8

Climate Change Adaptation using Agroforestry Practices: A Case Study from Costa Rica

Maren Oelbermann and Carolyn E. Smith
University of Waterloo
Canada

1. Introduction

Conventional agricultural practices in tropical latitudes, using modern plant breeding techniques, fertilizers, and irrigation, have resulted in an increased grain yield (Huxley, 1999). However, these agricultural practices have also played a major role in increasing the global total area of marginal land that is now substandard for the long-term production of food and livestock (FAO, 1990), and has contributed significantly to the accumulation of greenhouse gases in the atmosphere (IPCC, 2007). Such activities are most notable in developing countries which are strongly affected by climate change due to their lower capacity to adapt compared to developed nations (IPPC, 2007). Comparatively, developed nations have the infrastructure and financial capabilities to cope more effectively to a changing climate.

As a result of the inherent environmental degradation and poverty associated with deforestation and conventional agriculture, there is a resurgence in the implementation of sustainable land-use practices including agroforestry (Kandji et al., 2006). In this paper agroforestry is defined as the deliberate integration of woody species with agricultural crops and/or pastures on the same land-unit resulting in the integration of economical and ecological interactions between components (Young, 2002). The cultivation of trees in combination with agricultural crops was a common practice dating back to the beginning of plant and animal domestication. Since then, several models of various agroforesry practices, from Asia, Africa and Europe to North and South America, have been developed (King, 1987). In tropical latitudes, farmers imitated vertical forest structure and diversity by planting a variety of crops with different growth habits. It was not unusual to plant up to 24 species on a plot one-tenth of a hectare with each layer corresponding to the natural stratification of a tropical forest (King, 1987). Until the 1860s, the focus of agroforestry practices was on tree production. It was not until 1975, when the International Development Research Centre (IDRC) in Canada concluded that priority in research should be given to combined agroforestry production systems in tropical regions in order to optimize land-use, establish food security, and address the increasing problem of environmental degradation (King, 1987). Since then, agroforestry practices were promoted as a sustainable land-use management system in developed and developing countries. For example, agroforestry practices range from low-input systems such as alley cropping and short-term improved fallow with leguminous shrubs to shade-grown coffee (*Coffea arabica* L.) in tropical regions and high-input cereal-legume systems and riparian plantings in temperate biomes (Nair, 1993; Gordon & Newman, 1997).

In Central America, agroforestry practices were also diverse and commonly included a combination of trees with food crops, trees with livestock (pasture for fodder) or all elements combined (Budowski, 1987). In this region, pre-Columbian people mixed trees with food crops in a system similar to shifting cultivation. Other land-use techniques included home gardens and the integration of trees and crops along banks. Agroforestry practices in Central America were first described by O.F. Cook in a 1901 report to the U.S. Department of Agriculture, noting that coffee plants were growing under shade trees. Cook also noted the beneficial effects of leguminous shade trees on soil fertility. Since then there has been a plethora of information published on Central American, particularly Costa Rican agroforestry practices. For example, Holdridge reported on the practice of planting *Alnus acuminate* Kunth. in pastures in the Costa Rican highlands (Holdridge, et al. 1977). Budowski (1987) noted the use of *Cupressus lusitanica* L. windbreaks in the highlands and the use of *Cordial alliodora* L. in lowland pastures in Costa Rica. Other research from Costa Rica reported secondary forest management on abandoned coffee plantations (Budowski, 1987), and use of life-fences and increased biodiversity (Harvey et al., 2005). Alley cropping was established in Costa Rica as a new agroforestry practice in the early 1980s, where crops were grown between rows of trees (Kass et al. 1995). The aim of this modern agroforestry practice was to minimize the need for external nutrient inputs from fertilizers or manure, which are difficult or not economically feasible for small producers. Instead this agroforestry practice relied on the biannual input of organic material derived from leguminous plants, high in nutrient content, of completely shoot pruned of trees. The application of the organic material to the soil as mulch was synchronized with the seeding of crops, resulting in the maximum release of nutrients from the decomposing organic material to the growing crops. Over the past decade the potential of agroforestry systems to sequester carbon (Oelbermann et al., 2004; Oelbermann & Voroney, 2011), and their role in providing ecosystem services (Pagiola et al., 2008) has become the forefront of research as a result of global climate change.

Agroforestry systems are unique because they are a land management practice that simultaneously addresses biophysical, economical, and socio-ecological components. Such diversity and interactions leads to a greater functional and structural complexity compared to conventional agroeosystems (Nair, 1993). Leaky & Simmons (1996) suggested that over the long-term agroforestry systems become successively similar to natural systems, where biodiversity increases with each stage in the development of this succession. Such functional and structural complexity has led to the great diversity currently observed in modern agroforestry practices.

However, the adoption of agroforestry practices is based on socio-cultural and sociecological considerations including land tenure and land rights, in addition to providing enhanced biodiversity and ecological services (McGinty et al. 2008; Sood & Mitchell 2009). Currently, agroforestry practices are increasingly adopted due to their potential of providing ecosystem services. Ecosystem services not only provide an economic incentive but are also of value to society by maintaining environmental sustainability (FAO, 2007). The benefits derived from agroforestry practices occur over a range of spatial and temporal scales (Jose, 2009). For example, when comparing the large-scale removal of trees due to deforestation and its resultant high levels of erosion, agroforestry systems provide ecological services by decreasing soil erosion and preventing the sedimentation of waterways; ultimately protecting downstream fisheries (Pearce & Mourato 2004). Thus, ecological services provided by agroforestry systems are derived at the farm- and / or landscape-scale but are enjoyed by society at regional- and / or global-scales (Jose, 2009).

Verchot et al. (2007) suggested that agroforestry practices, apart from providing ecosystem services, are a means of diversifying agricultural production and increase food security for smallholder agricultural producers, especially under current climate change scenarios. For example, recent observations on inter-annual changes in temperature and precipitation along Costa Rica's Pacific coast have shown more intense and longer dry seasons, coinciding with changes predicted by the IPCC in this region (IPCC, 2007). Although maintaining agricultural productivity under changing climatic conditions will be challenging (Watson et al., 2000), Sanchez (2000) suggested that structurally and functionally complex agroecosystem management systems, including agroforestry practices, may show a greater resilience to changing environmental conditions. Although several studies have been published on the adoption of agroforestry practices (Pattanayak et al., 2003; Mercer, 2004), few studies have investigated the efficacy of agroforestry as an agroecosystem management practice with greater resilience to climate change compared to less diversified (conventional) agroecosystems. Verchot et al. (2007) noted that the contribution of agroforestry practices to buffer against climate shifts is currently not well understood. Such knowledge is of great importance because agroforestry is also considered as a key player in achieving the Millennium Development Goals as described in the United Nations annual report (Verchot et al., 2007). The goal of this research was to present a case study from Costa Rica that evaluated the knowledge and perception of agricultural producers on climate change. This study also evaluated the implementation of agroforestry practices as a strategy to climate change adaptation.

2. Study site

The research area and agricultural producers described in this paper corresponded to those currently under evaluation by the GEF-Silvopastoral Study (Pagiola et al., 2007; Yamamoto et al., 2007; Pagiola et al., 2008; Hänsela et al., 2009). The Silvopastoral Approaches for Ecosystem Management, or Global Environment Facility-Silvopastoral Study (GEF-Silvopastoral Study), is a pilot project that was initiated in 2002 in rural Nicaragua, Costa Rica and Colombia where degraded pastures were prevalent. Land owners participating in the project received payment for the ecological services they generated including the integration of trees on their land, improvement of pasture management, maintaining habitat for biodiversity conservation, enhancing soil and water conservation, and increasing carbon sequestration. In association with the Global Environment Facility, the World Bank, the Regional Integrated Silvopastoral Management Project (RISEMAP) and researchers from the Tropical Agricultural Research and Higher Education Center (CATIE) in Costa Rica, each participating agricultural producer was surveyed to determine baseline data and the type of already existing or new agroforestry practices, that ultimately provided ecological services, they were interested in implementing. Financial incentives were received over a four-year period, and were based on the type and increment of ecological services they implemented relative to the previously collected baseline data (Pagiola et al., 2008).

The GEF Silvopastoral study and our study was conducted surrounding the area of Esparza (09°59'N, 84°38'W), located in the Central Pacific Coastal region of Costa Rica. The study area surrounding Esparza encompassed 432 km^2, with land-use consisting predominantly of mixed-agricultural production under conventional practices with beef, dairy, rice, sugarcane, and fruit. The majority of agricultural producers in this area have a beef-dairy production (62%), followed by beef (20%), mixed crop-livestock (14%), and beef/dairy breeding stock production (8%).

The area surrounding Esparza was characterized as a sub-humid tropical forest zone. The average annual temperature was 27.9°C and the mean annual daytime temperature was 32°C and the mean annual nighttime temperature was 22°C (Figure 1). The average annual precipitation of this region was ~1599 mm, with a distinct dry season from December to April and a distinct wet season from May to November. The mean number of sunshine hours in this region was 10 h/day from November to April, and 6 h/day from May to October. This area had a relative humidity ranging from 65% during the dry season and 80% in the wet season. This region is also influenced by large-scale inter-annual fluctuations such as the El Niño or La Niña. The elevation above sea level ranges from 50 m near the Pacific coast to 1000 m in inland areas. The geology of this region was based upon volcanic origin and alluvial sedimentation. This led to the development of Nitisols, with a predominantly loamy texture. The soils of the region were dark red, brown or yellow in color with the presence of an agrillic B horizon, but lack ferric and vertic properties.

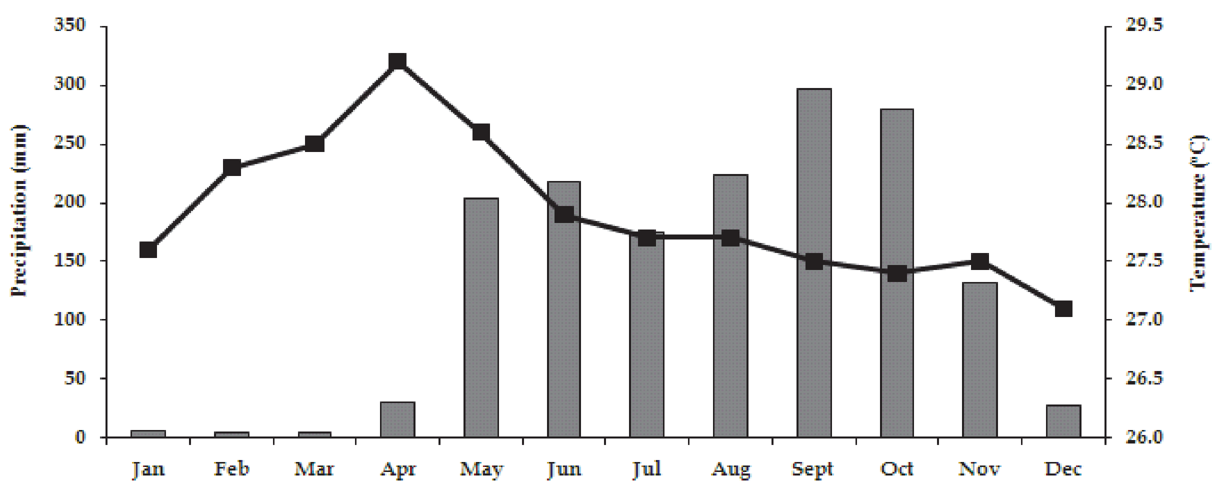


Fig. 1. Mean monthly maximum and minimum temperature (line graph) over 41 years and mean monthly precipitation (bar graph) over 64 years for Esparza, Costa Rica.

3. Sampling methods and statistical analysis

Agricultural producers that participated in this study were chosen because of their existing participation in the GEF-Silvopastoral Study. As such, the participating agricultural producers were already informed about climate change, ecological services, and payment for such services through interaction with CATIE researchers and extension personnel. In addition to conducting interviews with agricultural producers in association with CATIE rural extension officers and the Costa Rican Ministry of Agriculture, further information for this study was obtained from an existing database collected by the GEF-Silvopastoral Study. Information from this database, such as land biophysical characteristics and the type of agroforestry practices implemented provided more depth to the interviews conducted in our study.

In 2007, a total of 50 out of 105 agricultural producers were randomly chosen for our study; and were asked questions based on the following themes: 1) background and farming experience based on information not already collected by the GEF-Silvopastoral Study; 2) knowledge and perceptions about climate change; 3) knowledge on the effects of climate change on current agricultural production; 4) the type of agroforestry practice implemented and its outcome; and 5) why agroforestry practices were adopted. In order to evaluate the adaptive capacity of agricultural producers to climate change, and to contextualize how landowners perceived climate change, the survey included questions on changes in crop and livestock productivity, diseases and pests; changes in the amount and intensity of ambient rainfall and temperature, onset of rainy and dry seasons, frequency of droughts and how agroforestry practices helped to manage droughts. Additionally, landowners were also asked what strategies they were currently using to adapt to climate change and what their incentives (e.g. environmental, financial, extension support) were for implementing agroforestry practices. The semi-structured interviews lasted between 1-3 hours and each interview was recorded.

The surveys were developed and conducted in association with a representative from the Costa Rican Ministry of Agriculture as well as rural extension officers and researchers from CATIE. Details of the survey questions are presented in Smith (2008). Textual data included information provided by agricultural producers that elaborated on the questions of the survey. Recorded interview data was fully transcribed and organized manually into the different themes. In order to understand how the different themes are interconnected, each individual theme was analyzed using QSR NVivo® software (QSR International, Melbourne, Australia). This was done by counting who said what within each theme. Nodes and memos were created using NVIVO to mark relevant concepts, topics and themes. The model explorer tool in NVIVO was used to diagrammatically map out how the themes related to each other.

4. Results and discussion

4.1 Producer perception and understanding of climate change

Results from this study only incorporated agricultural producers with the greatest experience (more than 30 years) in farming because these participants were more likely to notice changes in climate. The majority of these producers (90%) understood the concept of climate change and its cause. Approximately 80% of those surveyed understood that climate change is currently impacting and will impact their land, their family and livelihoods in the future. Similar results were reported by Maddison (2007) who surveyed agricultural producers from 11 different African countries. He found that agriculturalists with the greatest amount of farming experience reported changes in climate. Our results found that many agricultural producers within the study region had knowledge on climate change likely as a consequence of their involvement with the GEF-Silvopastoral Study, and the social networks they established with other agricultural producers, the Costa Rican Ministry of Agriculture, and with researchers and extension personnel from CATIE. Agricultural producers in our survey noted that their primary source of information on climate change was derived from CATIE (56%) and from the Costa Rican Ministry of Agriculture (34%). Information from CATIE and the Costa Rican Ministry of Agriculture was gained through the participation of agricultural producers in organized workshops, seminars and / or on-farm visits.

Agricultural producers interviewed in this study observed several changes in climate, particularly relating to increased ambient temperatures and a prolonged dry season, in the Esparza region over the past 30 years and how this may potentially have affected agricultural productivity (Table 1). Approximately 90% of the agricultural producers noticed increased temperatures while 70% observed a more intense rainy season, but the overall amount of rainfall was lower. An additional 78% of the agricultural producers observed negative impacts on their land, crops, and livestock as a result of a prolonged and more intense dry season including a decrease in crop yield and water availability to livestock and their family. These observations coincided with those predicted by the IPCC (2007), who suggested that the Pacific region of Costa Rica is expected to be drier and hotter. A temperature increase of 0.1°C per decade was reported between the years 1901 and 2005 (IPPC, 2007). According to the IPPC, carbon dioxide (CO_2) started to have an effect on Costa Rica's temperature in the 1970s (IPCC, 2007). Walther et al. (2002) noted that Central America is one of the global regions where climate change impacts on the environment will be pronounced and the loss of species with climate change has already been identified. In the future, IPPC Climate models predict a minimum increase in temperature of 1.5°C and a maximum increase of 5.6°C, from current conditions for this region of Central America (IPCC, 2007). Predictions by the IPCC for changes in precipitation range from a decrease by 11 to 38% during the dry season and an increase of 7 to 21% during the wet season from current conditions. Agricultural producers in our study observed that changes in climate may have potentially led to a decrease in livestock weight, lower milk production, and a decrease in yield of their harvestable crops and pasture grasses. They also noted that the overall decrease in farm productivity affected food availability for their families and livestock. A prolonged dry season resulted in drought leading to a reduction of the farm's carrying capacity, thereby affecting the number of animals, harvestable crops, and the quantity and quality of milk produced. A mixed response, approximately 38% of the agricultural producers, also related climate change to increased pest outbreaks such as locusts (*Schistocera* spp.), ultimately affecting their crop productivity. Others, especially those at the higher elevations, noted an increase in snakes that are commonly found in lowland areas of the Pacific coast. These observations were similar to those reported by Raxworthy et al. (2008) who found that amphibians were moving upslope as a result of a warmer and drier climate at lower elevations.

Climate Characteristics	**Potential Changes in Farm Production Quantity and / or Quality**	**Landowner Observation (%)**
Increased Ambient Temperatures (IPCC, 2007)	Overall decrease in farm productivity	72
	Decrease in food production	76
	Livestock weight loss	80
	Decreased milk production	72
	Loss of harvestable products	38
Prolonged Dry Season (IPCC, 2007)	Decreased forage production	72
	Loss of livestock	76
	Loss of harvestable products	46
	Decreased milk production	74
	Decrease in water levels	64
	Overall decrease in water availability for livestock, crops, and people	54

Table 1. Agricultural producers observation of changes in quantity and / or quality of available food, feed and water potentially linked to the increase of temperatures and prolonged drought over the past 30 years in Esparza, Costa Rica (n=50).

4.2 Adaptation and implementation of agroforestry systems

As a result of the payment for ecological services (PES) program through the GEF-Silvopastoral Study, agricultural producers participating in our study had implemented a variety of agroforestry practices, including silvopasture with *Brachiaria brizantha* (Hochst. Ex A. Rich) Stapf. grass, fodderbanks, integration of trees on farmland or farmyards, and the establishment of live fences, that aided their adaptation to climate change. They were also aware that such activities helped in mitigating methane emissions from cattle and significantly increased the amount of carbon captured and stored for the long-term in trees and in soil. A total of 96% of the agricultural producers surveyed integrated trees on their land (Table 2). Specifically, agricultural producers adopted different strategies in order to cope with a longer and more intense dry season.

Agroforestry Land management Practice as a Climate Change Adaptation Strategy	Implementation by Landowners (%)
Silvipasture with *Brachiaria brizantha*	100
Maintenance/implementation of trees on farmland/farmyard	96
Fodder banks	56
Live fences	80
Shade for pasture grass and livestock	98
Enhanced nutrient cycling	98
Soil and water conservation	96
Fuelwood	100
Fruit production	69

Table 2. Percentage of agricultural producers implementing agroforestry land management practices as an adaptation strategy to a more intense dry season, and indicated other benefits (ecological services) as a result of implementing trees on their land in Esparza, Costa Rica (n=50).

For example, 100% of the agricultural producers in our study adapted *B. brizantha* as an improved pasture grass species when they initiated agroforestry silvopastural practices. *Brachiaria brizantha* is native to the African continent but it has been integrated in other tropical areas outside of its native range for use in permanent pasture, cutting for fresh feed, and as a ground cover for erosion control (Barnes et al. 2007). This grass species grows on a wide variety of soil types ranging from light to heavy soil textures and can tolerate a wide range in soil pH (4 to 8). *Brachiaria brizantha* is well adapted to a dry season ranging from 3 to 6 months in length during which time its leaves remain green while native species become dry, brown and unproductive. Additionally, *B. brizantha* can also endure wet soils and grows at an altitude up to 2000 m and thus can tolerate light frost (Barnes et al., 2007). Agricultural producers in our study found many advantages from growing *B. brizantha* on their land (Table 3).

Producers in our study observed an increase in milk production during the dry season by up to 70% as a result of establishing pastures with *B. brizantha*. Similar results were reported by Holmann et al. (2004) who found that the overall production of milk in Costa Rica increased by 55.5% as a result of establishing pastures or fodder banks with *B. brizantha*. This increase is likely due to the higher protein content in *B. brizantha* compared to other grass species traditionally used in Costa Rica (Cook et al., 2005). Results from our study showed that replacing conventional pasture grass with *B. brizantha* resulted in an improved management practice of grasslands, and also lowered grazing pressure and increased livestock carrying capacity, while at the same time provided a strategy to adapt to a changing climate. For example, Cameron (2002) observed that the implementation of *B. brizantha* grass into pastures resulted in soil and water conservation through a decrease in soil compaction and a reduction in external nutrient inputs.

Benefits Observed from *B. brizantha*	**Landowner Observation (%)**
Reduced erosion	96
Greater drought resistance	100
Increased forage production during dry season	98
Increased number of livestock per unit area	100
Livestock weight maintenance	92
Increased livestock meat and / or milk production	92
Improved calf health	96

Table 3. Benefits observed by agricultural producers by integrating silvopasture with *B. brizantha* grass in Esparza, Costa Rica (n=50).

Fig. 2. Fodderbank with *Gliricidia sepium* (Jacq.) Walp. The trees in the foreground show they were recently completely shoot pruned as fodder for livestock, and are already re-sprouting. Photo used with permission from M. Oelbermann.

Fodderbanks were another adaptive measure to climate change implemented by agricultural producers in our study (Figure 2). For example, a total of 56% of the agricultural producers surveyed used fodderbanks with commonly used tree species such as *Gliricidia sepium* (Jacq.) Walp. Pagiola et al. (2008) observed that adaptation of fodderbanks surrounding Esparza was much larger than that compared to other areas of Costa Rica, where they were virtually non-existent. This suggested that the integration of fodderbanks as an additional management practice was due to the close interaction between the agricultural producers, the Costa Rican Ministry of Agriculture, and CATIE researchers and extension officers taking part in the GEF-Silvopastoral Study. Agricultural producers found that *B. brizantha* fodderbanks helped to maintain livestock productivity during years with lower forage biomass and during drought or extended dry periods. A large proportion

(96%) of agricultural producers surveyed in our study implemented and maintained trees on their farmland or in the farmyard. Tree species most commonly established on farmland or in farm yards in our study included *Ficus hartwegii* (Miq.) Miq., *Guazuma ulmifolia* Lam., *Dipteryx panamensis* (Pittier) Rec. & Mell, *Enterolobium cyclocarpum* Jacq. Griseb., *Mangifera indica* L., *Byrsonima crassifolia* (L.) Kunth, *Psidium friedrichsthalianum* (O. Berg) Nied., *Gliricidia sepium* (Jacq.) Walp., and *Acrocomia aculeate* (Jacq.) Lodd. Ex Mart. Agricultural producers found that these trees served multiple functions such as the production of fruit for livestock and human consumption (69%), and the production of leaves for livestock fodder. They also expressed the hardiness of these trees during the dry season and as such did not shed their leaves. Other valuable services these trees provided included fuel wood (100%), shade for pasture grass and livestock, and enhanced nutrient cycling (98%), and soil and water conservation (96%).

Another agroforestry practice commonly implemented by participants in the GEF-Silvopastoral Study and widely used in Costa Rica included the use of live fences. In our study, all (100%) farmers surveyed implemented live fences and in a previous study by Harvey et al. (2005) over 80% of the agricultural producers surveyed in Costa Rica implemented live fences. In our study, the most common use of live fences was to provide an economical enclosure for livestock, and separating pastures from roads, forested areas, and waterways. Our study participants also observed that live fences provided shade for livestock and pasture grasses. In addition, many of the agricultural producers interviewed believed that live fences provided an ecological service by conserving biodiversity in addition to preventing soil erosion and protecting streams when they are used to separate pastureland from waterways. Live fences also provided foliage for cattle fodder. However, in our study, none of the agricultural producers surveyed discussed the use of live fences for this purpose. Similarly, Harvey et al. (2005) noted in their study that only 10% of Costa Rican agricultural producers used live fences for the production of fodder in addition to their use as an enclosure for pasture lands. This suggested that agricultural producers in Costa Rica were not aware of all possible benefits of live fences, but those that participated in the GEF-Silvopastoral Study had a greater knowledge on the diverse utility of live fences.

Other studies also revealed that the conversion of farmland previously containing few or no trees into areas dominated by agroforestry decreased the amount of degraded land by 15% over a 3-year period (Zamora-Lopez, 2006). Zamora-Lopez (2006) also found that the poorest agricultural producers were able to reduce pastureland degradation by introducing improved pasture with trees, by adopting fodder banks, and live fences. As such, a diversification in agricultural production systems included the implementation of a significant tree component that may buffer against income risks associated with current and future shifts in climate (Verchot et al., 2007). Kandji et al. (2006) also pointed out that agroforestry systems have the ability to improve the microclimate which in turn improves the adaptive capacity of land owners to climate change. Additionally, Kandji et al. (2006) suggested that the presence of trees in agricultural croplands can provide agricultural producers with an additional source of income that helps to strengthen their socioeconomic resilience. For example, tree products including fodder, resins, timber, and fruits provide a higher source of income than corps, and can also buffer against crop failure.

4.3 Producer contingency plans and adaptive capacity

According to the IPCC (2007) introducing a contingency plan to cope with unexpected changes in climate will increase food security and reduce financial losses. Our study showed that 28% of the agricultural producers researched the issue of climate change in detail and were able to explain what climate change is and how it will affect food security, their livelihood and families. These agricultural producers were able to link changes caused in the Earth's atmosphere to deforestation and industrial processes, and therefore had implemented a climate change contingency plan. These agricultural producers suggested, and were aware of, that those without a climate change contingency plan may face many additional challenges compared to those with a plan. An additional 50% of the agricultural producers in our study were seeking information about climate change contingency plans. This was because of their interaction with the GEF-Silvopastoral Study and the knowledge gained through this interaction. These agricultural producers expected that climate change will force them to make major adjustments to their land management practices in order to ensure food security and livelihoods for their family in the future. Approximately 56% of these agricultural producers relied on CATIE and 34% on the Costa Rican Ministry of Agriculture to obtain information on climate change and strategies for adaptation. The remaining agricultural producers from our study expressed that the different adaptation strategies they had already implemented as a result of their association with the GEF-Silvopastoral Study provided sufficient protection from negative impacts of climate change on their land.

Adger (2001) suggested that the capacity to adapt to climate change may be enhanced through the improvement of social networks that provide information about climate change. Such social networks, comprised of institutions and organizations fluent in issues surrounding climate change, should work in close association with agricultural producers to assist them in developing strategies to enhance their capacity to adapt to climate change (Gallopin, 2006). Our results showed that 84% of the agricultural producers sought assistance from CATIE and the Ministry of Agriculture to increase their capacity to adapt to climate change. Through the GEF-Silvopastoral Study, CATIE has played a key role in enhancing social networks in Esparza by connecting agricultural producers with the Costa Rican Ministry of Agriculture. A network specifically established for the agricultural producers in this region provided opportunities to connect with each other to learn about new climate change adaptation strategies through the implementation of agroforestry practices.

Nhemachena & Hassan (2007) observed that widespread information on climate change to agricultural producers enhanced their capacity to adapt to climate change, and led to the development and implementation of long-term contingency plans. Füssel (2007) also found that if agricultural producers understood the inherent changes expected as a result of climate change, then they improved their ability to adapt and decreased their overall cost of adaptation. Agricultural producers decided which land management practices to implement based on profit, grain yield and/or livestock productivity (Adger, 2001). Approximately 70% of agricultural producers in our study stated that market incentives either through credits or PES will increase their capacity to adapt to climate change. Based on the qualitative discussions with agricultural producers and the quantitative data collected in the surveys, several factors influenced their capacity and motivation to implement adaptation strategies (Figure 3). Our results showed that the producer's ability and motivation to implement climate change adaptation strategies was strongly influenced by financial incentives through a PES system which would also cover costs of tree planting and other expenses related to the adoption of agroforestry practices. Increased market incentives (e.g. eco-labelling) or other incentives to increase the marketability of their products, and non-financial assistance to help increase their capacity to adapt to climate change were requested by those surveyed in our study. Maddison (2007) pointed out that differences in the capacity to adapt to climate change may be due to the underlying differences in the perception of climate change. Some of the producers in his study expressed a lack of knowledge about adaptation strategies, rationing of key resources such as water, lack of appropriate seed, lack of market access and insecure property rights. Pagiola et al. (2008) also noted that the initial costs of implementing fodderbanks using *Brachiaria* grass species and the time lag before receiving any benefit from such activity in Costa Rica was a primary determinant of this management practice. Agricultural producers in our study, who thought climate change is not an environmental issue, were encouraged to implement environmental services for financial gain. The incentives offered by the GEF-Silvopastoral Study through a PES system and their increasing knowledge on the value of environmental services allowed them to understand and benefit financially through implementing these services.

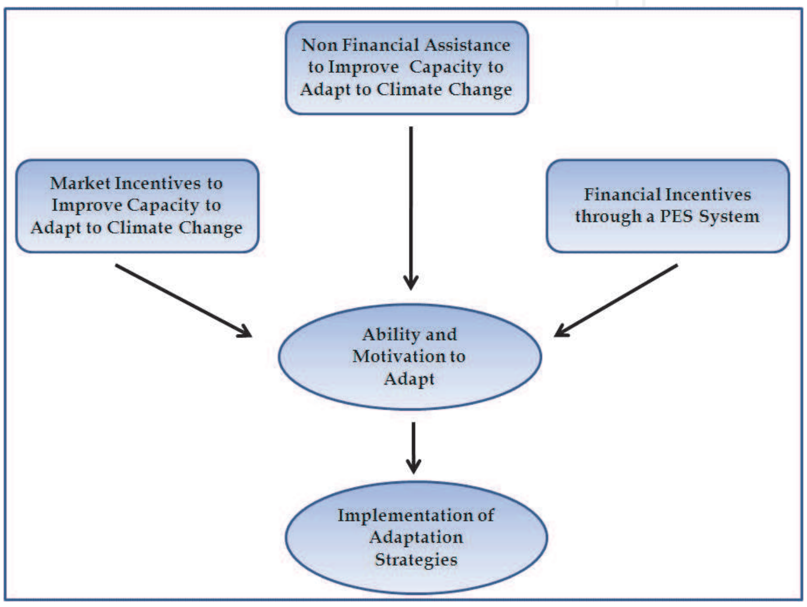


Fig. 3. Factors influencing the ability and motivation of agricultural producers to implement agroforestry systems as a climate change adaptation strategy, Esparza, Costa Rica (n=50).

5. Conclusions

Results from our study showed that the majority of agricultural producers had already implemented specific management practices to help cope with climate change. Our results also suggested that producers implemented specific agroforestry practices under the direction and guidance of CATIE extension personnel, researchers and the Costa Rican Ministry of Agriculture as part of the GEF-Silvopastoral Study. Through this interaction, agricultural producers became aware that the adoption of agroforestry practices also provided an ecological service, and therefore helped them to adapt to current and future climate change, for which they received a financial incentive. Only a small number of agricultural producers had a contingency plan in place which would help them cope with imminent climate change and reduce financial losses while maintaining food security and livelihoods for their families. However, a large proportion of agricultural producers were seeking further information on climate change contingency plans and relied on social networks built through their interaction with the GEF-Silvopastoral Study. A large number of agricultural producers in our study would readily adopt agroforestry practices as part of an incentive program including a PES system and market incentives, and receive further advice (non-financial assistance) from extension personnel on increasing their capacity to adapt to climate change.

6. Acknowledgements

Financial support was provided by Inter-American Institute for Co-operation in Agriculture, Canada, the Global Environment Facility Silvopastoral Study, and the University of Waterloo. We also thank Dr. M.A. Ibrahim and C. Cepulveda for assistance with research logistics and access to the GEF-Silvopastoral Study data base. We thank Francisco Casasola, and the Costa Rican Ministry of Agriculture for assistance in the field.

7. References

Adger, W.N. (2001). Scales of governance and environmental justice for adaptation and mitigation of climate change. *Journal of International Development* 16:238-281, ISSN 1099-1328.

Barnes, R.F., Nelson, C.J., Moore, K.J., Collins, M. (2007). *Forages: The Science of Grassland Agriculture*. Wiley-Blackwell, ISBN 0813806801, NJ, USA.

Budowski, G. (1987). The development of agroforestry in Central America. In: *Agroforestry: A Decade of Development* H.A. Steppler, Nair, P.K.R., pp. 69-88. International Council for Research in Agroforestry (ICRAF), ISBN 92 9059 036, Nairobi, Kenya.

Cameron, A.G. (2002). *The value of improved pastures*. Agnote 297, No. E32. Agdex 131. Australian Agronomy Society. ISSN No. 0157-8243.

Cook, B.G., Pengelly, B.C., Brown, S.D., Donnelly, J.L., Eagles, D.A., Franco, M.A., Hanson, J., Mullen, B.F., Partridge, I.J., Peters, M. and Schultze-Kraft, R. (2005). *Tropical Forages: An Interactive Selection Tool*, [CD-ROM], CSIRO, DPI&F (Qld), CIAT and ILRI, Brisbane, Australia, http://www.tropicalforages.info/.

Food and Agriculture Organization of the UN (FAO). (1990). *Production Yearbook*. ISBN 9789250030678, Rome, Italy.

Food and Agriculture Organization of the UN (FAO). (2007). *State of Food and Agriculture Report*. FAO Economic and Social Development Department, Corporate Document Repository. http://www.fao.org/docrep/010/a1200e/a1200e00.htm.

Füssel, H.M. (2007). Adaptation planning for climate change: Concepts, assessment approaches, and key lessons. *Sustainability Science* 2:265-275, ISSN 1862-4057.

Gallopin, G.C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change* 16:293-303, ISSN 0959-3780.

Gordon, A.M., Newman, S.M. (1997). *Temperate Agroforestry Systems*. CAB International, ISBN 0851991475,Wallingford, U.K.

Hänsela, G, Ibrahim, M.A., Villanueva, C, Andradec, H.J. (2009). Exploiting synergies between silvopastoral system components for carbon sequestration and an increase cattle productivity: Experience from Costa Rica and Nicaragua. *Proceedings of the XIII World Forestry Congress*, Buenos Aires, Argentina 18-23rd October, 2009, http://www.cfm2009.org/es/programapost/trabajos/exploiting_synergies_fd.pdf

Harvey, C.A., Villanueva, C., Villacis, J., Chacon, M., Monuz, D., Lopez, M., Ibrahim, M., Gomez, R., Taylor, R., Martinez, J., Navasa, A., Saenz, J., Sanchez, D., Medina, A., Vilchez, S., Hernandez, B., Pereza, A., Ruiz, R., Lopez, F., Lang, I., Sinclair, F.L. (2005). Contribution of live fences to the ecological integrity of agricultural landscapes. *Agriculture, Ecosystems and Environment* 111:200-230, ISSN 0167-8809.

Holdridge, L.R., Greneke, W.C., Hatheway, W.H., Liang, T., Tosi Jr., J.A. (1977). *Forest Environments in Tropical Life Zones*. Pergamon Press, ISBN 0080163408, Oxford, U.K.

Holmann, F., Rivas, L, Angel, P.J., Pérez, E. (2004). Impacts of adoption of *Brachiaria* grasses: Central America and Mexico. *Livestock Research for Rural Development* 16:1-9, ISSN 02123784.

Huxley, P. (1999). *Tropical Agroforestry*. Blackwell, ISBN 978-0-632-04047-6, Oxford, UK. IPCC. (2007). Climate Change 2007 – Impacts, Adaptation and Vulnerability. *IPCC Fourth Assessment Report*.http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml.

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: An overview. *Agroforestry Systems* 76:1-10, ISSN 1572-9680.

Kandji, S.T., Verchot, L.V., Mackensen, J., Boye, a., Van Noordwijk, M., Tomich, C.K., Ong, C.K., Albrecht, A., Palm, C.A. (2006). Opportunities for linking climate change adaptation and mitigation through agroforestry systems. In: *World Agroforestry into the Future*, Garrity, D.P., Okono, A., Grayson, M., Parrott, S., pp. 113-121. World Agroforestry Centre (ICRAF), ISBN 9290591846, Nairobi, Kenya.

Kass, D.L.C., Araya, J.S., Sanchez, J.O., Pinto, L.S., Rerreia, P. (1995). Ten years of experience with alley farming in Central America. *Proceedings of the International Alley Farming Conference*, IITA, Ibadan, Nigeria, pp. 393-402.

King, K.F.S. (1987). The history of agroforestry. In: *Agroforestry: A Decade of Development* H.A. Steppler, Nair, P.K.R., pp. 3-13. International Council for Research in Agroforestry (ICRAF), ISBN 92 9059 036, Nairobi, Kenya.

Leakey, R.R.B., Simons, A.J. (1996). The domestication and commercialization of indigenous trees in agroforestry for the alleviation of poverty. *Agroforestry Systems* 38:165-176.

McGinty, M.M., Swisher, M.E. Alvalapati, J. (2008). Agroforestry adoption and maintenance: Self-efficacy, attitudes and socio-economic factors. *Agroforestry Systems* 73:99-108, ISSN 1572-9680.

Maddison, D. 2007. The perception of and adaptation to climate change in Africa. *Policy Research Working Paper WPS4308*. The World Bank, Development Research Group, Sustainable and Urban Development Team, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1005547.

Nair, P.K.R. (1993). *An Introduction to Agroforestry*. Kluwer Academic Publishers, ISBN 0792321340, Dordrecht, NL.

Nhemachena, C., Hassan, R. (2007). Micro-level analysis of farmer's adaptation to climate change in Southern Africa. *International Food Policy and Research Institute Discussion Paper 00714*. Environment and Production Technology Division, http://www.ifpri.org/sites/default/files/publications/ifpridp00714.pdf.

Mercer, D.E. (2004). Adoption of agroforestry innovations in the tropics: a review. *Agroforestry Systems* 74:311-328, ISSN 1572-9680.

Oelbermann, M., Voroney, R.P., Gordon, A.M. (2004). Carbon sequestration in tropical and temperate agroforestry systems: A review from Costa Rica and southern Canada. *Agriculture, Ecosystems and Environment* 104:359-377, ISSN 0167-8809.

Oelbermann, M., Voroney, R.P. (2011). An evaluation of the Century model to predict soil organic carbon in tropical and temperate agroforestry systems. *Agroforestry Systems* 81: DOI 10.1007/s10457-010-9351-6, ISSN 1572-9680.

Pagiola, S. (2007). Payments for environmental services in Costa Rica. *Ecological Economics* 6: 712-724, ISSN 09218009.

Pagiola, S., Rios, A.R., Arcenas, A. (2008). Can the poor participate in payments for environmental services? Lessons from the Silvopastoral Project in Nicaragua. *Environment and Development Economics* 13:299-325, ISSN 1355770.

Pattanayack, S.K., Mercer, D.E., Sills, E., Yang, J.C. (2003). Taking stock of agroforestry adoption studies. *Agroforestry Systems* 57:186-203, ISSN 1572-9680.

Pearce, D., Mourato, S. (2004). The economic valuation of agroforestry's environmental services. In: *Agroforestry ad Biodiversity Conservation in Tropical Landscapes*, Schroth, G., da Fonseca, G.A.B., Harvey, C.A., Gascon, C., Vasconcelos, H.L., Izac, A.M.N., pp. 67-86. Island Press, ISBN 1559633565, Washington, USA.

Raxworthy, C.J., Pearson, R.G., Rabibisoa, N., Rakotondrazafy, A.M., Ramanamanjato, J.B., Raselimanana, A.P., Wu, S., Nussbaum, R.A., Stone, D.A. (2008). Extinction vulnerability of tropical montane endemism from warming and upslope displacement. *Global Change Biology* 14:1703-1720, ISSN 1354-1013.

Sanchez, P.A. (2000). Linking climate change research with food security and poverty reduction in the tropics. *Agriculture, Ecosystems and Environment* 82:371-383, ISSN 0167-8809.

Smith, C.E. (2008). Encouraging climate change adaptation though the payment for environmental services: Case studies in the Pacific region of Costa Rica. MES Thesis, Department of Environment and Resource Studies, University of Waterloo, Canada.

Sood, K.K, Mitchell, C.P. (2009). Identifying important biophysical and social determinants of on-farm tree growing in subsistence-based traditional agroforestry systems. *Agforestry Systems* 75:175-187, ISSN 1572-9680.

Verchot, L.V., van Noordwijk, M., Kandji, S., Tomich, T., Ong, C., Albrecht, A., Mackensen, J., Bantilan, C. Palm, C. (2007). Climate change: Linking adaptation and mitigation through agroforestry. *Mitigation and Adaptation Strategies for Global Change* 12:902-918, ISSN 1381-2386.

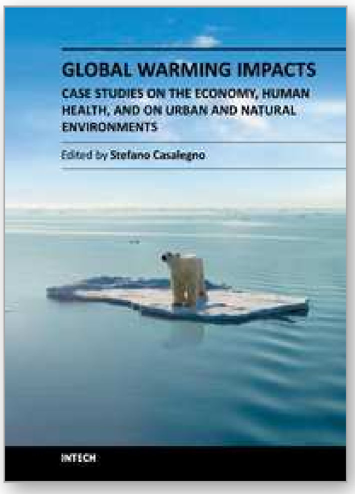
Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Formentin, J.M., Hoegh-Gugdberg, O., Bairlein, F. (2002) Ecological responses to recent climate change. *Nature* 416:389-395.

Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J., Dokken, D.J. (2000). *IPCC Special Report on Land Use, Land-use Change and Forestry*. http://www.grida.no/climate/ipcc/land use/

Yamamoto, W, Dewi, I.A., Ibrahim, M.A. (2007). Effects of silvopastoral areas on milk production at dual-purpose cattle farms at the semi-humid old agricultural frontier in central Nicaragua. *Agricultural Systems* 94:368-375, ISSN 0308-521.

Young, A. (2002). *Agroforestry for Soil Management*. CAB International, ISBN 0851991890, Wallingford, UK.

Zamora-Lopez, S.E. (2006). Efecto de los pagos por servicios ambientales en la estructura, composición, conectividad y el stock de carbono presente en el paisaje ganadero de Esparza, Costa Rica. M.Sc. Thesis Centro Agronómico Tropical de Investicación y Enseñanza (CATIE), Turrialba, Costa Rica.



Global Warming Impacts - Case Studies on the Economy, Human Health, and on Urban and Natural Environments
Edited by Dr. Stefano Casalegno

ISBN 978-953-307-785-7
Hard cover, 290 pages
Publisher InTech
Published online 03, October, 2011
Published in print edition October, 2011

This book addresses the theme of the impacts of global warming on different specific fields, ranging from the regional and global economy, to agriculture, human health, urban areas, land vegetation, marine areas and mangroves. Despite the volume of scientific work that has been undertaken in relation to each of each of these issues, the study of the impacts of global warming upon them is a relatively recent and unexplored topic. The chapters of this book offer a broad overview of potential applications of global warming science. As this science continues to evolve, confirm and reject study hypotheses, it is hoped that this book will stimulate further developments in relation to the impacts of changes in the global climate.