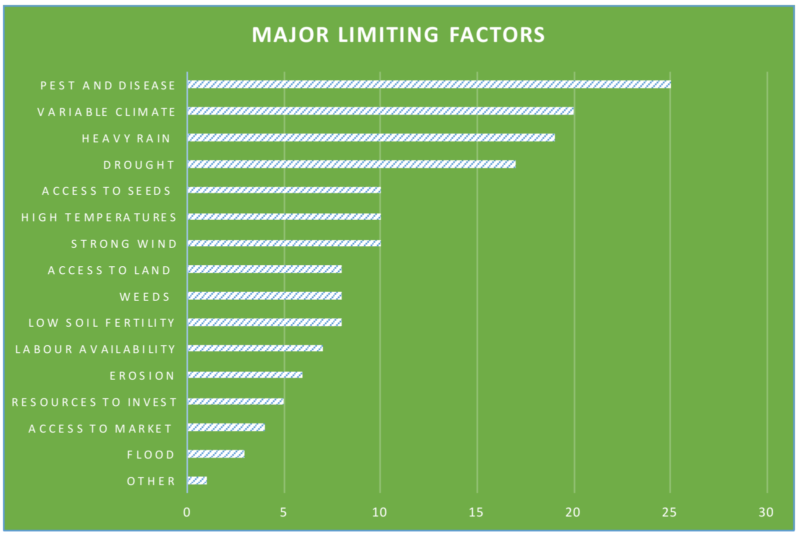
Section B: Future scenarios: Opportunities, barriers and potential interventions

RQ2: *What are the opportunities for optimizing farming systems using crop diversity?*

As we have seen, farmers in Waslala are pioneers. Over the last 20 years they have experimented with integrating new crops into their system. Section 1 sought to explore how farmers are managing this diversity and analyse the structure and function of diversity in their current agroecosystems. This next section outlines some of the opportunities for the future identified with farmers in the diversity tool, including possibilities for agroecosystem redesign and for optimizing the use of existing diversity.

1. Current limiting factors to production

Figure 14: Major limiting factors to production



Household surveys highlighted the main limiting factors as pest and disease (83% of farmers), variable climate (68%), drought (temporary / unseasonal) (57%) and heavy rains (63%) and access to seeds (33%) (see fig. 14).

These issues were discussed in more detail in the second part of the diversity tool. These were some of the key areas farmers chose to target in the potential redesign of agroecosystems.

2. Likely future scenarios

Together with farmers and local technician's likely future scenarios and potential challenges to agricultural production were identified. The most common was greater climate variability; which reflects CIAT climate scenarios which predict higher temperatures and heavier rainfall (Bouroncle et al, 2014). Local stakeholders suggest that these changes are also likely to have associated effect on pest, disease and crop production (Carlo, AMFVWG, pers. Comm).

Due to poor road conditions, transport limits access market

Waslala is also growing rapidly – farmers accounts show that immigration, population growth and expansion of the large-scale livestock sector is also placing increased pressure on land. It is likely that in the coming 20-30 years, farmers will need to intensify production onto a smaller area of land, particularly as farms are split for subsequent generations.

However, this growth is likely to be accompanied by improvements in infrastructure. The paved road from Matagalpa is planned to reach Waslala within the next 18 months, however improved roads into remote communities such as Santa Rosa Dudu are unlikely in the short-term. This could both open up market opportunities for products such as fruits and nuts, however it will also improve access for larger-scale producers to bring in produce which can be sold cheaper. Increased market access may also reduce the need for cropping system diversity, as produce could be bought. Market volatility for cash crops, is likely to continue – for example the bean price is currently high due to an export agreement with El Salvador which is likely to expire soon (Antonia, Pers. Comm). The potential role of diversity in adapting to these changing conditions, and to fill the gaps identified in the previous section was the final theme of the diversity tool.

3. Potential future strategies

In the second part of the diversity tool, potential future farm designs and uses of diversity to optimize the systems were discussed with farming families. Despite high levels of diversity – opportunities exist to utilise the crops and potential interactions between them to enhance the farming system and livelihoods of farmers. Farmer's knowledge of agroecological functions and microclimate regulation helped to inform the design of more resilient agroecosystems. As I learned from the farmers about what some of them were doing I was to some degree able to play the role of ‚knowledge broker' (Klerkx et al, 2012) to share ideas and experiences between farmers.

Although all farmers are currently managing high levels of diversity in their farming systems, some are considering different strategies to agroecological diversification in the future. Whilst some are keen to enhance structural and functional diversity, some farmers are choosing to reduce diversity and focus on a narrower range of (mainly cash) crops. These strategies are roughly grouped as;

- **Diversification** (increase diversity): farmers integrate new crops to enhance dietary diversity, agroecological functions and income diversity.
- **Intensification** (maximize use of existing diversity): farmers manage crop composition to maximize the use of land, to enhance beneficial crop interactions and to make the most of existing diversity adding value and finding new markets, system reconfiguration.
- **Specialization** (reduce diversity): farmers looking to simplify their system and focus on increasing production of a few crops such as cacao/ coffee, improved pasture, vegetables. Some removing staple crops such as grains and relying on income for food security.
- **No change**

Although currently most farmers are focusing on the diversification strategy, there is increasing opportunity for the intensification strategy as access to land becomes a more limiting factor. As market access improves there is also a chance that more may move more to a specialization approach. This therefore has implications on the type of future scenarios and interventions which local organisations should support and promote to ensure all farm typologies are supported which will be discussed in the following section.

Most farming families intend to use a combination of these approaches in order to optimize their systems and enhance socio-ecological resilience. There were also some patterns in regards to the farm typologies. ‘Resource poor’ and ‘agroecologically intensified’ farmers were interested to look at how to intensify land use with diversity and improve diet / income. However, there was heterogeneity among the ‘Diversified farmers’ some of whom were keen to look at how to diversify and incorporate more practices for agroecological functions and others were looking to select specific crops and combinations for specialization. Interestingly, the business farmers explored both options for new high value niche crops and opportunities for enhancing key agroecological functions.

4. Opportunities for system redesign

The species cards in the diversity tool played a useful visual role in identifying potential future species, and combinations. The proposed actions and species selection were documented for each farm, in addition to the key barriers to implementation and areas for support. The outcomes of this process were then discussed with local organisations to help identify potential interventions, facilitate information flow and to encourage action as a result of the study.

The table below attempts to synthesize some of the main opportunities for agroecosystem redesign / optimization that were mentioned by farming families and discussed with local organisations. The barriers to implementing them and the potential areas for support from organisations.

Table 7: Synthesis of opportunities for system redesign

	Opportunities for agroecosystem redesign / optimization	Barriers / risks mentioned	Potential solution / intervention identified
Strategy 1: Increase diversity (Diversification)			
Dietary diversity	Production of vegetables (cabbage, tomatoes, onion, peppers)	Varieties are not adapted to the zone (vulnerable to pest and disease and seasonal drought), most are imported hybrids from China and USA. Limited knowledge of horticultural production Access to seeds – need to travel to agrichemical outlets in Matagalpa and only sell in large quantities. New crops can increase pest and disease pressure (e.g tomatoes)	On farm experiments / participatory breeding to develop open pollinated varieties appropriate to zone. IPM and use of companion planting, trap crops and repellent crops (such as San Diego) Biointensive gardens. Drip irrigation, mulching, drought resistant varieties. More training on horticultural production / seed saving and opportunities to share knowledge. Local seed enterprise to replicate locally adapted open pollinated seed Promotion of locally adapted ‘under-utlilised’ vegetables such as cohombro, batata and criollo pumpkins.
	Introduce more crops high in iron (leafy green vegetables) and vitamin A (papaya and sweet potato fill seasonal gaps) to ensure year around availability.	Access to seed	Local seed enterprise to replicate locally adapted open pollinated seed Opportunities to learn how to save seed

	Alternative grains / protein sources (pigeon pea, ojoche, soya) which are more nutritious and resilient than current grain crops	Access to seed	Local seed enterprise to replicate locally adapted open pollinated seed Promotion and education on the health and ecosystem service benefits of Ojoche (maya nut).
Income	Integration of high value / niche market crops; spices (cinnamon, black pepper, achiote, cardomon), seeds (vegetables / green manure) ojoche, pejbaye, breadfruit. Sale of vermicompost / worms. Sale of vegetables Feeding excess fruits and roots to pigs as insurance / bridging income source. Maximize land productivity with increased use of multispecies systems, making use of layers, intercrops and undersowing. Use of species and varieties adapted to intercropping Integrate improved forages such as cratyila, caliandra (also N fixers) and energy banks	Limited knowledge of production / processing methods (e.g. cinnamon) Difficult to access markets and reach scale Farmers struggled to maintain worm populations Difficult to compete on quality with production from other regions of Nicaragua Managing negative interactions between crops Access to seeds of grain varieties appropriate for intercropping	Opportunities for learning and farmer-farmer knowledge sharing Participatory value chain study and formation of producer's cooperatives Training and support on vermiculture Develop markets within the community Farmer-field school approach to learn about managing interactions in multispecies systems Local seed enterprise to replicate and sell locally adapted seed
Soil	Integrate livestock to make use of manure in other land uses	Cost and labour, investment in corrals and / or fences	Some utilise manure of neighbours Loans for livestock investments? Living fences for multiple benefits
	Green manures (macuna, canavalia, pigeon pea, forage peanut)	Replication / maintenance of seed Difficult to establish forage peanut	Local seed enterprises Farmers experiments and knowledge sharing of impact on soil
	Living barriers (pineapple, bananas, yuca, valerian)	Some species take over (e.g Taiwan (napier)) Cost / time of establishment	Farmer knowledge sharing of preferred species?
	Vermiculture	Maintaining worm populations	Support development of local vermicompost / worm suppliers
	Integrate more trees – in particular those with known agroecological benefits (see section 2). Revival of the Quesungual system to prune and mulch N fixing trees.	Competition for light, labour to prune.	Local tree nurseries Further research into impact of quesungual and optimum management of interactions
Pest and disease	"Push and pull" – integration of plants repellent (push) and attractive (pull) to pests e.g borders of sorghum, bananas (pull) and san diego, lemongrass, chilli, gliricidia (push) intercropped in grains	Managing crop interactions is complicated New crops can increase pest/disease pressure	Participatory research focused on pests and natural enemies and push and pull effects of different crop / natural species, building on local knowledge
	Living fences - planting of trees in place of posts along field and farm borders, provides habitat for natural enemies and slows movement of pest / disease.	Labour and time for establishment	Farmer work groups Plant trees in existing fences
	Maintenance of natural habitat (especially humid forest) for natural enemies e.g. boas, frogs, birds.	Increasing pressure to bring land into production	Maintenance of habitat in agroforestry systems Ecosystem service payments?
Climate	Integrate more climate resilient ‚emergency foods' (RTBs, breadfruit, ojoche, yuca, pejibaye) to increase resilience to environmental volatility. (Beans and maize are more vulnerable).	Cultural preferences for maize and beans and stigma attached to ‚poverty foods'.	Raise awareness of these traditional crops and importance for food security and resilience Local nurseries and seed businesses
	Pasto de corte / silage to ensure food for animals in case of drought	Investment costs	
	Undersowing grains with macuna and squash and mulch to maintain water in soil.		
	Use of Criollo varieties, mixtures and	Seeds have been lost with introduction	Conservation and replication of criollo

	populations for drought tolerance and climate resistance (also for pest and disease resistance)	of improved varieties and hybrids	varieties. Crossing with new varieties?
	Mixture of species to maintain desirable micro-climate and a buffering effect to climatic extremes (e.g. resistant to drought and excessive rains, caliente / fresca)		Further research and experimentation
Strategy 2: Maximize the use of existing diversity (Intensification)			
Dietary diversity	Eat edible leaves of iron rich plants (squash, yuca, black pepper)	Knowledge of which leaves are edible or not	
	Processing of sugar cane (reduce cost of buying sugar)	High cost for investment in sugar press	Community owned and run sugar cane press
	Protect and expand area of RTBs and other resistant crops which could play a larger role in diet and food security such as malanga, pejibaye, ojoche, plantain, yuca.		Raise awareness of the importance of these food security crops. Maintain local varieties. Promote recipes and new ways to cook.
	Livestock for meat and milk (multiple benefits with manure)		
Income	Sell more fruits, pejibaye, roots Add value to fruits / roots – drying, preserves, sweets, chips, flours Feed waste food to pigs / other livestock Sale of timber	Low prices in the market do not warrant cost / time of transporting it Regulations within BOSAWAS reserve require complicated registration process to allow sale of timber	Support to develop local and international value chains, brand for ‚agroecological' produce? Off season production for other parts of country and local ‚Mercado campesino' Increased advocacy in process for sale of timber, training on forestry management, transparent supply chain
Soil	Use of manure Compost crop waste	Difficult and time consuming to collect. Easier to buy and apply fertilisers	
	Crop switching from basic grains to agroforestry on very steep slopes to reduce erosion and landslide risk	Investment costs and long leadtime. Although grains are facing more production risk, still a risky strategy to remove grains from the system.	Plant beans and maize in establishing cacao crop to provide a meantime income. Increased consumption of alternative staples (Malanga, ojoche, pigeon pea)
Climate	Staggered planting dates	Careful management required	
	Mixing varieties to buffer risk	Grains are difficult to sell in a mixture – only for home consumption	
Pest and disease	Improved rotations (integrate more crops and livestock, rotate pasture and grains)	Pasture land is heavily compacted	
	Intercropping to (e.g. undersowing pumpkin or beans in maize)	Modern varieties are not appropriate for intercropping – too much competition and beans don't grow well	Reintegrate criollo varieties which are more appropriate for intercropping
	Make foliar sprays with existing crops (e.g. san diego, gliricidia)	Time	
Weeds	Feed weeds to livestock / graze grains		
Strategy 3: Reduce diversity (Specialisation)			
Income	Put more land into cash crops (cacao, coffee, livestock)	Investment for trees / livestock Increased labour demands More vulnerable to crop failure	Access to credit Securer markets Crop insurance schemes.
	Intensify livestock production – energy banks and corrals	Corrals are expensive to build	Training on construction of energy banks and corrales
	Remove grains from system (as considered to be too high risk. Buy instead)	More vulnerable to food insecurity if cash crops fails	Crop insurance schemes
	Reduce production and increase off farm income	More vulnerable if food prices rise	
Climate / drought	Use improved varieties of beans and maize (CIAT /INTA) more resistant to drought / fortified with iron etc	Varieties are not developed locally and may not be adapted to the zone / may be more vulnerable to other stresses.	Participatory plant breeding Cross breeding with local varieties
	Purchase a greater amount of food consumed and rely on the market to provide dietary diversity	Vulnerable to changes in food prices and to low yields of cash crops	Social safety nets
Other	Take out shade and fruit trees from cacao / coffee agroforestry systems	Can cause stress to cacao/coffee plants, reduces dietary diversity, less intensive use of land, labour cost for tree removal	Support to select the best trees to remove / retain / prune.

5. Potential interventions and support

The co-design of future farming systems identified a wide range of possibilities specific to the context of each farm. As part of the ‘engaged research’ methodology these outcomes were periodically discussed with technicians and local organisations. Enabling joint learning and identification of potential interventions and support to farmers seeking agroecological diversification. Although there are no silver bullets below is a summary of the key opportunities and potential areas for support from local organisations.

a. Promoting the use of underutilized and neglected crops

A number of underutilized indigenous species – such as Ojoche (Bromisum alicastrum), breadfruit (Artocarpus atilis), quequisque (Xanthosoma) and pejibaye (Bactris gaesipaes) were identified as having huge potential – not only are they highly nutritious (ojoche is high in vitamins, iron and protein, pejibaye rich in vitamin A) they are highly tolerant and fruit during the scarce season (See box 1). They also provide additional agroecosystem functions (shade, soil stabilization, microclimate management, alternative food for pests) and the timber of ojoche is used for construction and furniture. These crops have been neglected with modern dietary preferences for maize and beans and are to some degree considered ‘lower status’. Efforts could be made to raise the profile and image of these crops, much like Bioversity programmes promoting traditional finger millet in Nepal. There are also emerging international markets for pejibaye (Marie Soliel Turmel, Pers. Comm 2016) and ojoche (www.mayanutinstitute.org).

Ojoche based food products (image: www.mayainstitute.org)

Similarly seed replication and promotion of local traditional vegetable crops – such as cohombro, batata, chayote and criolla varieties of pumpkin, maize and beans – may be more appropriate than the promotion of hybrid imported vegetables. They are more adapted to the local agroecological conditions. The combination of criolla and improved varieties was considered a desirable approach.

Another multifunctional species farmer considered a good opportunity for the future is the pigeon pea (Cajanus cajan) an edible legume which is also a quality animal feed. Although a relatively new crop to the area and not considered a key food crop, farmers experience suggest that they could play a key role in more resilient future agroecosystems due to their resilience to drought and role in soil quality. In particular, intercropped with maize to provide nitrogen, the key barrier at present is to replicate enough seed to reach scale.

b. Participatory research and varietal selection

As pioneer farmers, one of the key barriers to integrating new crops is adaptation to the local agroecological conditions. Hybrid vegetable seeds imported from China and the USA are promoted by local organisations due to the lack of locally adapted varieties, and these suffer heavily from fungal disease in Waslalas humid climate. Farmers and technicians suggested that locally adapted, open pollinated seeds should be developed. As such I collaborated with students at FUMAT who will begin field trials with farmers to identify more resistant varieties of tomato and cabbage.

Seeds available in stores in Matagalpa are all imported hybrids

Farmer led research into the role of different crops and natural habitat on populations of pests and natural enemies and soil health would also provide useful information for farmer’s decision making and scientific understanding of these complex agroecosystems. For example designing cropping systems to enable the ‘push’ of pests out of the crop and ‘pull’ to alternative food in borders.

c. Local seed enterprises

Farmers also expressed that it was difficult to buy seeds locally, and in the quantities they needed and which they could save and sow again. One idea explored was the development of local seed enterprises or cooperatives to replicate and sell open-pollinated seed. This could be particularly useful for those seeds farmers were struggling to access such as pigeon peas and macuna, vegetables, rarer trees species (fruits and spices) as well as recovering some of the criolla varieties. Moreover, there was interest in this idea, particularly from women as it offers additional income opportunities. It is important to recognize that there is some existing informal seed sale and exchange (in particular for green manures such as pigeon pea and macuna) and ADDAC is also working to revive neglected varieties through cooperative seed banks. So caution must be taken to build on existing networks rather than replacing them. Some farmers, such as Josefa, also expressed an interest in trainings to learn how to save their own vegetable seeds.

d. Diversified value chain for diverse crops

The diversity in the cropping systems is not reflected in diversity of income sources. Observations and farmers accounts showed that produce is often wasted, with fruits (including mango, avocado, grapefruit, oranges) left on the floor. Farmers explained this is because prices in the market are low and do not justify the cost of transport. Although a minority travel to Waslala to sell on the streets, this is a huge untapped resource. One idea proposed is a ‹Mercado campesino' (farmers market) in Waslala – which would provide a regular space for farmers to sell produce, potentially collaborating with others in the community. Local organisations are now discussing this idea with the district council.

Another option discussed, particularly as road infrastructure improves, is to develop value chains for key crops. National and export value chains could be developed for spices (cinnamon, cardomon, achiote), chilli, ojoche, pejibaye and other niche products. Potentially to be marketed as ‹agroecologically produced'. Support for farmers to sustainably sell timber through the complicated BOSAWAS regulations was also mentioned as a key opportunity to better capitalize on-farm diversity (Don Falguni, CIAT pers. Comm, 2016)

e. Adding value to existing produce

Solar dryers could add value to waste produce (image: energypedia)

Some farmers are taking advantage of fruit waste to fatten pigs for sale, an innovative way of adding value! Other options discussed with farmers and local organisations include cooperatives to dehydrate fruits (such as coconut and mango), roast nuts (such as cashews), mill specialist flours (pejibaye, breadfruit and ojoche – all gluten free and highly nutritious) and create preserves. Organisations mentioned that they could support to coordinate groups, provide training, access to low-cost technologies (such as solar dryers) and link to markets.

f. Farmer learning and farmer-farmer knowledge exchange

Farmers also identified that they would like more opportunities for learning. In particular, on pest and disease management in vegetables, seed saving and agroecological diversification practices such as building living barriers, using green manures and managing varietal populations of maize. It is clear that a more knowledge intensive approach is required to manage agroecologically diverse systems and maximize synergies and minimize negative interactions.

Training of youths through FUMAT technical college was identified as a key flow of new knowledge and innovation into communities. However, it appears that knowledge exchange tends to take place only within families and patriarchal networks. More opportunities for farmer-to-farmer knowledge exchange was therefore highlighted as a potential area for support. In particular, there is space for farmer-led experimentation with crop diversity for pest and disease management and soil health through approaches such as farmer field schools. Improved communication between farmers may also be beneficial due to consider the management of agricultural biodiversity at a land-scape scale.

Overall, what is clear from this process is that there are a number of options for the use of crop diversity in redesign and optimization of agroecosystems in Waslala. Moreover, there are synergies and tradeoffs with each crop choice and how it relates to the wider cropping system. There is no silver bullet and every farm is different; different crops occupy different ‹socio-ecological' niches for different farmers. There is a space for local organisations and the Learning Alliance to support farmers in these choices and provide interventions to enhance their impact.

Section C: Coproduction of knowledge and joint learning

> "*Traditional knowledge is deep but local, while modern ecological knowledge is general but shallow. Is it too much to promote a research agenda that seeks to combine those two*?" Vandemeer and Perfecto, 2013

This final section therefore seeks to reflect on the process of joint learning and co-production of knowledge as part of the study, relating to the third research question;

What was the experience of the ‹co-production of knowledge' and how did it contribute to learning?

The study aimed to bring together ‹traditional' farmers and me the agroecologist in a joint learning process to explore the role of crop diversity in the functioning of their agroecosystems. Combining farmers deep, ‹tacit' and practical knowledge, and my broad ‹scientific' knowledge, the intention was to deepen understanding of the dynamics of these complex agroecosystems. In particular, the relationship between agroecosystem diversity and function. Moreover, to use this new knowledge to develop practical implications for agroecosystem optimization and redesign, in collaboration with farmers.

As stated by Akpo et al (2015, p369) "Beyond focusing on outcomes, initiatives in multi-stakeholder processes should also document and analyze social processes in order to better understand the mechanisms by which such processes foster socio-technical change". The wider remit was ‹Research for Development' working in partnership with International and local organisations working in the CGIAR Humid Tropics NicaNorte Cacao Alliance, (including CIAT, Bioversity International, FUMAT, Fundacion Madres, ADDAC and APROMUWAS) to deepen understanding of how they may be able to better support farmers in Waslala. Therefore, the joint learning process also included staff at local organizations who participated in a cycle of learning and reflection. It is also important to recognize that this study was part of a Msc Agroecology –intended to broadly fit the research focus of Wageningen Chair Groups Farming Systems Ecology, Knowledge, Technology and Innovation and the Agroecology programme at NMBU, Norway. All of these social forces played a role in shaping this process.

1. Process of developing and adapting ‹the method'

What did we learn in the process to enhance and develop ‹the method'?

Building on previous work, staff at Bioversity International were interested to develop a new participatory methodology for analyzing agrobiodiversity. A number of options were explored including Companion Modelling (Perfecto, 2013), Fuzzy Cognitive Mapping (Ozesmi and Ozesmi, 2004) and Participatory Gaming (Speelman et al, 2015). With guidance from Marie Soleil-Turmel at Bioversity, we took inspiration from these latest innovations to seek to develop a participatory analytical tool which would provide a space for farmers and agroecologists to analyse these complex agroecosystems and explore opportunities for system optimization. We envisioned a tool which would facilitate rich dialogue between researcher-farmer and farmer-farmer. The assumption being that engaging more strongly with farmers would result in new insights into these systems and promote farmer learning. Although the original intention was to develop the method based in Nicaragua, due to time pressure most of this was done in CATIE, Costa Rica, prior to arriving in Waslala. Although developed in consultation with researchers who knew Waslala, based on previous studies and in communication with organisations on the ground, I had not visited a single farm or met local stakeholders. On reflection, developing ‹the tool' to some degree took over from focus on what it was we were trying to find out and the people we were seeking to support.

On arrival in Waslala, I took time to speak to local stakeholders and to visit farms, talk to farmers and start to ‘read’ these foreign agroecosystems. However, a visiting researcher encouraged me to ‘start collecting data’. The research environment I was in – fellow and previous students, researchers and technicians – were mostly physical scientists. I found myself trying to fit into the ‘research trajectory’ of the previous studies in the area - feeling pulled between the ethnographic approach I had originally intended and a systematic approach to working with farmers which was considered more ‘scientific’.

Box 9: Participation of local technicians

Marie and I tested the diversity tool method with local technicians and agriculture students in the technical college, upon arrival in Waslala. They were enthusiastic about a new way of working with farmers and helped to adjust the cards, correct the seasons and define functional groups. The tool was adjusted based on their feedback, for example to have fewer participants in the workshop.

Some (such as Miguel, middle) also supported me to develop survey questions and the observation tool and engaged in ongoing discussion throughout the study.

Two workshops of four people were planned to time with visiting researchers from Bioversity International. Due to lack of phone signal in the community, setting up the workshop required multiple visits to organize food and other logistics. It was bean harvest time and so workshops were planned in the afternoon. The room was hot, farmers were tired and there was not enough table space and chairs for all the participants. Moreover, it was difficult for me to consider the complexity of the context on each farm and support multiple farmers to map and analyse their systems. It became clear to me that our method was not designed for reality! This required some serious adaptive management.

The farm diversity tool method was therefore rapidly adjusted to work with farming families one on one (see ‘Methodology’ section for more details). This enabled all the tools (including farm transect and observation, typology survey) to be conducted in one visit, with the participation of multiple family members. I had assumed that a workshop would be a more efficient way of collecting information – but working one on one was much less logistically complicated. Moreover, spending time on each farm and in some cases working together in the fields, enabled a much deeper understanding of the specific context of each farm. This experience enabled me to build a richer picture of how farmers in Waslala are managing crop diversity.

During development of the method in Costa Rica, it was difficult to take into account the sheer complexity of these systems in Waslala. Thus some elements were not included that should be considered in future iterations. The cards only included cultivated crops – but associated diversity is equally if not more important, such as areas of natural habitat, insects and wild animals. This came out in discussions with the farmers and their accounts of how it is related to crop diversity. Moreover, the reality is that farmers manage a mosaic of land uses, and the boundaries may be more fluid than we grouped them in the tool.

Feedback from farmers suggested that mapping crops with the cards and the discussions around the configuration of species provided a new way of looking at their agroecosystems. Although some farmers took ownership of the process of mapping out their systems by taking the cards and creating their own map, in some cases I had to take the lead and read out / move the cards for them. Perhaps, taking away a degree of agency. On reflection this systematic method of seeking to reduce, categorise and classify farmer’s knowledge and practice into our scientific boxes may have contrasted with the more fluid farmer’s reality. In fact, management of crop diversity is an ongoing ‘performance’, an iterative process of dealing with complex interactions and responses to their actions. But such intricacies are harder to capture.

Although the study was originally intended to enable co-analysis of current and future farming systems *with* farmers, in the end it was more a method of analyzing the current systems *of* farmers, with a heavier emphasis on the collection of quantitative data than originally intended. The household survey provided essential insights to farm configuration, however the process of data ‘extraction’ did change the dynamic with farmers. Moreover, some farmers were more engaged and enthused by the process than others! In response to this I complimented the diversity tool with more reflective informal discussions on farm and a workshop in each community to bring it all together. Handing the baton back to the farmers in a less structured environment, they were engaged in discussing their own experiences and ideas for the future. I could also bring together different experiences as a ‘knowledge broker’ and feedback from local organisations. This qualitative information provided a wealth of information – but was also challenging to analyse and to present as empirical evidence.

2. Co-production of knowledge

How did the "coproduction" of knowledge between farmers and agroecologists play out in the field?

By making farmers active participants in analyzing their own farms, the process changed the roles of ‘researcher’ and ‘subject’ to ‘co-producers of knowledge’. This was not without its challenges, but overall feedback suggests that farmers found it valuable to have a space to look at their whole farming system, how it works together and how it can be optimized. Moreover, they said it helped them to reflect on and learn about the ‘science’ behind their practices.

Box 10: What do the farmers say?

"*..for me it was useful to be able to see all of the farm at the same time and think about the future*"
Vidal, diversified farmer

"*What you have to understand is that we are not educated, we don't know all these big words…like ‘agrobiodiversity'!*"
Leopoldo, diversified farmer

"*I really enjoyed to exchange experiences…It helped me to see that there are other ways to control pests on my farm….A lot of people (researchers) and we don't know much what they are doing!*" Margarito, business farmer

In this sense, the crop species cards may be seen as a ‘boundary object’ – "the material or abstract object around which people coalesce and act" (Almekinders, 2011). The cards acted as both a visual aid and a catalyst to facilitate dialogue and knowledge exchange, bridging my world with their own understanding of their systems, but also a space to open up wider discussion and exchange of knowledge. Working through the systematic process together meant that farmers were able to apply this knowledge directly to their own farm, identifying untapped opportunities and practical actions for system optimization.

Equally, without farmer's participation it would have been impossible to ‘read’ what was happening in their farming systems. The exploratory process of observing and discussing their systems helped to slowly paint a picture and understand them through their eyes, such as the role of weeds and *caliente/fresca*. Some farmers also reported that they felt more confident in the value of their own knowledge as a result of participating in the process and that it was a unique method of learning.

Learning for action

Although without the diversity tool workshops there was less opportunity for farmer-farmer knowledge sharing than originally intended, once familiar with some of the farms, I was able to play the role of ‘knowledge broker’ sharing experiences and learnings between farms. Moreover, the final workshops proved a valuable space in which farmers could share knowledge and experiences on certain crops and practices.

I regularly met with staff from FUMAT, ADDAC and Associacion Madres to discuss what farmers were telling me. Together with these stakeholders we identified strategies to help farmers. For example, we learned that many of the seeds that organisations were distributing were hybrids imported from China and not appropriate to the zone. In response to this I researched further the seed systems across the county and found that there was a lack of open pollinated seed of horticultural crops like cabbage, onion and tomato available in Nicaragua. Together we identified opportunities to work with farmer seed cooperatives to seek to make open pollinated seeds available in the future. In this sense, the co-production of knowledge with local organisations can contribute to positive change.

Farmers scientists

Jesus showing me the impact of his soil practices on worm populations

However, this experience of bringing together local and scientific knowledge was perhaps not quite what I envisioned. Firstly, I quickly realized that the ‘local traditional knowledge’ I expected to find and document was in fact situated, dynamic and learned. Secondly, the boundary between ‘local’ and ‘scientific’ knowledge was more blurry than I had imagined (as reflected in Argawal, 1995). These farmers I interacted with are pioneer farmers, bringing seeds and landraces from other places and experimenting in a new environment. Their ‘knowledge’ included both a scientific understanding of their environment (which was taught through training and extension) with a more tacit, day to day performance. One elderly ‘agroecologially intensive’ farmer, Jesus, was well read and had a table full of books on agroecological production practices when I arrived.

These boundaries between scientific and local knowledge were highlighted in other ways, particularly language. Farmers used local ‘agro-slang’ which embedded certain knowns about their systems and how they understand them. For example, the use of ‘monte’ to mean weeds which protect the soil and as a mulch. Equally, following a community meeting, one farmer commented on my use of terms such as ‘agrobiodiversity’ and nitrogen fixation, and that they were not educated enough to understand me. I realised it was important to be aware of how language could create distance and sought to discuss ideas and share knowledge in a more locally appropriate way. This was particularly important as many farmers were not confident in their own knowledge, and felt it was inferior to ‘scientific’ knowledge. Some felt that scientists should be coming with the answers. Moreover, the classification of farmer’s knowledge and practices into ‘boxes’ of agroecological functions was the act of translating farmer knowledge to scientific knowledge and deciding what was ‘valid’ knowledge and what was excluded therefore involved an act of power (Pottier, 2003). This may have ignored important elements in farmer’s understandings of their systems.

Planned or improvised?

Technicians and representatives of local organisations had different opinions about the degree to which these systems are planned or improvised. Although it is clear that farmers do seek to manage interactions in their systems and harness diversity for certain functions, it may also be considered “layout of different crops in a field is not a design but the result of a completed performance” (Richards, 1989, p40). For example, in addition to planned crop diversity, discussions showed that farmers also leverage “associated” diversity (self-sown trees are selected, maintain natural areas, “*buenazas*”). This has implications for how improvements can be designed and the process of planning a strategy / redesign for the future was perhaps new for some.

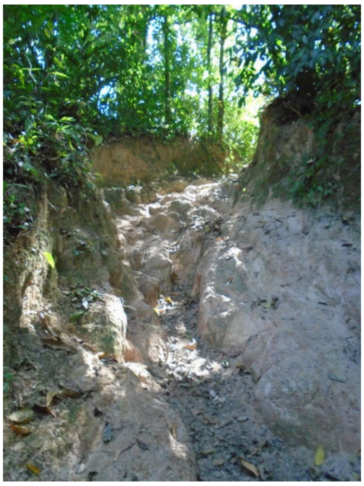
The intention to use the farmers brain to ‘model’ complex scenarios was perhaps a little too much expectation on the farmer’s time. It also says something about my belief as a ‘scientist’ that these systems are planned and can be optimized systematically. Perhaps it is most realistic to see that farmers do a bit of both, sometimes planning, sometimes performing. For example, it was clear that systems are to some degree managed for year around dietary diversity, however the crop mix on each is farm is likely the result of trial and error, selection of species as much as intentional planning as a scientist may consider it. This is also the case with species with many of the tree species with agroecological functions – they tend to be selected by farmers and those which are not considered beneficial are removed.

3. Reality of doing "engaged" research?

What lessons does this give about doing "engaged" research?

Safety and logistical difficulties

A key practical challenge both to myself and the local technicians who work in these communities every day is the complicated logistics. I under-estimated the impact this would have on my research. Most communities have very few mobile phones and very little reception. As such the only way to communicate with people is to go there. And going there isn't easy – with poor roads only serviced by occasional, overcrowded trucks! Within the communities, farms are very sparsely located, meaning it often took me more than an hour to walk between farms. And these are steep mountain trails in the forest. As such, another often unmentioned practical element of rural research is personal safety. I had been warned that there is a prevalence of violence and armed groups around some of these communities. An incident in El Chile in which I helped a young girl who had been violently attacked, meant that I was advised not to return and complete data collection. On a personal note, it was also difficult to be in very remote places alone, with limited support or people to share ideas and reflections with. These are the realities of conducting research in these remote places which warrant mention.



Walking in between farms was on rough trails

Challenges of "Research for Development" / engaged research.

Being an 'engaged researcher' was more challenging than I thought! Trying to meet expectations as a "scientist" whilst also trying to do something relevant and useful to farmers and organisations, I felt a tension between the rigor and relevance of engaged research (Levin and Ravn, 2007). It is challenging to keep to a predefined agenda and methodology vs adapting to changing local need and interest. To some degree it still felt like I had come to 'do' research rather than to engage local people in its design, namely due to time constraints. At the same time, it was also challenging to maintain true to predefined research goals when engaging a number of stakeholders and seeking to follow topics of relevance to them. It was also easy to get distracted by getting too involved in bringing about change, for example helping organisations find supplies of open pollinated seed.

As recognized by Levin and Ravn, 2007, there are also a lot of skills required including "understanding the dynamics of power....monitor, assess and improvise in the midst of dynamic, incalculable and ungovernable processes". A number of unexpected challenges arose and called for the need for adaptive management. It is also worth noting that this style of research places a lot of expectations on the time of farmers, technicians and local organizations who are under resourced. During the study period other researchers / organizations were going to the same innovative farmers who always participate! Another key reflection is that engagement of farmers does not necessarily lead to successful participatory research (Almekinders and Richards, 2007). Although farmers were engaged in the process, it was not truly built from farmers own research interests, but also those of me, the Masters student and a range of organisations, each with their own agenda in shaping the research. Future studies could seek to facilitate greater agency of farmers in the research process, whilst being respectful to their time. Learning from this process also highlights considerations for future development of more engaged research approaches.

This final chapter was inspired by 'technographies': the analysis of the process of making, how groups of actors and their practices come together around a task (Almekinders, 2011). Reflecting on the co-production of knowledge is relevant to deepen understanding of what happens when you bring farmers and researchers together, and has also aided my own personal learning.

Although it is unlikely that all that is important to the farmers was captured by the tools of the scientists. This research has to some degree already acted as a catalyst for change. Linking local organisations who are now approaching the local government in regards to establishing a '*mercado campesino*', growing momentum for the development of local seed enterprises and students are working with some of the farmers to identify more resistant and vulnerable varieties for further research.

Discussion

This study sought to explore the role of crop diversity on agroecosystem function based on the experiences and knowledge of farmers in Waslala. Results suggest that despite some heterogeneity, these ‹pioneer farmers' are using diversity to maintain relatively stable and resilient agroecosystems – providing key functions for their own livelihoods and for the sustainability of their farms. There are opportunities to enhance agroecosystem function using crop diversity, however, there are no silver bullet as every farm is different and so interventions must be tailored accordingly. Moreover, the results show that the co-production of knowledge is a promising approach to understanding these complex systems however present some key learnings for the future.

Relationship between crop diversity and agroecosystem function

Results suggest that farmers in Waslala do perceive a link between diversity and function, that they have a knowledge of the role of different crops and their interactions in the functioning of their systems. As ‹pioneer farmers' experimenting in a new agroecosystem, farmers report that integration of a greater diversity of crops over the last 20 years has been accompanied with improvement in system performance – including a reduction in erosion, improved water retention and lower levels of damage from extreme weather events such as hurricanes. Results show that overall, agroecosystems in Waslala and contain high levels of species richness and dietary diversity. Farmers are using a range of agroecological diversification practices such as agroforestry, green manures and intercropping which enhance both structural and functional diversity. Analysis with farmers demonstrated this diversity is managed to provide multiple functions and enhance the productivity, stability and resilience of agroecosystems.

Explorations of current agroecosystems with farmers highlighted a number of ways in which they are using crop diversity to enhance productivity, resilience and stability. Findings reflect the three hypotheses suggested by Vandemeer et al (1998), regarding the link between crop diversity and agroecosystem function; 1. Different species perform slightly different functions 2. There are more species than there are functions and 3. Those components which are redundant at one time become more important when some environmental change occurs. These concepts are explored below with a consideration for the role of diversity in the productivity, stability and resilience of agroecosystems in Waslala;

- **Productivity**

As a result of crop diversification farmers report producing *different species which perform slightly different functions* in the system. Namely the provision of a wide range of food crops which enable year around high levels of dietary diversity. Although some food groups, such as vitamin A rich crops and leafy green vegetables were less represented, results show a positive relation between crop diversity, dietary diversity and food security. Many farms also include multiple income sources and use crop diversity to manage income and labour productivity over the year, however many rely on a small number of crops for the majority of their income and food supply.

Many systems also integrate crops which support agroecological functions such as soil quality and pest control, which likely enhance productivity. For example, the inclusion of species which repel and provide alternative food for pests, enhance soil fertility through the provision of nutrients or prevention of soil erosion and the regulation of microclimate to maintain optimum conditions for crop production. Although further study is required to measure the impact on performance. Interestingly the ‹business farmers', who have the highest production levels are also those who harness the highest species richness.

‹Agroecological farmers' were able to generate the highest income per Mz, which suggests that careful crop mixing allows complimentary use of resources and facilitative effects between plants. Different crops have different demands for resources - due to different rooting depths, nutrient and light requirements and other plant growth characteristics and such ‹niche differentiation' can increase productivity per land area (Tilman et al, 1999). Moreover, farmers felt that facilitative interactions between crop plants can also have a positive effect on productivity – for example nitrogen fixing shade trees such as inga planted in cocoa. This therefore supports the theory that agroecological diversification could be a valid strategy for enhancing productivity and intensification of land use. However, farmer's experiences suggests that the selection and composition of crops is as important as species richness in regards to enhancing productivity.

Farmers also highlighted trade-offs of crop diversity on productivity, in particular competition for resources and negative interactions between plants (such as the impact of caliente species on crop growth, or the effect of excess humidity from cocoa shade trees in enhancing fungal disease), which warrants further study.

- **Stability**

Results also show that on the majority of farms, *there are more species than there are functions*. Most farms have high levels of diversity, integrating multiple crops which provide the same function in the system – for example nutrition, nitrogen fixation or income. This builds ‹functional redundancy' into the system, ensuring that the function will persist with the loss of key species (Vandemeer, 1998). Agroecosystems in Waslala tend to include crops that are considered more tolerant to climate stresses, pest and disease as well as those that are more vulnerable. Providing a buffer against environmental changes as per the ‹insurance hypothesis' (Yachi and Loreau, 1999). Thus even if some species are lost following a perturbation, others will survive, allowing adaptation to changing environmental and economic conditions. Income crops also provide additional stability as food can be bought if a key food crop fails. Moreover, as the agroecosystems studied tended to have several income crops this may enable them to maintain a more stable income, particularly if price variations for those products are not correlated (Malezieux, 2009).

Therefore, although the yield of one particular crop may not be more stable year to year, diversity provides greater stability of production at a farm system level. Farmers also referred to the temporal nature of diversity and how it helps to provide year around income. For example, the production of cacao which is harvested year round and the fattening of pigs on waste food during the dry season. Thus diversity helps to maintain key functions and stability of production over the year.

- **Resilience**

Results suggest that the integration of a diverse range of crops can enhance the ability of systems to recover by regulating the microclimate, have differing tolerances to biotic and abiotic stresses and providing services such as preventing soil erosion. Farmers explained that despite climatic variability and environmental shocks they have been able to maintain a sufficient level of productivity and stability at a farm level. Crop diversity can support the ability of an agroecosystem to "retain its organizational structure and productivity following a perturbation" (Lin, 2011). In particular, farmers accounts suggest that they were able to buffer the effect of Hurricane Mitch in 1998, suffering from very little soil erosion, landslides or economic losses, due to the increase in tree cover, in particular the use of agroforestry systems. Reflecting findings of Holt-Giménez (2002) who found that more diverse systems suffered less from hurricane damage.

Experience in Waslala suggests that it is not just diversity per se, but also careful selection of species to have a portfolio of crops that are tolerant to different hazards and regulate microclimate. Participatory classification of crop species by functional and response traits, identified farmers' perceptions of the role of specific crops in micro-climate regulation, tolerance to specific stresses and pest suppression. Farmers explained how they manipulate the interactions between system components to enhance resilience to climatic extremes for example, integrating crop species which create cooler environments, maintain humidity. In particular, the integration of trees was highly valued, particularly given the risks posed by steep slopes and heavy rainfall, creating systems which mimic natural forest ecosystems. Farmers proposed a number of ways in which diversity can provide greater resilience. Identifying some specific crops, crop mixtures and practices such as pigeon peas – food for people, soil and animals; vitamin a rich crop such as papaya and sweet potato and trap crops such as musa spp, sorghum and pejibaye to control pest damage. Moreover, methods to optimise and intensify the use of existing diversity such as on farm processing of fruits, manipulating microclimate and intercropping, were also explored. The classification of plants as hot (‹caliente') and cold (‹fresca') also provides guidance on appropriate crop associations, to maintain optimum growing conditions and micro-climate manipulation. In particular, the use of caliente and fresca species to maintain a ‹calido' environment for cacao. This reflects studies which show more structurally complex agroforestry systems buffer crops from large fluctuations in temperature, including heavy rains / storms / low rainfall and drought, keeping crops in closer to optimal conditions (Lin ,2007).

There are also species which *may appear redundant, at one time become more important when some environmental change occurs* (Vandermeer, 1998). Allowing for continued ecosystem functioning and provision of services. An example of this are the ‹emergency crops' such as breadfruit, ojoche, bananas and malanga which may be underutilized in a good harvest year, but provide insurance against main crop failure and food shortages. Food is also shared between farming families building resilience through landscape scale diversity and cooperation.

➢ Capacity for learning and adaptation

Although crop diversity is often considered to be based on ‹traditional' knowledge, experience in Waslala shows that farmers are actively increasing diversity based on a mixture of traditional and learned ‹scientific' knowledge. According to Mijatovic (2013) capacity for learning and adaptation is one of the key indicators of resilience. In Waslala diversification is not a simple one-way strategy. Farmers adapt and change, making decisions and weighing up the trade-offs between diversity, agroecosystem function, dietary diversity and potential higher returns.

"*Management of agricultural biodiversity is a dynamic process of continuous innovation that integrates new experiences and information into ‹traditional' knowledge and practices*" (Mijatovic, 2013).

It is also argued that diversity enables faster adaptation to change (Malezieux, 2009) For example the intercropping of beans and maize with establishing cacao means that farmers are able to adapt to changes in the grain markets (low prices) and increased levels of crop loss in recent years, with a longer term investment in cacao. "Intercropping a new crop with a traditional crop is also a way of cautiously entering a new market, without much knowledge" (Malézieux, 2009). Thus many farmers in Waslala are constantly experimenting, trying out new crops, changing the composition of their agroecosystems, and learning from their experiences. As Pioneer farmers / there is less "traditional" knowledge and more improvisation and learning by doing, influenced by the interventions of local organisations. Moreover, some ‹traditional' agroecological diversification practices have also been revived, such as the use of criollo varieties and the quesungal system.

Implications of the findings

This study has sought to provide new light on the role of crop diversity and agroecosystem function from the experience and perspective of farmers. Overall farmer's experiences reflect the idea that "more diverse systems with a broader range of traits and functions will be better able to perform under changing environmental conditions" (Lin, 2011 p184). This is important as more extreme events; particularly unseasonal droughts are expected in the future. Results provide an indication that there is a link between diversity and function, but not concrete proof. However, it is important to note that these interactions are also difficult to manage at a farm scale and negative interactions must be traded off with benefits. As mentioned by Vandermeer, 1998, it is difficult to prove either way if there is an impact of diversity on agroecosystem function. Although the diversity–function relationship can to some degree be empirically measured in ecosystems, in farmers' fields the relationship is more ‹messy', especially when we bring in socio-economic aspects of production such as labour, income and nutrition. Thus although diversity is not a solution to all problems for all farmers, the results of this study suggest that agroecological diversification could be a viable strategy for enhancing the productivity, resilience and stability of similar agroecosystems, however further study is required.

It also highlights that there are many challenges ahead, not least increased climate variability, pressure on land and farming on very steep hillsides. Diversity is of course not the only solution and other options are also necessary, but the results of this study suggest that it could form part of a multi-pronged approach with other practices. Together with farmer scientists, opportunities for agroecosystem redesign, using crop diversity to enhance resilience in the face of current and future challenges, such as overcoming micronutrient deficiencies, building up soils and adapting to climate variability were explored. This also gave space for ‚knowledge brokering' of classification of species and practices used by other farmers and information from scientific sources (such as ecocrop database and academic papers). It was clear that although there is no one silver bullet, there are number of common crop species and practices which farmers identified which may suit different farm contexts and strategies. Key barriers to diversification included access to markets and value chains for diverse produce, lack of seeds adapted to the zone and the complexity of managing multiple crops vs seeking to optimise a few. Strengthening access to open-pollinated seed through local enterprises, on-farm research and knowledge sharing and development of new value chains were some of the key areas in which organisations can support.

In designing interventions to support farmers it is important also to recognize the heterogeneity between farm types. Five groups or typologies of farms were identified: Resource poor, agroecologically intensified, part-time, diversified and business farmers. Each taking slightly different approaches to diversification and levels of species richness. Local organisations should therefore consider the needs of each – for example resource poor farmers need crop diversity options with minimal investment costs and land requirements.. Farmers also proposed to take different strategies regarding crop diversity in the future: Intensification (greater use of existing diversity), diversification (integration of more species) and specialization (reduction of diversity to focus on fewer core species). Farmers that are specializing could still consider the role of interactions between crops to enhance their systems. Future studies could elaborate further on the differences between these groups.

The value of this approach is that much of the analysis was done together with the farmer and local stakeholders, I plan to develop a short summary of the findings and implications to ensure the efforts of this research are fed back.

Limitations and future studies

This study was a somewhat ambitious endeavor! Seeking to measure the impact of diversity in farmers' fields, engaging farmers as scientists and working together with local organisations to seek to bring about positive change. Moreover, different schools of thought in natural and social sciences on fundamental aspects of how research should be done, made it challenging to bring them together. As such there are a number of limitations both in the methodology and to the generalization of the findings;

Firstly, it is important to recognize that this is just a snapshot of a particular group of people, in a certain place and time. A longer term study, considering the impact of different seasons could provide a more representative picture. The self-selection of the participants also means that they are perhaps those who are most willing and innovative, with more time and interest to engage. Although I made an effort to explore heterogeneity in the data, I am conscious I still make some broad generalizations about ‚what farmers do'. It was challenging to take the rich information collected from working with farmers one-on-one and synthesizing it to understand what is happening at a wider scale. As such I have perhaps fallen into the trap of suggesting ‚farmers are collectively rational' (Pottier, 2003). It is clear that every farm is different, but it is difficult to fairly represent this diversity. Moreover, as the majority of farmers in the study were ‚diversified farmers', and that farmers from some groups were more engaged than others, it also under-represents certain groups, in particular ‚resource poor' farmers. Future studies could therefore seek to better understand the variability either through a more quantitative approach and better use of farm typologies or through a more ethnographic approach which enables a deeper understanding of the context on a smaller number of farms of different typologies.

Another limitation was my lack of understanding of the context and experience of these farming systems. This also poses the question: Was I the right person to conduct this research? I would argue perhaps not! Ideally such an approach should be led by a local person who understands this world, local terminology and farming systems who is actively engaged with local organisations to take these things forward. As such the whole process could be better set up to be truly participatory and based on farmer's interests and needs. But on a positive note, having an alien on the farm perhaps helped these farmers to see things a little differently.

Farm system scale analysis

Despite the value of analysis at a whole farming systems scale together with the farmers, it also seriously limited the level of detail when dealing with such complex systems. Within the time and budget constraints of the study it was not possible to measure the impact on such a huge range of crop species, combinations and land-use systems. As such the analysis is a little too broad to provide meaningful results. Therefore, although some performance data was collected – such as observations of soil erosion, ground cover and soil texture, which provided some insight, it was not robust enough to include in quantitative analysis. In future studies it may therefore be desirable to ‘zoom in’ and collect more biophysical data on agroecosystem performance, such as soil tests, erosion levels, incidence pest and disease and yield. Although this would not yield the same understanding of how farmers are managing whole systems diversity, focusing on a specific agroecosystem function with farmers, collecting biophysical data and ‘local knowledge’ together could yield more valuable results.

The research questions were purposefully broad to be able to tailor to local interests, however a narrower focus may also have aided a more focused analysis.

Improvements to data collection tools

There are also a number of ways the data collection tools could be improved. Firstly, there were a lot of different tools that yielded a wealth of information, but some of which was redundant. A future study could better streamline the data collection tools. In regards to the diversity tool – not all species were included. Although there were spare cards to add species, it is likely that some were ignored, as such it could be that some of the underutilized and neglected species were excluded. The amount of information on the card was also perhaps a little overwhelming and some elements could be removed (such as crop function and growth form). 24-hour recall (as used by Remans et al, 2011) could also be a useful tool to relate the diversity of the agroecosystem to food consumed.

The diversity tool also did not allow the analysis of interactions between species to the detail that what we had originally envisioned, however we underestimated the complexity of these systems and as such seeking to explore. Computer-based models could facilitate deeper analysis of such information. A ‘companion modelling’ (ComMod) approach to incorporate farmer knowledge and experience could be beneficial to facilitate deeper analysis of the complex interactions, agroecosystem composition and explore potential scenarios for the future (Etienne, 2011). The diversity tool could also be adapted to create an agent based game which enables farmers to further explore scenarios, consequences of decisions and even landscape scale analysis with other farmers as part of a ComMod process (see Speelman et al, 2013). As the original intention was to develop a methodology which enabled group analysis of farming systems to also facilitate farmer-farmer learning, this could also be developed as a workshop. Such a collaborative process may also be more enjoyable for the farmer.

In order to better understand the different elements of crop diversity – species richness, ADDS and agroecosystem diversity practices perhaps a diversity score / index could be developed to bring these together. Additionally, diversity indexes such as Shannon could provide interesting insights into the impact of the composition of agroecosystems on function, but this also requires data on species abundance.

In regards to functional classifications, data was collected on the number of farmers who mention the role of each species, farmers who currently use and farmers who plan to use in the future. However, this was not included in the report as it was complicated to present with so many species, instead figure 1 was used to summarise the roles of each crop per main function. Future studies could seek to better analyse and present this data.

Ideally data would have been analysed using more professional software such as SPSS. Learning to use R was as useful tool, but a steep learning curve and as such the figures are not of excellent quality.

Potential further research topics

In the study many farmers highlighted an interest to expand their knowledge and understanding of natural enemies and biological control of pests. Therefore, another possibility for the future is collaborative research between farmers and scientists into the identification of natural enemies and their habitats to further facilitate the co-design of pest suppressive systems. More detailed functional trait analysis could also explore more the specific roles of each species and their interactions on soil, pest, disease and climate functions, for example looking at rooting depths, C4/C3 pathways, allelopathy and the traits of *caliente/fresca* species. This study was also perhaps biased in such a way to look more at the positive interactions between crops than negative. Future studies could seek to explore the trade-offs and negative interactions, such as competition, allelopathy and attracting pests in more detail. It would also be of interest to explore other agroecosystem functions in more detail, such as land use intensification and water quality and to explore the role of ‘associated' diversity. Although the method was intended to be participatory it was to a large degree top down, in particularly in regards to identifying the topic. Future studies could aim to be more stakeholder led by talking to farmers about areas of interest to them.

Despite all the challenges and limitations mentioned here, I think it is important to stress that the endeavor was to some degree successful! It was a very rich experience to help to understand what is happening in these complex agroecosystems from the perspectives of the farmers. The broad remit meant that analysis could some degree be tailored to specific farm contexts and farmer's interests. It was useful to document farmer's knowledge of crop functions and responses to stress. Although not everything could be captured by the tools of the scientists, the exchange of knowledge at a field level contributed to both my own and farmers learning and helped consider new visions for the future.

Conclusions

The co-production of knowledge between farmers, NGOs and scientists in the analysis and design of diverse farming systems took place through a participatory joint learning approach. In combination with other quantitative and qualitative methods, a diversity mapping tool acted as a ‹boundary object' to facilitate dialogue between farmers and scientists to explore potential opportunities for system redesign based on local and scientific knowledge. Links between agroecosystem diversity, function and resilience were explored together with farmers and local stakeholders.

As ‹pioneer farmers' experimenting in a new agroecosystem, farmers report that integration of a greater diversity of crops over the last 20 years has been accompanied with improvement in system performance – including a reduction in erosion, improved water retention and lower levels of damage from extreme weather events such as hurricanes. Although often considered ‹traditional' practice, farmers demonstrate that they are actively increasing diversity and experimenting with new species and combinations.

Main finding 1: Farmers in Waslala are managing diversified agroecosystems to enhance productivity, stability and resilience.

Results show that overall, agroecosystems in Waslala are highly diversified and contain high levels of species richness. Analysis with farmers demonstrated this diversity is managed to provide multiple functions and enhance the productivity, stability and resilience of agroecosystems.

- **Productivity**: Provision of a wide range of food, income and timber crops whilst supporting agroecological functions which enhance productivity such as soil quality and pollination, and enable the intensification of land use.
- **Stability**: Year around crop availability and diversity provides more stability at a farm scale – in the case of crop loss there is always something else to provide key functions.
- **Resilience**: Able to maintain productivity and stability despite climate and economic shocks. Integration of crops which regulate the microclimate, have differing tolerances to biotic and abiotic stresses and provide services which enhance the ability of systems to recover.

Participatory classification of crop species into agroecological functional groups and responses to stress, identified farmers' perceptions of the role of specific crops in agroecological functions and micro-climate regulation. However, it is important to note that these interactions are also difficult to manage at a farm scale and are association with negative interactions that must be traded off with benefits. Thus although it is important to recognise that diversification is not a solution to all problems for all farms, the results of this study suggest that agroecological diversification is a viable strategy for enhancing the productivity, resilience and stability of similar agroecosystems.

Main finding 2: The combination of farmer and scientific knowledge identified a range of opportunities to use crop diversity to optimize farming systems for the future

Together with farmer scientists and local organisations, opportunities for agroecosystem redesign using crop diversity were explored in order to enhance resilience in the face of current and future challenges. Identifying some specific crops, crop mixtures and practices as well methods to optimise and intensify the use of existing diversity. This also gave space for ‹knowledge brokering' of classification of species and practices used by other farmers and information from scientific sources. It was clear that although there is no one silver bullet, there are number of common crop species and practices which farmers identified which may suit different farm contexts and strategies.

Key barriers to diversification included access to markets and value chains for diverse produce, lack of seeds adapted to the zone and the complexity of managing multiple crops vs seeking to optimise a few. Strengthening local seed systems, on-farm research and knowledge sharing and development of new value chains were some of the key areas in which organisations can support.

Key finding 3: Participatory methods contributed to positive change and a new understanding of the situation for farmers and researchers, but can be challenging to implement successfully.

The collaboration between farmers, researchers and other local stakeholders in this process facilitated the production of new insights and perspectives that would may have otherwise been overseen. Seeking to understand these systems with the farmer agents who manage them led to the generation of new knowledge including the functional classification of crop species and potential future configurations. Reflection together with local organizations also enabled identification of areas for support, new dialogue between key stakeholders, opening up new potentialities for action.

An emerging insight was that seeking to identify and document ‹local knowledge' was ambitious task. Although local knowledge on crop diversity is often considered to be static and ‹traditional', knowledge on the management of crop diversity in Waslala is dynamic, situated and learned as ‹pioneer farmers' adapt to new agroecological conditions and experiment with new crops. Aligning with the discourse of farmers as innovators (e.g Richards (1985), Diversification can be seen as performance, and the resulting crop mixtures are an outcome of ongoing selection of species and adaptive management of the system.

It is clear that this study was ambitious in its intentions to bring together farmers and scientists, to provide information for action for a wide range of stakeholders, to bridge the natural and social sciences and to integrate qualitative and quantitative methods. As such we could assess that the study has to some degree been successful, however it also provides important learnings for future research. Despite the challenges of this ambitious endeavor, it does provide some hope for the role of participatory research in the future and its potential to lead to positive change.

In conclusion, ‹pioneer farmers' in Waslala have transformed the landscape and the functioning of their agroecosystems through crop diversity. These heterogeneous systems produce a range of crops for food and income throughout the year. Classification of crops into agroecological functional groups demonstrated farmer knowledge of different crops role in enhancing climate resilience, soil quality and pest control. Farmers experience suggests that careful selection and composition of species may contribute to increasing **productivity** through providing dietary diversity and key inputs to agriculture such as biomass, nutrients, pest suppression and regulation of microclimate. The production of multiple crops which provide the same functions, are harvested in different seasons and are tolerant to different stresses, may also be understood to enhance the **stability** of the systems over time and **resilience** to environmental shocks. Despite these indications, it is difficult to draw solid conclusions about the relationship between crop diversity and agroecosystem function from this study. However, the exploration together with farmers in their fields has shed some new light on the debate and also identified some practical ways in which they can seek to further enhance their agroecosystems through crop diversity in the future. This experience reinforces suggestions in the literature that farmers can play a key role in analysis of agroecosystems and in system redesign. Exploration together with farmers provides a deeper insight into theories which hypothesise a link between agroecosystem diversity and function, from the perspectives of those who manage these diverse systems. As farmers in other parts of the world are facing increasing challenges – climate variability, and feeding a growing population on smaller areas of land – experiences in Waslala suggest that agroecological diversification could be a viable option to increase system productivity, stability and resilience in the face of change.

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Appendices

Appendix 1: Key Stakeholders consulted

Elisa Rocha Valdivia, Falguni Guharray, Martin, Katherina Schiller; CIAT, Managua, Nicaragua
William Muñoz, Marlon Gonzalez Rodriguez, Sonia Tremino, Oscar, William; FUMAT, Waslala, Nicaragua
Marie Soleil-Turmel, Charles Staver; Bioversity International, Turrialba, Costa Rica
Eduardo Somarriba, CATIE, Turrialbla, Costa Rica
Esmelda, Cacaonica, Waslala, Nicaragua
Xacil, CEN Bosawas, Peñas Blancas, Nicaragua
Jenny Ordonez, ICRAF, Turrialba, Costa Rica
Nelly Granado, Martha Castro and Carlo at AMFVGW, Waslala, Nicaragua
Doña Doribel, Juan, APROMUWAS, Waslala, Nicaragua
Manuel & Brenda, Cooperativa Nueva Waslala, Waslala, Nicaragua
Jose Ramon Valenzuela, Otto, Ramon and Matias at ADDAC, Waslala, Nicaragua
Santos at Agroeco –agricultural inputs store, Matagalpa
Daniel at Agrifuerte – agricultural inputs store, Waslala
Fruit and vegetable traders in Waslala and Matagalpa
Evert Guiterrez, FUMAT student and field support, Waslala, Nicaragua

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Appendix 2: Index of Latin names of crop species

English	Latin Name	English	Latin Name
Acacia	*Acacia*	Laurel	*Cordia alliodora*
Achiote	*Bixa orellana*	Lemon	*Citrus limon*
Anona	*Annona reticulata*	Lemongrass	*Cymbopogon citratus*
Areno	*Unknown*	Leuceana	*Leucaena leucocephala*
Avocado	*Persea americana*	Macuna	*Mucuna puriens var utilis*
Bamboo	*Bambusoideae*	Madroño	*Garcinia madruno*
Banana	*Musa spp.*	Mahogany	*Swietenia macrophylla*
Bean	*Phaseolus vulgaris*	Maize	*Zea Mays*
Bee	*Anthophila*	Malanga	*Colocasia esculenta*
Beetroot	*Beta vulgaris*	Mamon_chino	*Nephelium lappaceum*
BlackPepper	*Piper nigrum*	Mamon_verde	*Melicoccus bijugatus*
Brachiaria	*Brachiaria brizantha*	Mandarin	*Citrus tangerina*
Breadfruit	*Artocarpus altilis*	Mangle	*Unknown*
Cabbage	*Brassica oleracea*	Mango	*Mangifera indica*
Caimito	*Chrysophyllum cainito*	ManiForrejero	*Arachis pintoi*
Caliandra	*Caliandra*	Melina	*Gmelina arborea*
Canavalia	*Canavalia spp.*	Mombasa	*Panicum maximum*
Carao	*Thunnus albacares*	Ñame	*Discorea rotundata*
Carrot	*Daucus carota*	Nancite	*Byrsonima crassifolia*
Cashew	*Anacardium occidentale*	Naranjilla	*Solanum quitoense*
Cedro	*Cedrela odorata*	Noni	*Morinda cirtifolia*
Ceiba	*Ceiba spp.*	Ojoche	*Brosimum alicastrum*
Chayote	*Sechium edule*	Onion	*Allium cepa*
Chicken	*Galliformes gallus*	Orange	*Citrus sinensis*
Chilamata	*Unknown (Chilmate)*	Papaya	*Carica papaya*
Chile	*Capsicum annuum*	Passionfruit	*Passiflora edulis*
Cinnamon	*Cinnamonum*	Pejibaye	*Bactris gasipaes*
Cocoa	*Theombroma cacao*	Pepper	*Capsicum annuum*
Coconut	*Cocos nucifera*	Pera	*Syzygium malaccense*
Coffee	*Coffea arabica*	Pig	*Sus spp.*
Cohombro	*Solanum muricatum*	Pineapple	*Ananas comosus*
Corncob	*Zea Mays*	Plantain	*Musa spp.*
Cratylia	*Cratylia argentea*	Pochote	*Pachira quinata*
Cucumber	*Cucumis sativus*	Poro	*Erythrina poeppigiana*
Culantro	*Eryngium foetidum*	Quequisque	*Xanthosoma sagittifolium*
Dragon Fruit	*Hylocereus undatus*	Rabbit	*Oryctolagus cuniculus*
Elequeme	*Erythrina berteroana*	Radish	*Raphanus sativus*
Gandul	*Cajanus cajan*	Rice	*Oryza sativa*
Garlic	*Allium sativum*	San Diego	*Tagetes erecta*
Genizaro	*Samanea saman*	Sonzapote	*Licania platypus*
Gliricidia	*Gliricidia sepium*	SourOrange	*Citrus aurantium*
Goose	*Anatidae*	Squash	*Curcubita*
Granadilla	*Passiflora ligularis*	Starfruit	*Averrhoa carambola*
Granadillo	*Dalbergia retusa*	Sugar Cane	*Saccharum officinarum*
Grapefruit	*Citrus paradis*	SweetPotato	*Ipomoea batatas*
Guanabana	*Annona muricata*	Taiwan	*Pennisetum purpureum*
Guanacaste	*Enterolobium cyclocarpum*	Tamarind	*Tamarindus indica*
Guapinol	*Hymenaea courbaril*	Teak	*Tectona grandis*
Guava	*Psidium guajava*	Tomato	*Lycopersicon esculentum*
Guineo	*Musa spp.*	Turkey	*Meleagris gallopavo*
Horse	*E f Caballus*	Valerian	*Valeriana officinalis*
Inga	*Inga edulis*	Water apple	*Syzygium malaccense*
Jicaro	*Crescentia alata*	Watermelon	*Citrullus lanatus*
Jobo	*Spondias mombin*	Yuca	*Manihot esculenta*
Jocote	*Spondias purpurea*	Zapote	*Manilkara zapota*

Appendix 3: Data collection tools

a. Household survey
b. Diversity tool guidelines
c. Observation tool (for transect walk)
d. Sample of crop species cards

Comunidad____ Fecha_______________ Investigador_________________________________

Nombre			
Numero Celular		**M/F**	
Tamaño de finca (Mz)*	**Propio**	**Alquilado**	**Familiar**

1. Cuantos personas dependen en la finca?

Para su alimentación	
Económicamente	

2. Cuantos personas trabajan en la finca?

Familiar (cada día)		Contractada (permanente)	
Familiar (ocasional)		Contractada (ocasional)	

3. Como se aproxima la cantidad de producción en la finca por autoconsumo, intercambio y venta?*

	Nada	**Poco**	**Medio**	**Mayoría**	**Todo**
Autoconsumo					
Intercambio					
Venta					

4. Como se aproxima la cantidad de la alimentos que consumen en la casa?

	Nada	**Poco**	**Medio**	**Mayoría**	**Todo**
Compra					
Produce					
Intercambia					

5. Cuales son las factores mas limitantes a la producción en la finca actualmente?

Baja fertilidad de suelo		Plagas y enfermedades	
Erosión del suelo		Malezas	
Vientos fuertes		Disponibilidad de mano de obra	
Lluvias fuertes		Acceso a semillas	
Inundaciones		Acceso al mercado (para vender)	
Sequia		Acceso a terreno	
Temperaturas altas		Bajos recursos para invertir	
Clima variable		Otro (explica abajo)	

(3 = Grande limitación, 2=Medio limitación, 1=Pequeña limitación, 0=No hace limitacións)

6. Cuales practicas de diversificación usan en la finca?*

Rotación de cultivos		Rubros intercalados	
Sistema Agroforestal		Uso de mas que uno variedad	
Sistema Silvopastoral		Plantas repelentes a plagas	
Abonos Verdes		Dar hábitat para enemigos de plagas	
Barreras Vivas		Dar comida alternativa para las plagas	
Frijol tapado		Sistema mixto (animales y rubros)	
Cultivos de relevo		Uso de pisos múltiples (parras, sombra..)	
Otro			

Explicación

7. Uso de las agroquímicas*

Agroquímica	**Granos**	**Pasto**	**Patio**	**SAF**	**Otro**
Pesticidas					
Herbicidas					
Fertilizante *Tipo* *Cantidad*					

Cuantos veces por año

8. **Área y rendimiento de los rubros mejores el año pasado (incluyendo metros de madera por uso propio y vender)***

Rubro	Área (Mz)	Rendimiento /Mz	Ingreso estimado (por año)
Total			

9. **Hay otros fuentes de ingresos al hogar fuera de la venta de productos?**

Fuente	Ingreso aproximada (por año)

10. **En las últimas cuatro semanas / la ultima época de escasez han pasado las próximos escenarios?***

	Ultimas cuatro semanas	Ultima época de escasez
¿le preocupó que en su hogar no hubiera suficientes alimentos?		
¿usted o algún miembro de la familia tuvo que comer una variedad limitada de alimentos debido a la falta de recursos?		
¿usted o algún miembro de la familia tuvo que comer menos de lo que sentía que necesitaba porque no había suficientes alimentos?		

(¿Con qué frecuencia sucedió esto? 0 = Nunca 1 = Pocas veces 2 = A veces 3 = Con frecuencia (más de diez veces)

11. **Como consigue consejos y conocimientos para la toma de decisiones y la innovación en la finca?***

Observación de la granja de otra productor		Atreves de los jóvenes que estudian afuera	
Discusión con vecinos y otros productores en la comunidad		Visitas a la granja de los técnicos y especialistas agrícolas	
Información dado en capacitaciones (cuales organizaciones?)		Conocimientos compartidos en reuniones con otros productores	
Información en el radio / periodical / posters		Conocimiento familiar / tradicional	
Experimentando en la finca		Otra (explica)	

12. **Por cuales razones / beneficios esta manejando un grande cantidad de cultivos en la finca?**

Mas resistente a riesgos climáticos		Bajar el daño por plagas y enfermedades	
Tener una dieta diversa y nutricional		Autosuficiencia - no hay que comparar	
Aprovechar interacciones beneficiales entre las plantas (sombra, nutrientes, MO)		Rubros de uso múltiple - madera, leña, medicina	
Manejar mano de obra durante el año (no todo el trabajo en una sola temporada)		Bajar riesgo de perder toda las cosechas – siempre hay algo	
Tener suficiente comida todo el año (seguridad alimentaria)		Intensificar el uso de suelo	
Tener varios fuentes de ingresos		Otras	

1) Especies que hay en la finca

Explicar las tarjetas y la información que tiene – grupo alimenticio, temporada de cosecha, uso, formar de crecer.

2) Diversidad nutricional

Cuales especies comen: colocar las en el papelón. Cuales grupos tiene ***mas o menos rubros****? Cuales especies dan* ***un grande, medio y pequeña*** *contribución a la dieta? (área y rendimiento de los mas importante en la encuesta si no hay)*

a) Hay tiempos del ano cuando hace falta un grupo o los que dan un grande contribución a la dieta? (Cual?) Que hacen durante estés tiempos?

b) Si hay perdidas grandes de un rubro importantes por la dieta, que hacen?

c) Cuales oportunidades hay para mejorar la dieta - aumentar la producción de unos rubros o integrar nuevas rubros para mejorar la dieta? Cuales?

d) Cuales son los factores limitantes para hacer esto?

3) Ingresos

Cuales rubros venden? Cuales rubros dan un contribución grande, moderada, pequeña a los ingresos? (ingreso anual por cada uno?/ rendimiento, área)

a) Hay tiempos del año cuando no vende productos o vende menos? Que hacen durante estés tiempos?

b) Cuales tienen precios muy variables?

c) Existe oportunidades para vender otros rubros o integrar rubros nuevos para mejorar / establacer los ingresos? Hay espacios en el sistema por ellos? Cual le gustaría vender? Porque?

d) Cual son los factores limitantes para integrar este rubro?

4. Intensificación agroecológica
En esta sección – escribir las respuestas macados con * en la herramienta de observación
Seleccionar los **usos de suelo** que hay en la finca. Marcar una área de cada uso de suelo y colocar las tarjetas.

a. Mire cada sistema de uso del suelo – que es **mas diversa y menos**?

b. ¿Hay cosas que **siembran** juntos / revueltos? ¿Cual? Porque?

c. Hay unas **interacciones positivas y negativas entre los rubros** en los varios usos de suelo? Ejemplos? Como manejan?

d. ¿Alguna de estas cosas sean más **vulnerables a los riesgos climáticos o de plagas y enfermedades**? Algunos son más resistentes? Son unos en que les dependen mucho por ingresos y comida?

e. Cualquier otras **asociaciones beneficiosas**? ¿Existen interacciones entre los usos de suelo?

i. Suelo

a. ¿Unos de estas rubros ayudan con la **calidad del suelo**? ¿Cual? ¿Cómo?

b. ¿Alguna de estas rubros **fija nitrógeno**? Cuales? Si aprovechan? Se puede noticar una diferencia?

c. ¿Alguna de estas cosas **protegen el suelo de la erosión**?

d. ¿Alguna de estas cosas **dan material orgánica y mejorar la biología del suelo**?

e. ¿Quales rubros podría añadir para mejorar el suelo?

f. Que son los factores limitantes para añadir lo?

ii. Plagas y enfermedades

a. ¿Alguno de estos cultivos o combinaciones ayudan a controlar **plagas y enfermedades**? ¿Cual? ¿Cómo?

b. ¿Alguno de estos cultivos son **hábitat de los enemigos** de plagas? (¿Las malas hierbas o áreas del monte / bosque también?)

c. ¿Alguno de estos cultivos proporcionan **alimento alternativo** para los plagas de otros cultivos?

d. ¿Alguno de estos cultivos se **repelen las plagas** de otros cultivos?

e. ¿Algunos tiene menos daño por plagas y enfermedades?

f. Qué podría añadir para estes beneficios?

iii. Riesgos climáticos

a. ¿Alguna de estas cosas ayudan a la resistencia a los **riesgos climáticos**? Por ejemplo:
   - ➢ Dar sombra (manejar un microclima fresco)
   - ➢ Mantener agua en el suelo (evitar la sequia)
   - ➢ Proteger de lluvias fuertes
   - ➢ Rompa los vientos fuertes
   - ➢ Mas resistente a temperaturas altas / sequia
   - ➢ Mas resistente a lluvias fuertes y inundaciones

b. ¿Qué podría añadir para dar estés servicios?

c. Limitaciones?

iv. Otra

a. ¿Utiliza **pisos múltiples** en sus sistemas? Donde? De cuales rubros? Porque?
   Piense en intensificar el uso de suelo aprovechando el uso de piso? Cuales rubros?

Diseño de la finca del futuro

Tomando estes cosas en cuenta – como puede diseñar un sistema para el futuro? Que cosas quiere añadir? Por que?

En cual parte de la finca? Cual uso de suelo? Colocar las tarjetas en la finca.

En cual cosas hay que pensar antes de sembrar estes cosas?

Caracteristica funcional	Rubros	Combinacion / practica	Uso de suelo	Actual	Potential
Resiliencia al clima					
Sombra (mantenga ambiente fresco)					
Rompa viento					
Resistencia a sequia / alta temperatura					
Resistencia a inundaciones y humedad (drenaje)					
Protégé de lluvia fuerte					
Suelo					
Control de erosion / barrera viva					
Fija Nitrogeno					

Material organica / mulch					
Nutrientes (Abono / estiercol)					
Plagas. Enfermedades y malas hierbas					
Refugio para enemigos					
Repellente a plagas					
Comida alternativa					
Mas resistente a plagas enfermedades					
Supression de malas hierbas					
Cercas vivas					

Nombre___________________________________ Comunidad_________________________________ Fecha_________________

Patio / Huerto: Area (Mz)

Plano		**Inclinado (%)**		**Sombra(%)**		**Abierto**		**Alto**		**Bajo**	

% estimada de pérdidas del rendimiento de los rubros mejores el año pasado por daño de extremas de clima y plagas?*

Observación daño por plagas? Cual? Alta, medio o bajo nivel?

Cubierto del suelo estimado (%)*

Malezas dañosas		**Malezas nobles**		**Rubro**		**Hojarosca / mulch**		**Forraje/ abono**		**Suelo desnudo**	

Evidencia de erosión*

Bastante		**Medio**		**Poco**		**Nada**	

Análisis de suelo visual (Alta, media, baja)*

Efervescencia		**Lombrices**		**Oscuridad**	

Uso de residuos

Dejado		**Forraje**		**Pastear**		**Composto**		**Otro**	

Insumo de fertiizante (Libras por año)

Fertilizante		**Estiercol**		**Composto**	
Cual tipo		**Animal?**			

Observaciones (Barreras? Áreas naturales? Uso de piso? Plagas comunes)

Nombre____________________________________ Comunidad__________________________________ Fecha__________________

SAF: Area (Mz)

Plano		**Inclinado (%)**		**Sombra(%)**		**Abierto**		**Alto**		**Bajo**	

Rubros con mas área (%)				

Riesgos climáticos que afectan mucho?

Lluvias fuertes		**Sequia**		**Alta Temperatura**		**Clima variable**	
Viento fuerte		**Inundaciones**		**Baja Temeratura**		**Otro**	

% estimada de pérdidas del rendimiento de los rubros mejores el año pasado por daño de extremas de clima y plagas?*

Observación daño por plagas? Cual? Alta, medio o bajo nivel?

Cubierto del suelo estimado (%)*

Malezas dañosas		**Malezas nobles**		**Rubro**		**Hojarosca / mulch**		**Forraje/ abono**		**Suelo desnudo**	

Evidencia de erosión*

Bastante		**Medio**		**Poco**		**Nada**	

Análisis de suelo visual (Alta, media, baja)*

Efervescencia		**Lombrices**		**Oscuridad**	

Uso de residuos

Dejado		**Forraje**		**Pastear**		**Composto**		**Otro**	

Insumo de fertiizante (Libras por año)

Fertilizante		**Estiercol**		**Composto**	
Cual tipo		**Animal?**			

Observaciones (Barreras? Áreas naturales? Uso de piso? Plagas comunes)

Nombre________________________________ Comunidad______________________________ Fecha________________

Pasto: Area (Mz)

Plano		**Inclinado (%)**		**Sombra(%)**		**Abierto**		**Alto**		**Bajo**	

Numero de animales		**Frequencia de mover**	

Riesgos climáticos que afectan mucho?

Lluvias fuertes		**Sequia**		**Alta Temperatura**		**Clima variable**	
Viento fuerte		**Inundaciones**		**Baja Temeratura**		**Otro**	

% estimada de pérdidas del rendimiento de los rubros mejores el año pasado por daño de extremas de clima y plagas?* ______

Cubierto del suelo estimado (%)*

Malezas dañosas		**Malezas nobles**		**Pasto**		**Hojarosca / mulch**		**Forraje/ abono**		**Suelo desnudo**	

Evidencia de erosión*

Bastante		**Medio**		**Poco**		**Nada**	

Análisis de suelo visual (Alta, media, baja)*

Efervescencia		**Lombrices**		**Oscuridad**	

Insumo de fertiizante (Libras por año)

Fertilizante		**Estiercol**		**Composto**	
Cual tipo		**Animal?**			

Observaciones (barreras? Áreas naturales? Uso de piso?)

Nombre________________________________ Comunidad______________________________ Fecha________________

Granos: Area (Mz)

Plano		Inclinado (%)		Sombra(%)		Abierto		Alto		Bajo	

Rubros con mas área				

Calendario del año (sembra, cosecha de cada rubro en la misma parcela?)

Enero	Feb	Mar	Abril	Marzo	Mayo	Junio	Julio	Agosto	Sept	Oct	Nov	Dec

Observación de daño por plagas? Cual? Cuales rubros? Alta, medio o bajo nivel?

% estimada de pérdidas del rendimiento de los rubros mejores el año pasado por daño de extremas de clima y plagas?*

Cubierto del suelo estimado (%)*

Malezas dañosas		Malezas nobles		Rubro		Hojarosca / mulch		Forraje/ abono		Suelo desnudo	

Evidencia de erosión*

Bastante		Medio		Poco		Nada	

Análisis de suelo visual (Alta, media, baja)*

Efervescencia		Lombrices		Oscuridad	

Uso de residuos

Dejado		Forraje		Pastear		Composto		Otro	

Insumo de fertiizante (Libras por año)

Fertilizante		Estiercol		Composto	
Cual tipo		Animal?			

Observaciones (barreras? Áreas naturales? Uso de piso?)

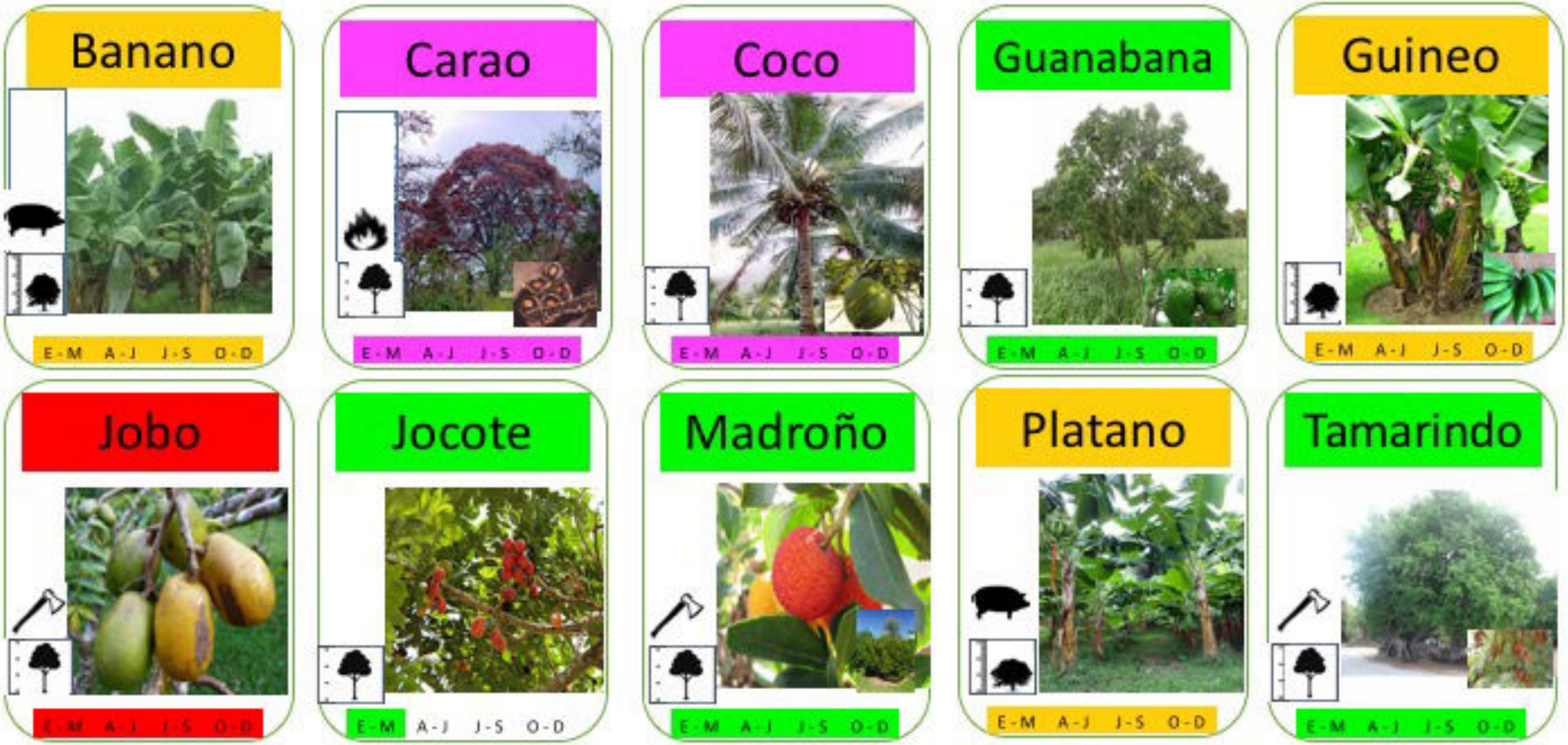
Nombre____________________________________ Comunidad__________________________________ Fecha__________________

Uso de prácticas de ABD:

Rotación de cultivos	RC	Barreras vivas	BV	Cultivos intercalados	I	Sembra abajo	SA
Uso de stratas multiples	SM	Abono verde	AV	Cultivos repelentes a plagas	CR	Parra	PA
Comida alternativa para plagas	CA	Variedades multiples	VM	Sembra 'Relay'	SR	Otro	O

Cuales 'funciones' o beneficios tienen estés especies para la finca? (Funciones agroecológicas?)

Uso de Suelo	Uso de ABD	Cultivos / interacciones	Función / beneficio	Factores limitantes	Fuente de conocimiento	Observaciones / notas


Banano
E-M A-J J-S O-D
Carao
E-M A-J J-S O-D
Coco
E-M A-J J-S O-D
Guanabana
E-M A-J J-S O-D
Guineo
E-M A-J J-S O-D
Jobo
E-M A-J J-S O-D
Jocote
E-M A-J J-S O-D
Madroño
E-M A-J J-S O-D
Platano
E-M A-J J-S O-D
Tamarindo
E-M A-J J-S O-D

Mango

E-M A-J J-S O-D

Papaya

E-M A-J J-S O-D

Pejibaye

E-M A-J J-S O-D

Maracuya

E-M A-J J-S O-D

Castaño

E-M A-J J-S O-D

Marañon

E-M A-J J-S O-D

Ojoche

E-M A-J J-S O-D

Caña

E-M A-J J-S O-D

FrijolAbono

E-M A-J J-S O-D

PastoNatural

E-M A-J J-S O-D

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