MULTI-AGENT SIMULATIONS OF THE HUMAN IMPACTS AND LANDSCAPE DYNAMICS OF AGROFORESTRY ADOPTION IN THE UPLANDS OF SOUTHERN PHILIPPINES

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ABSTRACT

A large and rapidly expanding portion of the Philippine upland landscape is being converted to permanent annual cropping resulting in fragmentation of upland areas. Human settlements rapidly developed and the need for food increased. Annual crops were continuously cultivated to meet the increasing food demand. However, these farming systems pose a great threat to the stability, productivity and sustainability of upland regions while agroforestry is an ecologically sound approach to managing upland landscapes. A model using the Common Pool Resources and Multi-Agent Systems (CORMAS) was developed to help understand the impacts of agroforestry adoption on landscape changes in Claveria, Misamis Oriental, southern Philippines. Farmers decide on the type of agroforestry system, the trees and crops to be planted. The model simulates changes in the landscape as farmers shifted to agroforestry from annual cropping. The model scenarios also serve as decision support for policymakers, farmers and other stakeholders towards sustainable management of resources.

1 INTRODUCTION

Sloping upland are geographically the most extensive ecosystems in Southeast Asia, constituting from 60 to more than 90% of the total land area of their respective countries. They are also the most threatened ecosystems in the region due to increasing populations of subsistence farmers cultivating the infertile soils causing land degradation, soil erosion and deforestation (Garrity 1993). The Philippine uplands is home to about 30% of the country's total population (Cruz and Zoza-Feranil, 1988).

There are many factors that limit the stability, productivity and sustainability of upland farms, including inappropriate land use considering land topography, soil fertility, vulnerability to soil erosion; lack of planting materials; climatic variation and lack of irrigation systems; biological stresses; insecure land tenure; and social and economic uncertainty. New technologies will be essential in sustaining the stability and productivity of the upland farms.

Agroforestry is a dynamic, ecologically based, natural resource management system that integrates trees to cropped fields (Leakey 1996). It is a sustainable alternative agricultural system to address the increasing degradation of farm areas in upland ecosystems, which, can best meet smallholder farm household's food needs as well as provide environmental services. However, agroforestry systems are typically more complex than traditional agriculture.

In the past three decades, a stream of government programs and externally funded projects have been introduced and implemented in Claveria, southern Philippines. The adoption of agroforestry systems was found to be concentrated at specific locus points and lacked widespread adoption in the municipality.

A model to understand the adoption of agroforestry technologies in Claveria was developed using a combination of participatory approaches such as household surveys, and agent-based modeling. In developing the model, we follow the "companion modeling approach," in which we start with a preliminary model of initial ideas about the system that is eventually revised and rebuilt. The SAFODS-MAS (Smallholder Agroforestry Options for Degraded Soils – Multi-Agent Systems) model is a work in progress and will eventually result in a genuine knowledge-based system, which allows interactions between researchers and stakeholders (Berkes and Folke 1998, as cited in Commod group, 2003).

The SAFODS-MAS model will be used to simulate and predict land-use change in Claveria as a result of agroforestry system adoption by the different farmer types. It aims at supporting discussion and coordination among stakeholders at the study site to better manage their resources by simulating the decision-making strategies of upland farmers in adopting crops and trees.

2 THE STUDY SITE

Claveria is a landlocked agricultural municipality in the province of Misamis Oriental, Mindanao, Philippines. It has a total land area of about 82,475.31 ha and is considered the largest municipality in the province. The study area covers 17 barangays in the municipality with a total of 6,918 households, of which about 89% are engaged in farming. The area is divided into two topographic regimes: Upper Claveria with an elevation of 650–915 masl and Lower Claveria with an elevation of 390–650 masl.

Soils from Claveria are derived from pyroclastic materials and classified as acidic-upland (fine-mixed, isohyperthermic, Ultic Haplorthox) with a depth of more than 1 m (Garrity and Agustin 1995). The soils are usually characterized by high organic matter content, low pH (4.2–5.2), and low CEC and anion activity (Hafner 1996, CCLUP 2000). Rainfall patterns vary with elevation, with the upper areas of Claveria receiving relatively greater amount of rainfall than the lower areas (CCLUP, 2000). Hence, the traditional cropping pattern follows the rainfall pattern in most farming areas. Wet season (monthly rainfall >200 mm) begins in May and dry season (monthly rainfall <100 mm) begins in November (Predo, 2002). Average monthly rainfall is about 267.33 mm.

The municipality of Claveria has a total estimated open cultivated/agricultural land area of 26,055 ha. The dominant crop in Claveria is maize (*Zea mays*), with 51% of the arable land devoted to its production. In Upper Claveria, 1,837 ha are planted with tomatoes (*Lycopersicum esculentum*). Cassava (*Manihot esculenta*) is a widely grown root crop in Lower Claveria (CCLUP 2000). Crop and tree occurrence and frequency changes with elevation, except for maize, which is cultivated at all elevations. Corn is produced mainly for household consumption. Other traditional permanent crops cultivated by farmers are banana (*Musa spp.*), coffee (*Coffee spp.*), and coconut (*Cocos nucifera*). Promising high-value permanent crops such as durian (*Durio zibethinus*), rambutan (*Nephelium lappaceum*), mango (*Mangifera indica*) and lanzones (*Lansium domesticum*) are beginning to thrive in the area.

Significant soil erosion occurs in sloping areas cultivated with annual crops (Beniest and Franzel 1999). Increased pressure from rapid population growth has resulted in the clearing of remaining forests and grasslands, causing watershed degradation. Several NGO-assisted projects advocating agroforestry technologies to minimize soil erosion, restore soil fertility, and improve crop production have been introduced to farmers at the site but have not been widely accepted (Mercado et al 1999). The low adoption rate is associated with the constraints of high labor requirements for establishing and managing agroforestry systems, the longer time for a return on the investment, above- and below-ground competition of crops and trees causing poor crop yield, and the lack of marketing knowledge for timber and other tree products (SAFODS 2003).

3 METHODOLOGY

The SAFODS-MAS model was developed using a stepwise approach. A series of Participatory Rural Appraisal (PRA) activities, case studies and household interviews were conducted to gather information on the study area. Particular consideration was given to the farmers' and stakeholders' perceptions, motivations and actions.

PRA is a growing family of approaches and methods to enable local people to express, enhance, share and analyze their knowledge of life and conditions, to plan and to act (Chambers, 1994). A four-day PRA with key informants from different barangays in Claveria was conducted. The barangay is the primary planning and action unit for government programs and projects.

The PRA was conducted to obtain an initial biophysical characterization of the study site and a socio-economic profile of the farmers in the area. These activities were carried out to come up with a stratification scheme or typology of farmers based on resource endowment, ratio of land to family labor, motivations to plant trees, and local ecological knowledge on soil conservation and tree-crop interactions.

A reconnaissance survey and transect of the area's landscape, biophysical conditions, and existing agroforestry and cropping systems were conducted on the first day. One-on-one interviews were conducted with selected key informants, including farmers, barangay officials, elders, and research extensionists in the area. Mind mapping was conducted to understand the motivations of farmers to adopt tree growing or agroforestry. The activity was done with two separate groups of farmers: Upper Claveria and Lower Claveria farmers.

The results of the PRA facilitated the stratified random sampling used to select the respondents for the subsequent household survey. Interviews of 300 households were conducted to collect primary data on farmers' demography, farm biophysical resources, household socioeconomic data, motivations for planting trees, and ecological knowledge.
Verification of the information gathered from the household survey was carried out through case studies, traders' interviews, consultations with farmers and government agencies.

Explicit assumptions about the elements and structure of the agroforestry adoption in Claveria were created. These assumptions were used and implemented in CORMAS (Common-pool Resources and Multi-Agent Systems), an object-oriented programming environment created in VisualWorks using Smalltalk programming language. It is designed for developing simulation models of coordination modes between individuals and groups that jointly use common resources (CIRAD, 2001).

4 GENERAL STRUCTURE OF THE MODEL

Cormas uses the Unified Modeling Language (UML) in specifying, visualizing, constructing and documenting the structure and design of a system. The UML diagrams are illustrated with class diagram (Fig. 1) and flow or activity diagrams (Figs. 2 and 3). The class diagram describes the attributes and operations of a class or entity possesses, as well as the relationships of this class from other classes. Each box contains the set of attributes or characteristics of each entity and the various methods characterizing the main behaviors of each entity. It displays the features of the different model entities: the spatial entity, the passive objects and the social or communicating agents. The spatial entity is the environment where both the passive objects and social agents interact. Passive objects are entities that the agents can perceive, create, remove and modify while social agents are entities that can communicate and form an association (Ferber, 1999). The activity diagrams in Figs. 2 and 3 represent the flow of actions for a particular operation of an object in the model.

5 COMPONENTS AND ASSUMPTIONS OF THE MODEL

The decision-making process of the farmer on whether to adopt agroforestry is influenced by the complex interplay of physical, biological, demographic, institutional, and socioeconomic factors (Garcia 2000, Lapar and Pandey 2000). In the SAFODS-MAS model, the following factors affecting agroforestry adoption were considered: (1) the availability of planting materials, from one's own farm and the barangay nursery; (2) the effects of farmers' network or linkages on the adoption of agroforestry; (3) the farmers' market information; and (4) total area of the farm, as farmers with larger farms are more likely to adopt new technologies than farmers with smaller farms (with less land to spare).

The plot represented the spatial entity. Attributes like area, slope and elevation are included in the biophysical characteristics of the plot. The passive objects in the model were crops like maize and tomato, timber trees like *Gmelina arborea*, fruit bearing perennials like banana and the market. The crops are characterized by their yield and elevation where it is suitable to plant them while trees are attributed with their age or the maturation to harvest. The market is attributed with the lists of possible prices of crops and trees. The communicating agents like the farmers perform the most number of activities such as adopting certain agroforestry system (AFS), maintaining the AFS, harvesting the trees and crops and selling them, while timber tree traders and crop traders have the cash to purchase tree products and crops, the set of prices and the knowledge of the market.

Farmers' associations were introduced thus: a farmer knows a set of farmers in the neighbor network. Farms close to each other formed a network within which farmers can observe the activity and methods of other farm members. Farmers' decisions to cut and sell trees depend on both selling price and the actions of neighboring farmers, as they may imitate what the neighbors are practicing.

The model also featured farmer typologies based on AFS and their financial capital: block planting, parkland system, border planting, and hedgerow or contour planting of trees.

Block planting. The farmer implements this system if he has 3 or more plots, but only one plot will be fully planted with trees. Initially, he must also have the financial resources to afford the high-cost of planting and maintaining trees. Crops may be planted on the same plot for the first three years or six time steps and/or after the tree-stumps (left after the last harvest of timber) have decayed. Most of these farmers are motivated by an increase in income and have the greatest financial capital.

Hedgerow system. Farmers adopting this system are usually motivated by soil and water conservation. This is implemented when plots have slope greater than 18 degrees. The decision to adopt is made before cropping. Initially, he must at least have the funds to plant corn. Effective area devoted for crops is 70 percent of the plot while trees can occupy at least 30 percent of the area. Initially, about 33% of the total number of trees planted are fruit bearing perennial (banana) while 67% are timber tree (*Gmelina arborea*).

Border planting. This system is adopted when the farmer could cover the effective area for cropping. The decision to adopt is made after cropping. Trees are usually planted on the buffer areas to mark the farm boundaries.

Parkland system or scattered planting. This system is adopted if the farmer cannot meet the requirements of starting a block, hedgerow or border system. The decision to adopt is made after cropping. Initial trees planted are banana while gmelina is incorporated depending on the remaining area after crops and banana have been planted.

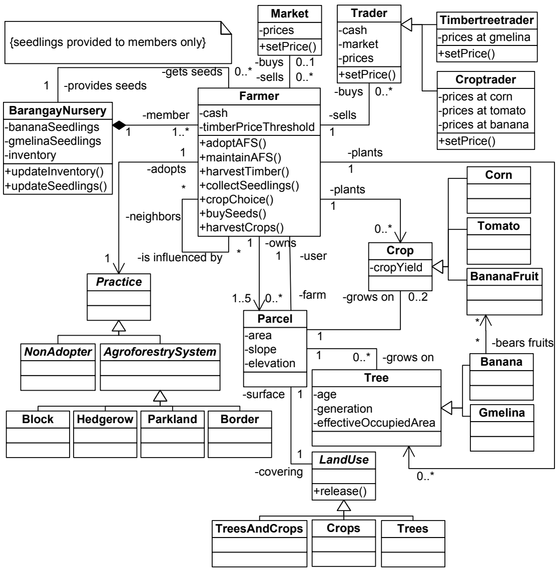

Figure 1 Class diagram of the SAFODS-MAS model.

Thirty percent of the farmers are non-adopters of agroforestry. They plant tomato and corn only on their plots. Each cropping season, the farmer will plant a crop if he has enough money to secure food for the household.

Other communicating agents included are the timber and crop traders. In the activity diagram, farmers must perform four activities (as shown in Fig. 2). These are: 1) collection of seeds for barangay nursery, 2) agroforestry system adoption and/or crop planting, 3) harvesting and sale, and 4) observation of agroforesting neighbors.

6 DECISION-MAKING PROCESSES AND ACTIVITIES IN THE MODEL

Farmers were classified into agroforestry adopter and non-adopter (Fig. 2). Non-adopters need to perform three activities: (1) the choice of crops, (2) harvesting and sale of crops and (3) observing their neighbor agroforestry adopter. After each harvest farmers updated their cash. Because of the farmer's neighbor network they can observe and compare their income with those of the agroforestry adopters. The chance of shifting from non-agroforestry adopter to agroforestry adopter is highly associated with the level of income received. The extent of farmers' knowledge of the crop, timber and fruit market affects his decision to sell his tree products (Fig. 3).

Adopters on the other hand performed four activities: (1) crop choice, (2) agroforestry adoption, (3) collection of seeds for barangay nursery, and (4) harvesting and sale of crops and trees. They have to assess the availability and sufficiency of planting materials. If adopter farmer is a member of the barangay nursery, he has to give the nursery excess tree seedlings from his collection of planting materials. These planting materials are pooled together by the barangay nursery, which are equally distributed to members.

Farmer adopters then assess the availability of space to adopt block planting, as this system requires at least 1.5 hectares of farm area. If the farm area is limited, farmers need to see if they can adopt border planting or the parkland system instead. Hedgerow planting is limited to areas with slope more than 18 degrees. Initially, farmers have to buy the planting materials for timber and banana. Later on, these initial trees and banana plants will be sources of planting materials for the farm and the barangay nursery (Fig. 2).

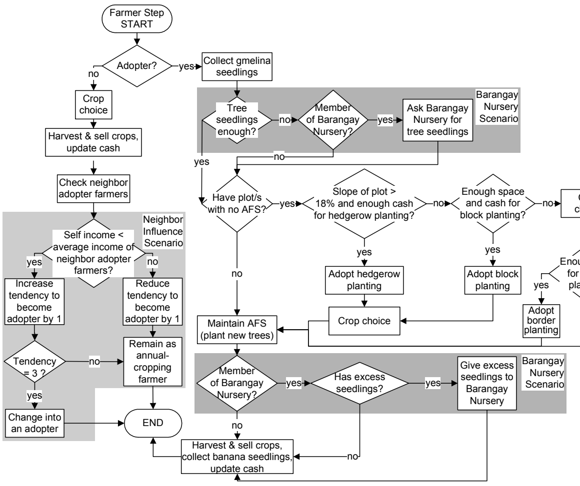

Figure 2 Activity diagram of farmers' adoption of agroforestry and the neighbor's influence.

In marketing the crops and trees (Fig. 3), farmers have the option to sell them to the market or to the set of traders he is acquainted with. Farmers will sell their harvested ground crops (maize and tomato) to the crop traders with the highest buying price. They allocate a portion of their maize harvest (30%) and banana harvest (20%) for home consumption. The rest of the maize harvest will be sold to the crop trader with the highest buying price and banana is sold in the local market.

In selling the timber, the farmers may decide to imitate other farmers within their network of farmers who are selling timber trees, reflecting the social network effect (Janssen and Jager 2001). The observation of the effects of the farmer network and the timber traders network on the selling price will determine the decision to harvest the trees. If price is acceptable to farmers, they will sell the timber. However, in cases where selling price at farmer network and traders are both not acceptable, farmers knowledge of the market price is an advantage.

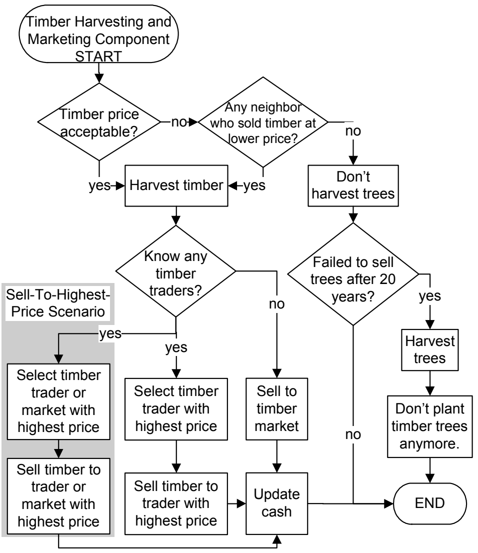

Figure 3 Activity diagram of marketing timber.

VISUALIZATION AND INITIALIZATION OF THE MODEL

Polygons representing farm plots were created in the CORMAS platform. The plots were randomly allocated to twenty farmers. The number of plots varied according to the size of the farm. A farmer can own 1–5 farm plots with each plot equal to 0.5 ha.

These plots may contain a single ground crop type and may be planted with trees. Each crop and tree is represented as a single object and can both occur at the same instance. Each time step of the model is equal to one cropping cycle or six months. Ground crops and trees have different maturity periods, two cycles of annual crops are grown within one year and harvested at the end of each crop cycle while trees are grown for 7 years to be cut after 14 crop cycles.

At the initialization stage, the study area is divided diagonally into three portions to represent the three elevation classes of the landscape: lower elevation, middle elevation, and upper elevation.

7 SCENARIO SIMULATIONS

Different scenarios to observe the cumulative income from agroforestry, the neighbor influences on agroforestry adoption, the effect of marketing information on income and the impact of tree seedling nursery establishment on tree planting and income from agroforestry were simulated.

At the end of the simulation, the model displayed the spatial distribution of crops and trees in the landscape as well as the distribution of the different agroforestry systems (as shown in Fig. 4). Each polygon in the figure shows the agroforestry system, type of crops and trees planted in each plot. All the results presented are average of 10 simulations, with each simulation run for 100 time steps.

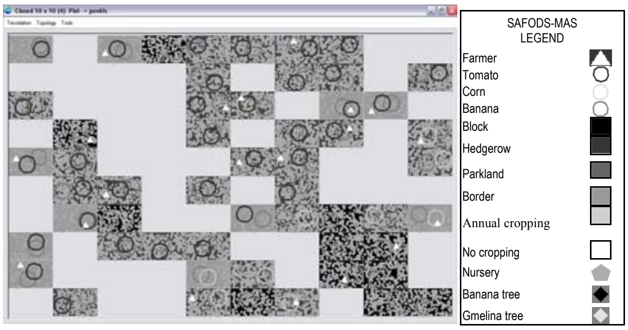

Figure 4 Distribution of agroforestry systems in Claveria, Misamis Oriental.

Simulation results showed the effects of the interactions among farmers in the diffusion of agroforestry systems in the area. The indices of income from crops and tree products over time allowed comparisons of economic benefits gained in the adoption of agroforestry systems and annual cropping. It also served as an important indicator to illustrate socio-economic status of farmers. The simulations also allowed the evaluation of the consequences of farmers' marketing knowledge. It displayed the effects of establishing a common nursery for the barangay and the influence of farmers' neighbors. Some of the most important results are discussed below.

Cumulative income of agroforestry adopters and non-adopters. The cumulative income of adopters and non-adopters is presented in Fig. 5. At early time steps, the cumulative income of agroforestry adopters is lower than the cumulative income of non-adopters. This can be attributed to the initial costs of establishing trees. However, at time step 45 or 23 years, agroforestry adopters started to gain higher income than non-adopters. Although farmers received positive income from trees after 100 time steps, the increase in income from adopting agroforestry is relatively small compared with the income contributed by the production of high value annual crops like tomato (Fig. 6). The long gestation period from planting to marketing tree products is an important factor.

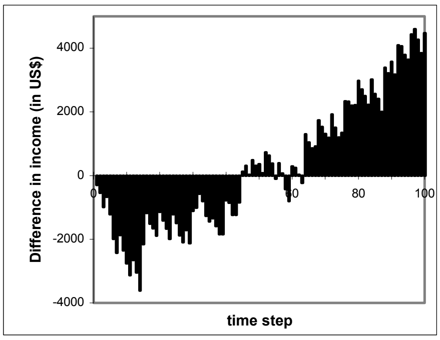

Figure 5 Seasonal farm income of agroforestry adopters relative non-adopters.

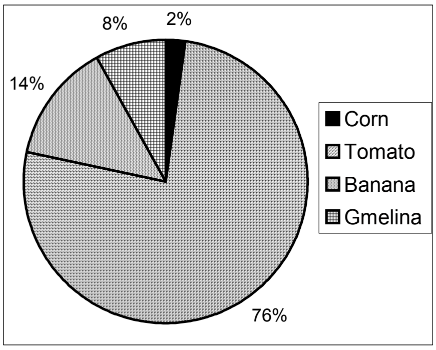

Figure 6 Contribution of each commodity to the farmers' total gross income after 100 time steps.

Neighbor effects. To determine the extent of neighbor's influence in agroforestry adoption, two scenarios were simulated using the model. In both scenarios, each plot will have four neighboring plots. The farmer may have adjacent plots, in which case, he will not include himself in the observation.

In the first scenario, about 30% of the population (7 out of 20 farmers) are annual cropping farmers or are not adopting an agroforestry system while the other 70% are agroforestry farmers. In the second scenario, 95% are annual cropping farmers and only five percent of the population (one out of 20 farmers) is an agroforestry adopter as illustrated in Fig. 7.

Simulation results of the first scenario showed that at time step 4 or at the second year, about 15% of the non-adopters adopted a certain agroforestry system. On the other hand, simulation results of the second scenario showed a gradual or slower rate of agroforestry adoption up to the 30th time-step. In both scenarios plateaus are reached. In the first scenario plateau was reached at time step 14 while in the second scenario, plateau was reached at time-step 30.

Results showed that farmer neighbors have great influence on the spread of agroforestry in Claveria. The more farmers adopting agroforestry system in the neighbor network the greater is its influence to motivate the non-agrofrestry farmers to practice an agroforestry system. Farmers shifted because of the increased income from harvesting and selling banana fruits and adoption of agroforestry was observed even at the 14th time step or the seventh year when gmelina trees are matured and ready for harvest (Fig. 7).

Plateau was attained at an earlier stage in scenario 1 because shifting from non-adopter to adopter ceased at an earlier time. The remaining non-adopter farmers are those with 3 to 5 parcels and are able to plant tomato. They have a much higher income than those farmers adopting agroforestry. In the second scenario, the plateau is reached at a later time because of the spatial distribution of adopter farmers in the environment. The likelihood of an agroforestry adopter occurrence in the neighbor network is less, thus, it will take several time steps for a non-adopter to shift to agroforestry. The spread of agroforestry is slow across the environment in the second scenario.

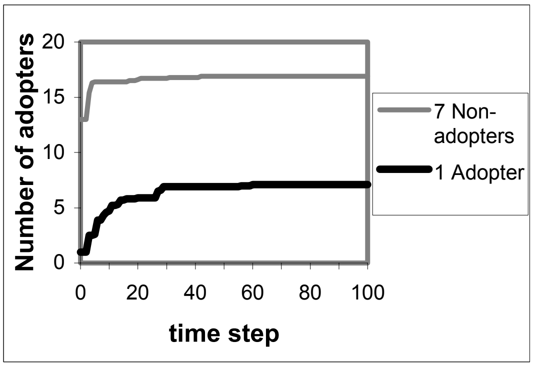

Figure 7 Effects of neighbors to the adoption of agroforestry.

***Market Information*.** Market state is one of the major factors that contribute to sustainable agroforestry. Farmer adoption of agroforestry technologies is highly affected by the availability of market for crop and tree products. In this scenario, market information is implemented by allowing the farmers to compare the prices between the market and the traders, which is not done in the base model. In the base model, a farmer who knows traders would automatically sell its produce to the trader with the highest price without going to the market, which may have a higher price than the trader. If farmers have limited access to information on market prices, they cannot optimize the opportunity to sell at the highest price offered in the market. Fig. 8 shows the increase in income by allowing the farmers to compare the prices between the traders and the market and being able to sell at the highest price.

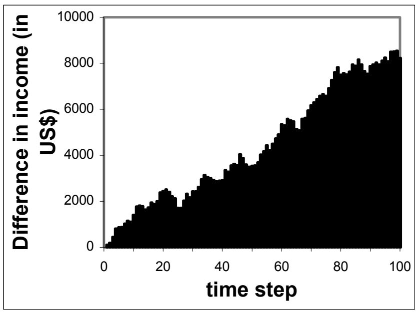

Figure 8 Cumulative difference of income of farmers with market information relative to farmers with limited market information.

Establishment of tree seedling nursery. The establishment of a barangay tree seedling nursery increased the availability of planting materials for gmelina tree and banana. The nursery establishment has two major effects: the income from banana dramatically increased (Fig. 9) and less gmelina is planted because banana is preferred by farmers because it is a perennial with shorter gestation period than gmelina. Banana starts to bear fruits after about 18 months and the income from selling banana contributed greatly in the household income of the farmer (Fig. 10).

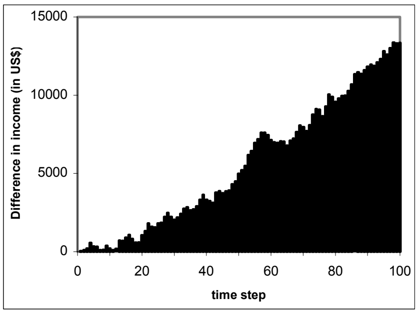

Figure 9 Cumulative difference in income of farmers with access to seedlings from barangay nursery relative to farmers without access to seedlings.

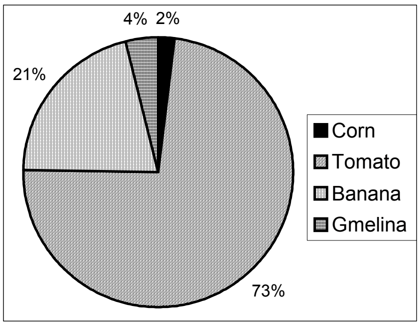

Figure 10 Proportional contribution of each of the four commodities to farmers' gross income.

8 CONCLUSIONS

The SAFODS-MAS model is a work in progress, being revised and improved through repetitive confrontations with the real situations in the field. The iterative process with the model is useful in probing deeper into the decision-making process of farmers in adopting an agroforestry system.

Scenario simulations can serve as a tool to facilitate interactions between stakeholders and scientists and in the future as a decision support for policymakers, farmers and other stakeholders towards sustainable management of resources. It is envisioned to produce information useful for the design and dissemination of agroforestry technologies to other sites.

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