CPWF Project Report

Quesungual slash and mulch agroforestry system (QSMAS): Improving crop water productivity, food security and resource quality in the sub-humid tropics

Project Number 15 (PN15)

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Program Preface

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase water productivity for agriculture—that is, to change the way water is managed and used to meet international food security and poverty eradication goals—in order to leave more water for other users and the environment.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface

PN15 - Quesungual slash and mulch agroforestry system (QSMAS): Improving crop water productivity, food security and resource quality in the sub-humid tropics: The knowledge and principles generated by CPWF-PN15 confirm that QSMAS can be a model production system for implementing conservation agriculture to achieve food security and sustainable development in drought-prone areas of hillsides in the sub-humid tropics, while providing ecosystem services in the face of land degradation and climate change. As an adoptable option to replace the slash and burn traditional system, QSMAS can improve smallholder livelihoods through eco-efficient use and conservation of natural resources. Participatory validation activities suggest that the conservation agriculture principles embedded in QSMAS can be readily accepted by resource-poor farmers and local authorities in similar agroecosystems.

CPWF Project Report Series

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RESEARCH HIGHLIGHTS

Results of research activities carried out by CPWF-PN15 partners for over four years time period indicate that:

- **Objective 1:** Quesungual Slash and Mulch Agroforestry System (QSMAS) acceptance and dissemination in the reference site (Honduras) was facilitated by the high biophysical and socioeconomic vulnerability resulted from the long history of extensive use of slash and burn agriculture (SB). Driving forces behind QSMAS adoption are multiple and are well articulated. The success of the system is particularly a reflection of a community-based process in which local people and extension service providers shared ideas and learn together.
- **Objective 2:** QSMAS is an integrated land use management strategy based on four principles of conservation agriculture that contribute to its superior performance. These key principles are: (1) No slash & burn, through management (partial, selective, and progressive slash-and-prune) of natural vegetation; (2) Permanent soil cover, through continual deposition of biomass from trees, shrubs and weeds, and crop residues; (3) Minimal disturbance of soil, through no tillage, direct seedling, and reduced soil disturbance during agronomic practices; and (4) Efficient use of fertilizer, through appropriate application (timing, type, amount, location) of fertilizers.

  The production practices applied in QSMAS have beneficial effects on the soil-plant-atmosphere continuum. Specifically, QSMAS contributes to food security through sustainable maize and common bean production under sub-humid conditions on steep slopes, by improving crop water productivity and soil quality, compared to SB system. Additionally QSMAS is eco-efficient through the use of renewable natural resources and provides ecosystem services by reducing deforestation, soil erosion and global warming potential in comparison to SB system.
- **Objective 3:** Extrapolation domain analysis for QSMAS showed good expectations of potential impact in a number of tropical countries in Latin America, Africa and Asia. Experience from validation in Nicaragua and Colombia indicates that changing from SB system to QSMAS may not be difficult since farmers easily appreciate the multiple socioeconomic and biophysical benefits from the system.
- **Objective 4:** QSMAS can be used as a crop production strategy to deliver ecosystem services, while simultaneously conserving biodiversity and restoring degraded landscapes. However, these benefits should be increased through intensification and diversification with high value components (livestock and fruit crop options), which would require access to credit and markets, and policies for the payment for environmental services. Farmer-to-farmer proved to be a useful mechanism for the promotion and dissemination of the system.
- Practice of QSMAS is already facing challenges in Honduras and Nicaragua. To overcome those problems, research should be conducted to improve crop management by finding alternatives to the use of chemical herbicides, introducing improved varieties and optimizing fertilizer application. There is also need to evaluate the impact of tree management and integration of livestock production on QSMAS sustainability. For the introduction of QSMAS, it is essential to develop strategies for sites where the environment (e.g. local culture and knowledge, socioeconomic and biophysical issues) is not favorable for research or agroforestry. Quantifying the impacts of QSMAS at watershed level and on the hydrological cycle is still pending.

EXECUTIVE SUMMARY

Problem statement: Water availability is expected to be one of the main factors limiting food production in the near future. In fact, most agricultural areas on hillsides in developing countries already suffer from seasonal water scarcity and dry spells. The incidence and impact of these events is increasing because of the lack of adequate soil and crop management practices and global climate change. Improving production systems to reduce land degradation while adapting to, as well as contributing for mitigation of, climate change is a major objective in today's agriculture. Particularly challenging is the increase of crop water productivity –the amount of food produced per unit of water invested– in developing countries that depend on rainfed agriculture to feed their growing population.

In south-west Honduras, local farmers and experts from FAO developed a production system named Quesungual. The 'Quesungual Slash and Mulch Agroforestry System' (QSMAS) is a smallholder production system, comprising a group of technologies for the sustainable management of vegetation, water, soil and nutrient resources in drought-prone areas of hillsides in the sub-humid tropics. Initially QSMAS was practiced by over 6,000 resource-poor farmers on 7,000 ha of southwest Honduras, mainly to produce major staples (maize, bean, sorghum). During the last five years, the system has also been adopted in other subhumid regions of southwest and southeast Honduras, northwest Nicaragua, and Guatemala. This success in improved adoption has been partially driven by QSMAS' substantial contribution to food security, remarkable resilience to natural extremes of water deficit and water excess, and suitability to replace the environmentally unfriendly production systems based on the practice of slash and burn (SB).

Objectives: The main goal of this project[1] was to use QSMAS to improve livelihoods of rural poor through increased water resources and food security in sub-humid hillside areas, while maintaining the soil and plant genetic resources for future generations. The main objective was to determine the key principles behind the social acceptance and biophysical resilience of QSMAS by defining the role of the management components f the system and QSMAS' capacity to sustain crop production and alleviate water deficits on steeper slopes with high risk of soil erosion. The specific objectives were: (1) to assess socioeconomic and biophysical context of QSMAS and to systematize information into database; (2) to define QSMAS management concepts and principles and to develop relevant tools to monitor soil and water quality; (3) to evaluate and document potential areas suitable to QSMAS; and (4) to develop tools for dissemination, adaptation and promotion of the QSMAS management strategies.

Methods: The objectives of this four years time period project were accomplished by the evaluation of the agronomic and environmental performance of QSMAS compared with the traditional SB system in the reference site of Lempira, Honduras (Apr 2005 to Dec 2007), and in the validation sites of

[1] Project partially funded by the CPWF (PN15: "*Quesungual slash and mulch agroforestry system (QSMAS): Improving crop water productivity, food security and resource quality in the sub-humid tropics*") of CGIAR. It was co-executed by the MIS Consortium in Central America including INTA and UNA in Nicaragua, and ESNACIFOR, UNA and FAO in Honduras; CIPASLA and National University of Colombia – Palmira campus, Colombia; University of Western Australia, Australia; ARIDnet Consortium and Soil Management CRSP, USA; and CIAT in Honduras, Nicaragua and Colombia.

Somotillo, Nicaragua (May 2005 to Dec 2007) and Cauca, Colombia (Aug 2007 to Feb 2008).

The areas of research in the reference site included the water dynamics and crop water productivity, soil losses, nutrient and soil organic matter dynamics, natural vegetation, greenhouse gas and energy fluxes, soil fauna, pests and diseases, and grain yields. In the sites of validation, studies were focused on the adaptation of QSMAS to local conditions and acceptance by farmers and other stakeholders. Other key activities included the analysis of the biophysical and socioeconomic contexts in the reference site, and the generation of extrapolation domains for the adaptation of the system to other suitable regions in the tropics.

Research findings: Results of research activities indicate the following:

- QSMAS can be a model production system embracing principles of conservation agriculture to achieve food security and sustainability in drought-prone areas of the sub-humid tropics.
- In the reference site in Honduras, the integrated multidisciplinary efforts made to replace the SB system with QSMAS resulted in three biophysical and socioeconomic contexts: (i) the period of high vulnerability when SB system was the predominant source of food; (ii) the period of transition while QSMAS was being developed and disseminated; and (iii) the period of recovery of the landscape and the welfare of the communities as a result of the holistic development strategy that included QSMAS as the main instrument of change.
- QSMAS is an integrated land use management strategy based on four principles that contribute to its superior performance in terms of productivity, sustainability, and biophysical resilience. These key principles are:
  1. **No slash and burn**, through management (partial, selective, and progressive slash-and-prune) of natural vegetation;
  2. **Permanent soil cover**, through continual deposition of biomass from trees, shrubs and weeds, and crop residues;
  3. **Minimal disturbance of soil**, through no tillage, direct seedling, and reduced soil disturbance during agronomic practices; and
  4. **Efficient use of fertilizer**, through appropriate application (timing, type, amount, location) of fertilizers.
- High natural variation in QSMAS plots (i.e. predominant vegetation, number of trees and shrubs, and soil properties) and marked differences on their management (e.g. crop production and crop residues) demonstrates that the implementation of its principles strongly relies on criteria of individual farmers that are influenced by current and future needs of the householders.
- QSMAS is a suitable option to replace the environmentally unfriendly production systems based on the SB practice, traditionally used by resource-poor small-scale farmers in the Pan tropical world.
- Under experimental conditions, QSMAS is equally effective as SB system for the production of maize, and more efficient than SB to produce common bean. Undoubtedly, QSMAS performance is favored by management practices leading towards resilience, efficient nutrient cycling, improved crop water productivity, and increased and sustained C synthesis and accumulation. The more dramatic effect is the increased productivity of water in the later part of the bimodal rainy season, when rainfall is usually irregular (dry spells on key stages of crop development) or inadequate (shorter rainy season).
- Compared to SB system QSMAS is not only eco-efficient through the use of renewable natural resources, but also provides ecosystem services including:
  1. *Provisioning services*: <u>food security</u> through improved crop water productivity and yields at lower costs; and <u>improved water cycling</u> through reduced runoff, erosion, water turbidity and surface evaporation, and increased infiltration, soil water storage capacity and use of green water.

2. *Regulating services*: reduced global warming potential through lower methane emission and improved C capture.
3. *Supporting services*: mitigation of soil degradation through improved structure, biological activity, organic matter, nutrient cycling and fertilizer use efficiency; and restoration and conservation of biodiversity.
4. *Cultural services*: improved quality of life through the regeneration of the landscape.

- Preliminary analysis on the payment for environmental services (PES) showed that QSMAS has a high potential to generate additional sources of income to communities that decide to adopt the system or its principles. A new analysis including the whole watershed would increase the potential PES, since QSMAS generates important amounts of environmental services at landscape level.
- Driving forces behind QSMAS adoption are multiple and articulated. The success of the system in Honduras and Nicaragua is specially a reflection of a community-based learning process in which local people and extension service providers share ideas and learn together.
- Positive results on QSMAS validation in Nicaragua and Colombia underpin its potential to enhance support for livelihoods in vulnerable rural areas in sub-humid tropics, including marginal soils on sloping lands. Of high value is knowledge of farmers' consciousness of the negative impacts of SB system, suggesting that changing to QSMAS may not be difficult since they easily perceive the multiple socioeconomic and biophysical benefits from the system.
- Extrapolation Domain Analysis (EDA) revealed high expectations of potential impact for QSMAS in a number of countries in Latin America, Africa and Asia. However, the results are limited to the availability of data from the reference and target sites in the tropics. Although adoption beyond reference sites is not a simple process to be determined from basic data, the EDA can be used as a means to explore what key factors could induce or restrict wider adoption.

Outcomes: The main outcome generated by the project is the knowledge of the effect of agroforestry on water, soil quality, landscape and environmental quality, confirming that it is possible to achieve food security and other benefits by applying principles of conservation agriculture in drought-prone areas of the sub-humid tropics, without compromising resource quality.

Impacts: The project generated three major impacts:
- Increased capacity of young professionals in the Mesoamerican region to design and conduct research activities in different topics (agroforestry, farm systems, water and nutrient cycling, soil conservation and climate change, among others).
- Reduced use of inputs in the reference site through improving efficiency in the use of fertilizers by the optimizing timing and splitting the supplementary N application in maize.
- Besides the positive agronomic and economic results obtained in the validation plots in Nicaragua, the system had a good acceptance and an early dissemination among neighboring farmers. According to a recent study, after four years of validation efforts, around 90% of the 120 farmers in La Danta watershed (where Negro River is born) eliminated burning to manage residues and about 70 of them are already using QSMAS.

International public goods: The international public goods produced include:
- Databases of the experimental data from three PhD and two MSc theses on biophysical factors, and one study on socioeconomics, supported by the project; and of literature pertinent to QSMAS (mainly in Spanish).
- Sixteen theses including four PhD, two MSc and 10 BS, reporting of the methodologies used and the main findings of these studies (most of them in Spanish).

- A document including relevant information of QSMAS, guidelines for the establishment and management of the system, and the potential target regions recommended for its validation based on the EDA.

Recommendations

- Targeting and adapting QSMAS (or its principles of conservation agriculture) to other drought-prone areas in the sub-humid tropics may be facilitated by:
  1. Clarification of the main processes which underpin its success;
  2. Identification of the biophysical and socioeconomic pre-conditions that enable dissemination (e.g. financial mechanisms for key inputs and strong collective action);
  3. Application of the main management principles behind its productivity and sustainability, and knowledge of technologies of management associated with these principles;
  4. Identification of suitable sites where QSMAS has the potential to be an alternative to slash and burn agriculture (EDA based on biophysical and socioeconomic contexts in the reference site); and
  5. Application of lessons learned from experiences on validation of QSMAS.
- For farmers to fully realize benefits from QSMAS there is need for intensification and diversification of the system by including high value market oriented fruit and vegetable crops and livestock production, facilitating higher profits while reducing risks and contributing to QSMAS' sustainability.
- Policy implications for achieving wider impacts of QSMAS include enabling: (i) regional–national-local goals to improving sustainability of agroecosystems while enhancing their functionality; (ii) local agricultural and developmental extension systems: (iii) incentives to communities to adopt more sustainable and environmentally friendly production practices; (iv) financial mechanisms to facilitate adoption of proposed changes; (v) physical infrastructure to sustain productivity gains; and (vi) payment for the environment services (PES).
- Potential PES provided by QSMAS (or other forms of conservation agriculture) at plot and landscape level may enhance its attractiveness to local and national authorities in countries with policies to protect ecosystems in the face of climate change, and persuade communities towards its adoption for the sustainable management of natural resources.
- The need for further research on QSMAS includes:
  1. *Filling knowledge gaps at system level:* increase of crop water productivity, alternatives to the use of chemical herbicides and optimization of fertilizer application; resilience and profitability when integrated with livestock and fruit trees; contribution as part of a farming system (small scale) or as part of a multifunctional landscape (large scale); and potential to recover degraded soils.
  2. *Strategies to scaling up and scaling out of QSMAS:* validation-dissemination (linked to capacity building) in similar sites in the tropics; approaches for adaptation where the environment (social, economic and biophysical issues) is not favorable for research or agroforestry; development of drought insurance linked with the use of the system; and assessment PES at landscape level linked to the use of the system.
  3. *Generation of PES:* enhance landscape function for services related to water, C sequestration and mitigation of greenhouse gas emissions, soil quality and resilience (even to natural disasters), conservation of biodiversity, recovery of degraded soils, and ecotourism. Determination of QSMAS' impact at watershed level and on the hydrological cycle.

INTRODUCTION

Quezungual[2] is the name of an ancient rural village in southwest Honduras, Central America. The village's name is drawn from three indigenous words[3] that mean soil, vegetation, and a convergence of streams. Although today the steep slopes surrounding Quezungual are peppered with tall trees and produce bountiful crops (Figure I.1), just two decades ago the region was suffering from a long period of inappropriate agricultural practices that had resulted in loss of forest cover and soil degradation leading to declining crop yields. How did such change come about? The answer is the widespread adoption of the Quesungual Slash and Mulch Agroforestry System (QSMAS) that substituted the traditional slash and burn (SB) production system.

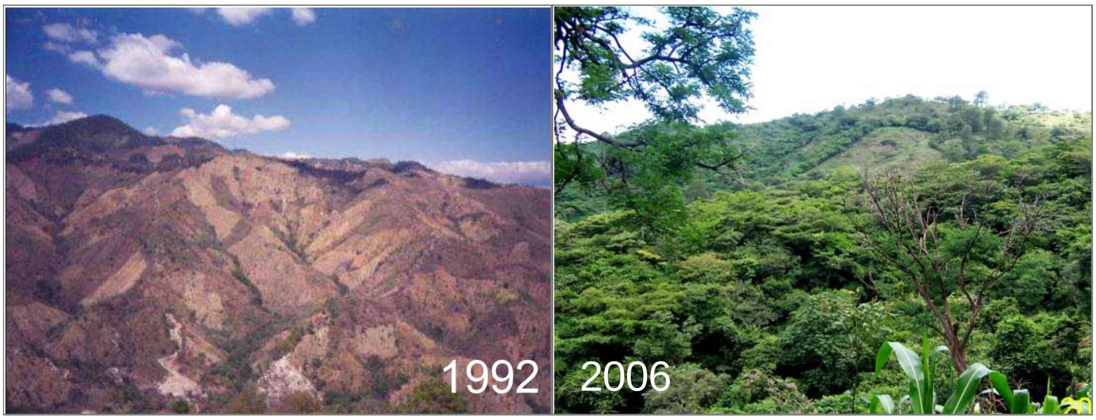


Figure I.1: *Two pictures showing the contrast in the landscape attributed to the widespread adoption of QSMAS by small-scale farmers in Lempira, southwest Honduras (Source: FAO-Honduras).*

QSMAS was developed in the early 1990s, when officers and technicians from FAO[4] identified native farming practices from the area around Quezungual village and worked together with farmers to come up with a more suitable agricultural system for that eco-region (Hellin et al. 1999). The result was a smallholder production system, comprising a group of technologies to manage vegetation, water, soil and nutrient resources in drought-prone areas of hillsides in the sub-humid tropics (Wélchez et al. 2008).

QSMAS is being practiced in south-west Honduras to produce major staples (maize, bean and sorghum). Reported benefits include:

- Food security to over 6,000 small-scale farmers practicing the system in around 7,000 ha.
- Increased productivity and profitability through crop diversification.
- High degree of resilience to extreme weather events such as the El Niño drought of 1997 and Hurricane Mitch in 1998.
- Maintenance and recovery of local biodiversity through the natural regeneration of around 60,000 ha of secondary forest.
- Improved environmental quality through the elimination of burning, reduction of cutting of forests (providing around 40% of the firewood required for domestic consumption), and mitigation of land degradation.
- Improved availability and quality of water for domestic use.

[2] Pronounced keh-soon-**gwahl**.
[3] Lenca language; an indigenous language practiced in El Salvador and Honduras.
[4] Lempira Sur Project (supported by the Honduran and Dutch governments), 1992-1999.

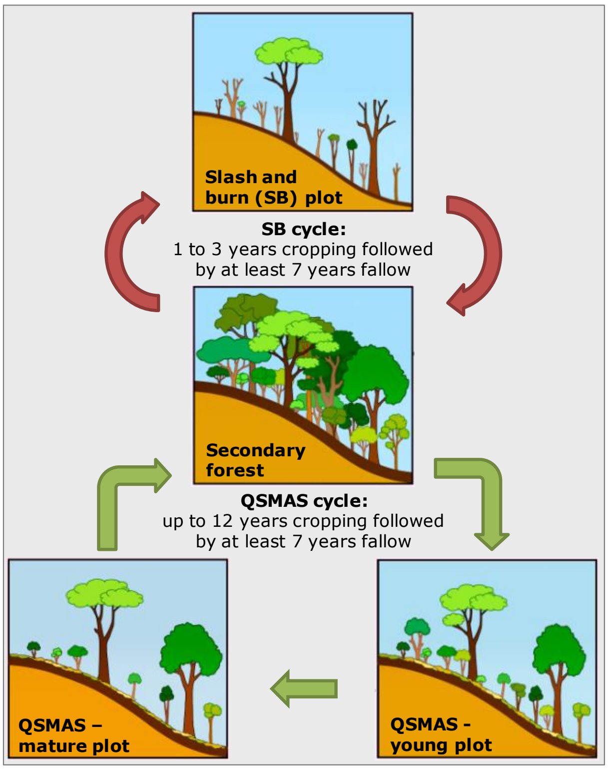


Figure I.2: *Illustration of the production cycles of SB system and QSMAS, starting from their established from secondary forests to the moment the productive plots are abandoned to initiate a new cycle of restoration of the natural balances. Adapted from N. Pauli, 2008.*

QSMAS management starts with the selection of a well developed (high amount and diversity of trees and shrubs) naturally regenerated secondary forests (Figure I.2). Then, "pioneer" crops sorghum (*Sorghum vulgare* L.) or common beans (*Phaseolus vulgaris* L.), whose seedlings are capable of emerging through the mulch, are sown by broadcast. Maize (*Zea mays* L.) is not sown as a pioneer crop because of too much quantity of mulch that affects the emergence of seedlings and also because of the late season planting (August) that does not provide adequate soil moisture for grain filling late in the season. After planting, selective and partial slashing and pruning of dispersed trees and shrubs in fallows is done, followed by the removal of the firewood and trunks and the uniform distribution of the biomass (leaves and fine shoots) that results as mulch. The outcome is a plot with numerous slashed trees, non-slashed high-value multipurpose timber and fruit trees, and slashed shrubs (that are used for production practices such as holding harvested bean plants to avoid infection of bean pods), and a dense layer of mulch. After the pioneer crop, for 10 to 12 years as the recognized system's productive life based on the regrowth potential of trees in the system, QSMAS practices include the annual production of maize as main crop intercropped with beans or sorghum using zero-tillage, the continuous slashing and mainly pruning of trees and shrubs in order to eliminate branches (to take out for firewood) and regrowth (to avoid shade for the crops), a continuous mulching (from litterfall, slashing of trees and application of crop residues), spot fertilization technologies, and sometimes the use of pre-emergence herbicides (Wélchez et al. 2006).

Of major importance is that according to farmers and development organizations, QSMAS is a validated option to replace the non-sustainable, environmentally unfriendly production systems based on SB practice, traditionally used by resource-poor farmers in the tropics (Wélchez and Cherret 2002).

Without a doubt, QSMAS contributed to the successful development strategy in improving rural livelihoods in south-west Honduras led by FAO. Understanding of the socio-economic and biophysical processes that drive to the adoption and successful performance of the system in this region is of critical importance to be able to derive principles that can be extrapolated to similar environments in the sub-humid tropics. This report summarizes the research activities conducted in QSMAS reference and validation sites and the main findings achieved by PN15 partners' in Central America and Colombia, during the period of 31 September, 2004 to 15 March, 2009.

1 PROJECT OBJECTIVES

The main goal of this project was to use QSMAS to improve livelihoods of rural poor through increased water resources and food security in sub-humid hillside areas, while maintaining the soil and plant genetic resources for future generations.

The main objective was to define the key driving forces and principles behind the social acceptance and the biophysical resilience of QSMAS by determining the role of the management components of the system (soil, trees, crop residues, tree pruning and no burning) and QSMAS' capacity to sustain crop production and alleviate water deficits on steeper slopes with high risk of soil erosion

The specific objectives of PN15 were:

1. To assess socioeconomic and biophysical context of QSMAS and to systematize information into database.
2. To define QSMAS management concepts and principles and to develop relevant tools to monitor soil and water quality.
3. To evaluate and document potential areas suitable to QSMAS.
4. To develop tools for dissemination, adaptation and promotion of the QSMAS management strategies.

Objective 1: To assess socioeconomic and biophysical context of QSMAS and to systematize information into database

In order to have an integrated picture of the biophysical and socioeconomic factors that may have facilitated the adoption of QSMAS, it was necessary to define the context of the southern region of the department of Lempira (south-west Honduras), the reference site where the system has been used as a successful land use option. This included the identification of the main biophysical and socioeconomic constraints before QSMAS impact on the region, and the elucidation of the main driving forces behind QSMAS success.

In addition, it was essential to identify farms including (or with possibilities to establish) QSMAS plots, SB plots as the production system traditionally used in similar agroecosystems, and/or the secondary forest that precede the establishment of both production systems, in order to systematically evaluate the agronomic and environmental performance of QSMAS and therefore to identify advantages and limitations associated to its adoption.

Methods

The methodological approach included the execution of two studies for the identification of the drivers for adoption of QSMAS; and the systematic visits to farmers for the identification of adequate farms for conducting on-site studies.

The first study was conducted by MIS consortium (led by CIAT and FAO-Honduras). It comprised two phases: the first phase consisted in reviewing and synthesizing existing information collected by the FAO-Lempira project during 1995-2005; and the second phase on the validation of the abovementioned information. The information was mostly grey literature, including PhD theses, draft publications, internal reports, project documents and technical bulletins. The validation was performed in collaboration with 15 key informants (six staff of the FAO-Lempira Sur project, four community leaders and five farmers that adopted QSMAS), focusing on the validity of the drivers elucidated from the literature review.

The second study was conducted by ARIDnet and MIS consortium and executed in November 2005 and the first semester of 2006. It was based on the application of the Dryland Development Paradigm (DDP) (Reynolds and Stafford Smith 2002) principles (Table 1.1). Analysis and synthesis were completed in two phases. The first consisted in an intensive case study approach performed by an international team of 20 natural and social scientists and involving the acquisition and integration of information from multiple sources (publications and grey literature). This allowed evaluating the extent to which QSMAS is currently addressing land degradation in the region, to identify the key variables associated with the evolution and success of QSMAS, and to predict the extent to which QSMAS will be able to limit land degradation and promote recovery in the future. This was followed up by on-site interviews with key informants (scientists, development workers, community leaders and farmers). In order to achieve a better understanding of the factors linked with the adoption of QSMAS, interviews were also conducted in the vicinity of nearby town of Guarita, where SB agriculture is being practiced. In the second phase, the analysis was refined through the application of the five DDP principles to three periods: pre-QSMAS, QSMSAS adoption and QSMAS' future. The retrospective analysis (pre-QSMAS) focused on the conditions that led to the development of the system; the current analysis (QSMAS adoption) addressed the relative success of the system through 2006; and the prospective (QSMAS' future) emphasized future challenges to the persistence and sustainability of QSMAS in the reference site.

The selection of farms for the establishment of the experimental plots was executed between 2004 and 2005. It consisted in two phases: (1) initial visit to farms and short interview to farmers; and (2) sequential and systematic screening of farms until the most suitable ones were selected. The initial farms visited had to have QSMAS as the production system, and for additional consideration also required to fulfill the following criteria: (i) a minimum size of 0.35 ha; and (ii) maize, common bean and/or sorghum as main crops. As result, eighty-five farms were identified. Subsequent analysis of information allowed the selection of thirty-two farms, considering the following criteria: (i) farmer with a good spirit of collaboration; (ii) no limitations for access; (iii) low-to-medium welfare (partial-to-total dependence on QSMAS); (iv) soil type and microclimate similar to other farms; (v) ownership of land; (vi) low influence of FAO (as developer and promoter of the system), to avoid bias towards the system. Out of this, eight farms were selected for the establishment and management of the experimental plots during the duration of the project.

Results and Discussion

Socioeconomic and biophysical characterization of the Lempira Region

The southern region of the department of Lempira is considered one of the poorest of Honduras. It comprises 20 municipalities located close to the border with El Salvador (Figure 1.1), with an area of 2,177 km^2 and a total population of 110,000 inhabitants. The upper part of this region (≤900 masl) is an important component of the Lempa watershed. This watershed provides about 60% of the water consumed in El Salvador and 57% of the hydropower used by this country. However, the region as a whole is isolated from the rest of Honduras due to poor road infrastructure and limited support from the Central government (FAO 1999). Infrastructure of the region is poor, as reflected by a Human Development Index of 0.55, the lowest within the country (UNDP-Honduras 2006).

The region falls within the Central American dry tropical forest zone, which has been almost completely converted to agriculture across its original extent since the initial settlement of the area over 1000 years ago. Topographically this region is dominated by steep slopes (95% of the landscape is hilly). The highlands within this region are thought to be composed of a complex sequence of basement uplifts, Mesozoic sedimentary strata, and overlying volcanic ignimbrite deposits. Soils are predominantly acidic (pH ≤5.1) Entisols (Lithic Ustorthents), with a gravely or stony (30-50% coarse fragments) loamy sand texture influenced by volcanic ashes associated with igneous and intrusive rocks. Soil organic matter content (2.8-3.9 %) and available P are usually low (around 3.5 mg kg^{-1}).

Figure.1.1: *Location of the department of Lempira within Honduras.*

The regions' life zone (Holdridge) is a sub-humid tropical semi-deciduous forest and pine tress, while its climatic classification (Köppen) is a Tropic Humid-Dry (Aw) region with a bimodal distribution of rainfall with 2 peak periods seperated by a brief dry spell (10 to 20 days) as shown in Figure 1.2. Annual precipitation is around 1200-1400 mm, with the rainy season extending from early May to late October. Usually, miaze is planted in the early part of the rainy season in May (generally refered to as "primera" or first season) while common bean is planted during August (generally refered to as "postrera" or second season) at the beginning of the late part of the rainy season. During the dry season (from early November to April), strong winds blow from the North and the enhanced evapotranspiration cause severe water deficits (over 200 mm in the middle of the dry season) until the onset of rains. The average annual temperature varies from 17 to 25°C.

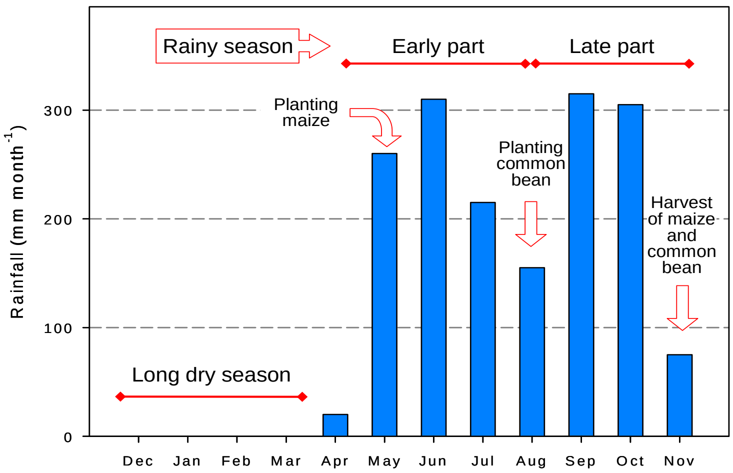


Figure 1.2: *Bimodal precipitation pattern with early part ("primera" in Spanish) and later part ("postrera" in Spanish) that is very common in Central America.*

Most of the farmers (75%) of the region are smallholders producing maize and beans as subsistence crops, while a small proportion grows coffee (10%) and extensively graze livestock (5%). Land resources development is concentrated (80%) around small farms (less than 5 hectares) with landless farmers renting land through lease or share cropping arrangements. Major production systems are based on subsistence crops (maize, common bean and sorghum) with very low yields (600-850 kg ha^{-1} maize, 250-300 kg ha^{-1} common beans and 500-800 kg ha^{-1} sorghum), combined with livestock at low stocking rates. Agriculture is limited by the long dry season and affected by severe dry spells. Small-scale animal husbandry (chicken, pigs), roots and tuber crops, horticulture and fruit trees are important components of household backyard gardens.

Local markets are limited and have low integration with the rest of Honduras. Basic grain production is partly oriented towards self-consumption and local delivery. However, cross-border trade with El Salvador is rapidly increasing due to the high population and better purchasing power available in the neighboring country. Since the local labor market is limited, informal labor exchange is a known practice. Seasonal migration takes place between the Northern coffee producing areas. Labor scarcity is acknowledged as a primary limitation for intensification of land use. Remittances from relatives living in the U.S. are an important additional source of income for families in the region.

QSMAS is mainly practiced in the municipality of Candelaria (14°4'60" N, 88°34'0" W, 200-900 masl). Smallholder farmers traditionally practiced shifting cultivation based on SB agriculture with long fallow periods to regenerate soil fertility. As in many parts of hillside Honduras and other countries of Central America, with population growth farmers were forced to shorten fallow periods to less than the minimum time necessary for recuperation of forest cover and soil productivity. The removal of soil cover by burning had increased the susceptibility to soil erosion, resulting in the continuous loss of productive capacity of soil with a major impact on water quality and availability for downstream users.

Milestone 1.1: Driving forces for adoption of QSMAS identified

QMAS has been the basis of an integrated strategy to improve farmer livelihoods and rehabilitate land and water services in the Lempira region. Although the development process was initially driven by short-term benefits at the farm level, widespread adoption of QSMAS among thousands of farmers and numerous communities can not be explained by productivity approach alone but by the complex interactions among enhanced productivity, social and political factors.

The following factors are suggested to be the key drivers contributing to enhanced adoption of QSMAS:

1. ***Integration of diverse elements without losing focus.*** Integrating socioeconomic and biophysical factors linked to food security, poverty alleviation and land degradation into a single-well focused strategy on land and water resources was the key driver for the successful implementation of the QSMAS. Early in the process, farmers and institutions realized that in order to improve livelihoods in the region, careful management of land and water resources was a prerequisite. Most development plans were based on the introduction of QSMAS as the means to improve food supply, access to clean water and health, and as additional benefits, education and better income opportunities.

2. ***Increased production and reduced labor.*** Improved practices associated with QSMAS resulted in enhanced productivity and resource quality and reduced risks that contributed to improve economic viability and social acceptance of the system. Crop yields have increased by more than 100% (average yields of maize and common bean are 2500 kg ha^{-1} and 800 kg ha^{-1}, respectively). Increased crop productivity allowed farmers to reduce the area devoted to traditional crops and the introduction of new crop options with market potential. Recent studies conducted by FAO show that 44% of the producers using QSMAS are also trying new options (different crop options, improved varieties, cattle) on 10% of their farm area. They are also exploring new technologies (irrigation, improved grain storage facilities) and services

(formal and informal credit markets). Due to improvements in soil fertility and water availability crop production with QSMAS can be doubled, allowing further intensification of the system. In addition, QSMAS implies reductions of 18% in land preparation and weed control and of 27% in other labor requirements (Clercx and Deug 2002).

3. ***Integration of local and technical knowledge.*** Local knowledge of people who have been interacting with their environment for an extended period can offer insights into sustainable soil and water management (Barrios and Trejo 2003). A major factor that promoted the rapid adoption of QSMAS was the familiarity of producers with the main components of the system. QSMAS was not only developed on the basis of an existing indigenous system found in the region, but also improved by including farmer criteria. Most farmers participating in the validation of the system were able to recognize improved soil quality under QSMAS (improved productivity, fertility, structure, and moisture retention). This capacity to understand and recognize soil improvement was a key factor to improve communication among farmers and to enhance adoption of the system.

4. ***Effective participation.*** Participatory design and management of the intervention process was a major driver for integrating research and development process in QSMAS. Events and problems in the establishment and management of the system were dealt with as they occurred within farmers' specific conditions, rather than being anticipated. As result, the technological focus and general interest of farmers and communities broadened over time to include other issues such as water supply, strengthening of local organizations, health and education.

   Scaling up of QSMAS was possible through the effective participation of extension agents of the FAO-Lempira Project and farmer groups. The process was built on the capacity of people to use and adapt QSMAS to their own conditions and on the use of participatory validation models. The usefulness of this approach was confirmed by the rapid adoption of QSMAS and the enhanced organization around Improved Natural Resource Management (INRM) issues: elimination of burning, efficient use of water and forest resources and improved soil management. Scaling up from individual farms to communities and municipalities was effected through social and political dimensions. Local development committees and community leaders strongly supported replication of QSMAS. Students in rural schools were integrated into the whole innovation process by being exposed to different technological alternatives and making them aware of the importance of INRM.

   The scaling-out process was facilitated through farmer learning tours and exchange visits across farms, communities and municipalities. The learning process was backed up by reference materials based on farmer's experiences.

   Matching technology providers with the farmers' own goals was the guiding principle in the development and adoption of QSMAS. The strategic orientation of the project was complemented with an effective operational framework.

5. ***Enhanced competence of farmers and communities.*** Farmer's capacity to innovate and solve problems improved over time. This increased the spirit of experimentation with soil and water management options and other natural resource management (NRM) technologies, to improve their management and effectiveness. More than 100 leaders were appointed by their communities to learn the main principles of QSMAS and assist other farmers in the implementation of the system. In some communities, rules and by-laws were

set up to forbid burning and manage common resources. All these changes demanded a continuous process of facilitation and capacity building to engage in innovative approaches and entrepreneurial activities. Continuous support from service providers was fundamental to scaling out of QSMAS. They raised awareness of communities to innovate and familiarized them with options to improve land and water management.

6. ***Farmers linked to markets.*** The development path followed by farmers practicing QSMAS showed that market orientation was an important consideration after they produced sufficient food for household consumption. Increased maize and bean production permitted QSMAS farmers to produce crop surplus and introduce new crops into the system such as vegetables. The establishment of linkages to outside markets was a key event that accelerated the integration of small farmers to markets and cross-border trade (El Salvador). This opening to new markets has been the key driver for increased crop diversification observed during more recent years in the QSMAS. It has also been the cornerstone for the emergence of a new agribusiness culture among rural communities in Lempira. Farmers are learning to administer land and water resources especially for irrigation purposes.

7. ***Rural financing.*** According to Ruben and Clercx (forthcoming), access to rural finance enabled farmers to purchase better seeds, fertilizers and herbicides to improve crop production and invest in irrigation systems for subsequent diversification. Communal banks were an important financial mechanism supporting the implementation of QSMAS. Their role was not limited to credit provision but also as an agency for collective action and enforcement of community control. Credit was restricted to farmers that did not burn their land. Membership of the communal banks thus developed a new moral order that facilitated the subsequent adjustment of their farming systems and livelihoods.

8. ***Supportive policies.*** Sustainable management of natural resources requires policies and incentives for its adoption (de Vries et al. 2002). QSMAS emerged in an environment where policies to reverse land and water degradation and improve food security were absent. However, during the process of implementation of QSMAS, awareness by local communities to problems associated with burning, deforestation and extensive grazing grew over time. As a result, municipal development committees and community-driven associations developed over time enforcement mechanisms to eliminate burning from agricultural practices. Consciousness about these problems reached equally to both upstream and downstream users.

   Land ownership is positively associated with the use of conservation practices (Jensen et al 2003). In the case of QSMAS small farmers owing their own land initially adopted the system. However, the practice has been extended over time to rented lands. Farmers growing crops on rented lands are now obliged to maintain the forest and permanent cover without burning. Interestingly, the value of land under QSMAS is higher than that under conventional management.

   The capacity of local communities and municipalities to protect, regulate and negotiate the use of their land and water resources has been lately reinforced by the decentralization of power and decision making promoted by central government. This is producing a positive impact on the scaling up and out of QSMAS.

The drivers mentioned above can be summarized in the three main pillars supporting FAO's strategy for scaling up and scaling out of up QSMAS in the Lempira region:

1. *Collective action,* including capacity building in organizational, educational and entrepreneurial development;
2. *Technological change* designed towards increasing the resilience of, and benefits from, production systems; and
3. *Policies and incentives* allowing controlled development of new production technology.

Other driving forces suggested by the DDP approach, are presented in Table 1.1

Milestone 1.2: Two socioeconomic and three biophysical major constraints identified

QSMAS is a suite of adaptive management systems that are being uniquely applied and modified by individual farmers. This diversity and dynamism led to difficult descriptions and generalizations of the system; however, they help explain its evolution and point to its potential future adaptation not only in Lempira but in other similar agroecoregions.

DDP approach to analyze of the period of pre-QSMAS (1970-1990) helped to identify the five major constraints in the region where QSMAS is being practiced, that may have facilitated its acceptance and adoption. These are:

Biophysical constrains:

1. Rapid expansion of agricultural activities on fragile sloping lands; and
2. Use of unsustainable management practices.

Socioeconomic constrains:

3. Increasing population growth (3% per year);
4. High poverty (80% of total population lived under the poverty line); and
5. Migration of the labor force.

The Table 1.1 shows human and environmental drivers linked to the dynamics of QSMAS across time. During the period of pre-QSMAS, thousands of resource-poor farmers practiced SB agriculture on communal native tropical secondary forest to produce maize, common beans and sorghum at the subsistence level (DDP Principle 1). Crop yields were low and insufficient to meet households needs (Flores 2005). Removal of forest vegetation and soil cover increased soil erosion, reduced soil fertility and water holding capacity (DDP Principle 1). Overexploitation of land and extensive deforestation rates eventually moved SB beyond the threshold of recovery since increasing water scarcity on a non-resilient system reduced its potential for production, which in turn triggered migration to urban areas and abroad (DDP Principle 3).

As consequence of the increasing need for food production and poverty alleviation, the central Government supported in the 80's the introduction of inputs including improved varieties, fertilizers and herbicides. During this period, reliance on chemical inputs increased from 25% to 80% of all farms. Despite the intensive promotion of this solution to declining yields, it had a limited success among small-scale farmers because of their limited access to capital and technological assistance.

Table 1.1: *Human and environmental drivers associated to the dynamics of QSMAS based on the Dryland Development Paradigm (DDP, Reynolds et al. 2002).*

DDP Principle	**Time Frame**		
	Pre-QSMAS (1970-1990)	**QSMAS adoption (1991-2006)**	**QSMAS future - issues to be addressed (2007-2020)**
P1- Human-environmental (H-E) systems are coupled, dynamic, and co-adapting, so that their structure, function, and interrelationships change over time	*Human drivers:* • High poverty • High illiteracy • Limited access to services *Environmental drivers:* • Slash and burn of native forest to produce food	*Human drivers:* • Reduced labor • Higher net profits *Environmental drivers:* • Improved crop productivity	*Human drivers:* • Enhanced capacity to access markets • Financial schemes supporting diversification *Environmental drivers:* • Market oriented production • Livestock production
P2 - A limited suite of "slow" variables are critical determinants of H-E system dynamics	*Human factors:* • Increasing population density *Biophysical factors:* • Low crop productivity	*Human factors:* • Collective action • Policies and financial incentives *Biophysical factors:* • Technological change	*Human factors:* • Long-term profitability of crop/livestock production *Biophysical factors:* • Livestock density • Demands for water and nutrients
P3 - Thresholds in key slow variables define different states of H-E systems, often with different controlling processes; thresholds may change over time	*Socioeconomic thresholds:* • Seasonal food and water scarcity *Biophysical thresholds:* • Loss of soil cover and biodiversity	*Socioeconomic thresholds:* • Enough food, water and firewood to meet households demands *Biophysical thresholds:* • Improved resilience	*Socioeconomic thresholds:* • Increased value of land • Payment for environmental services *Biophysical thresholds:* • Adequate balance between crops-trees and cattle in the landscape
P4 - Coupled H-E systems are hierarchical, nested, and networked across multiple scales	*Socioeconomic:* • Short-term food production to meet household needs at farm scale *Biophysical:* • Long term soil, water and vegetation losses affecting upstream ands downstream communities	*Multi-level connections:* Improved connection between short-term and long-term priorities at several scales: • Food production (household) • Water supply (community) • Health and education (municipality) • Infrastructure development and provision of environmental services (basin)	• New array of stakeholder interest and priorities as influenced by market force, improved infrastructure and health and education
P5 - The maintenance of a body of up-to-date local environmental knowledge is key to functional co-adaptation of H-E systems.	*Socioeconomic:* • High pressure to natural resources *Biophysical:* • Local knowledge ignored	*Socioeconomic:* • Bottom-up policies supporting no burning, improved water use and landscape conservation *Biophysical:* • Combination of indigenous and technical knowledge to improve crop yields and resilience	• New knowledge needed to support intensification and diversification • Improved capacity of farmers to apply technical and local knowledge under QSMAS

Source: M. Ayarza et al. (*forthcoming*)

Milestone 1.3: User friendly interface available to local organizations, researchers and decision makers

A database of literature collecting socioeconomic and biophysical information was assembled. The database includes publications and grey literature (PhD, MSc and BS theses; internal reports; project documents and technical bulletins). This database is included in the set of databases compiled by the project (see PN15 Project Completion Report).

Milestone 1.4: Set of farms of contrasting age, size, topographic position identified

Out of the 85 farms initially identified by the project, 8 were selected in order to evaluate the performance of QSMAS of different ages (young, middle age and old plots) compared to the traditional SB system and to the secondary forest (the natural condition which is needed for the establishment of either QSMAS or SB systems) as reference to both systems. The main characteristics of the selected farms and the treatments to be established in each one are presented in Objective 2.

Conclusions

- Although this document presents a general context of the region where QSMAS is being practiced, a more detailed description would show that in the last two decades this reference site have had three contexts. One corresponds to the period of high vulnerability before the implementation of the development strategy including QSMAS as the key component. The other two include the period of transition while QSMAS was being developed and disseminated, and the last period to the changes in the landscape and communities welfare as a result of the whole development strategy.
- Driving forces behind QSMAS adoption are multiple and articulated. The success of the system is specially a reflection of a community-based learning process in which local people and extension service providers share ideas and learn together.
- High natural variation in individual farms (i.e. predominant vegetation, number of trees and shrubs, and soil properties) and strong differences on the management of QSMAS plots (i.e. natural vegetation, crop production and crop residues), created difficulties in characterization of the system and therefore, the determination of QSMAS typologies. QSMAS management strongly relies on individual criteria which are influenced by the household biophysical and socioeconomic requirements.
- Undoubtedly, QSMAS can be a model production system to achieve food security and sustainability in drought-prone areas of the sub-humid tropics. Targeting of QSMAS to other suitable areas in the sub-humid tropics may be facilitated by:
  1. Clarification of the main processes which underpin its success;
  2. Identification of the biophysical and socioeconomic pre-conditions that enable dissemination, including financial mechanisms for key inputs (fertilizers) and strong collective action;
  3. Application of the main management principles behind its productivity and sustainability; and
  4. Application of lessons learned in experiences on its validation.

Objective 2. To define QSMAS management concepts and principles and to develop relevant tools to monitor soil and water quality

Increased resilience to sustain crop production despite extreme climatic events (i.e. severe drought or water excess) is one measure of the biophysical success that results from the integrated roles of QSMAS components (i.e. soil, water, trees and crops) and management (e.g. no-burning and no-tillage). Identification of the critical features behind QSMAS performance and widespread adoption in the reference site was a key objective of PN15, since it will greatly facilitate its scaling up and out to other similar regions. The vegetation, soil, water and atmosphere components of QSMAS (with especial focus on water driven processes) were studied across time and space in the farms selected for representing key farm typologies within the area of impact of the system in Honduras (see Milestone 1.4, page 11).

Ecosystem services (ES) are defined as the benefits people obtain from ecosystems, including provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth (MA, 2003). Given the characteristics (components and management) of Quesungual system that contribute to the generation of ES, two studies were conducted to provide insights on local indicators of soil quality and to quantify the potential payment for these services in the reference site.

Methods. The elucidation of the effect of the components of QSMAS and the principles that define their management, demanded studies on soil water dynamics; crop yield and water productivity; nutrient (N and P) and soil organic matter dynamics; greenhouse gas (GHG) fluxes; global warming potential (GWP); and emergy analysis including sustainability index and ecological footprint index. Specific methodologies were used according to the nature of the study.

Research activities were planned to evaluate the agroecological performance of QSMAS compared to the SB system and to secondary forests (SF) as reference treatments. Field plots (200 m^2) were delimited in farmers field for the comparison of 5 land use systems: (1) the SB production system; (2-4) QSMAS of different ages (<2 years, 5-7 years and >10 years old); and (5) the SF system. After the first sampling (April 2005) to define the baseline, plots including the four production systems (SB and QSMAS of three different ages) were split (100 m^2 plots) in order to apply a fertilizer treatment (addition vs. no addition), resulted in a total of 9 treatments since SF plots did not receive any fertilizer treatment. This would permit to quantify the relative contribution of fertilizer application vs. biomass and crop residue contribution on system productivity and sustainability. Each treatment was replicated in 3 different farms (Figure 2.1, Table 2.1).

Consistent with the traditional practices, SB and QSMAS plots were established (in 2005) or prepared (2006 and 2007) in April, before the start of the rainy season. The establishment of SB system had different management compared with subsequent management over the years. In 2005 the system was established through complete slashing of trees and shrubs, removal of firewood and uniform burning of the remaining dried material throughout the plot. Since the SB plots have a significant reduction in biomass production, in 2006 and 2007 the biomass was slashed and then piled and burnt in isolated sites within the plots. The QSMAS plots were managed in the same way in all three years, with the partial, selective and progressive slashing and pruning of trees and shrubs;

manual and/or chemical control of weeds; fertilization of maize (*Zea mays* L.) and common bean (*Phaseolus vulgaris* L.) crops; and the homogeneous distribution of litter, and biomass of trees, shrubs and of crop residues shortly before and at the middle of the cropping season.

Every year, maize (var. 'HB-104') and common bean (regional landrace 'Seda') were established in the early (late May) and later (late August) part of the rainy season, respectively. These crops were managed following the standard timing, spatial arrangement (relay intercropping), plant density (50,000 plants ha^{-1} of maize and 180,000 plants ha^{-1} of common bean) and management practices used in the region for the production of these basic grains under SB system and QSMAS. In the fertilized treatments, the maize received 49 kg N ha^{-1} and 55 kg P ha^{-1} at 8-10 days after planting (DAP) and 52 kg N ha^{-1} around 30 DAP; the common bean received 46 kg N ha^{-1} and 51 kg P ha^{-1} around 8-10 DAP. Initial fertilizations were made by applying diammonium phosphate (18% N y 46% P_2O_5), while the complementary one was done applying urea (46% N).

Water dynamics were monitored through the assessment of infiltration, runoff and soil water availability during the rainy and dry seasons of 2007. Water infiltration and runoff were measured through rainfall simulation for 30 minutes using two intensities (80 and 115 mm h^{-1}). Soil water content was determined through soil sampling at three depths (0-10, 10-20 and 20-40 cm). Susceptibility of the soil to erosion was assessed in erosion plots (5 m length x 1.5 m width) over 3 years. Soil losses were determined through the comparison of the indices of soil erodibility K-USLE [(t $ha^{-1}h^{-1}MJ^{-1}mm^{-1}$] and Ki-WEPP ($kg^{-1}s^{-1}m^{-4}$), corresponding to the Universal Soil Loss Equation (Wischmeier and Smith 1978) and to the Water Erosion Prediction Project (Nearing et al., 1989), respectively. Nutrient losses through erosion were quantified by determining total contents of N, P, K, Ca and Mg from samples of eroded soils. Water quality was assessed through the determination of NO_3^-, NH_4^+, total P, PO_4^{-3} and soluble solids in samples collected 45 DAP. Both eroded soil and water samples were collected in the erosion plots in 2007. Crop water productivity (CWP), expressed as kg of grain produced per m^3 of water used as evapotranspiration, was calculated using the crop yield and soil water data obtained in 2007 and by estimating the evapotranspiration according to the method of Penman and Monteith (FAO 1998).

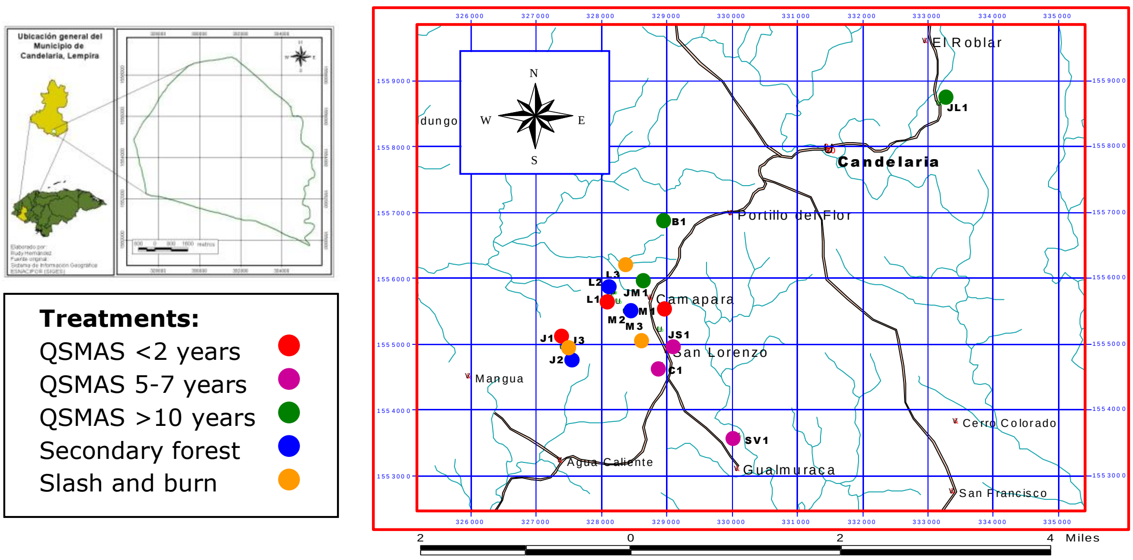


Figure 2.1: *Location of the experimental plots within the municipality of Candelaria, department of Lempira, south-west Honduras.*

Table 2.1: *Characteristics of the plots selected for the establishment and management of research activities in the Reference Site.*

Type of Land Use	Age	Farmer*	Community	Height (masl)	Geo-reference	
					X	Y
Secondary Forest	At least 7 years under natural regeneration	1	Camapara	565	16P0328386	UTM1555511
		2	El Obrajito	490	16P0327418	UTM1554963
		3	Camapara	518	16P0328199	UTM1555805
Slash and Burn	0 years old	1	Camapara	563	16P0328405	UTM1555516
		2	El Obrajito	451	16P0327451	UTM1554939
		3	Camapara	511	16P0328193	UTM1555810
QSMAS	<2 years old	1	Camapara	561	16P0328460	UTM1555516
		2	El Obrajito	439	16P0327439	UTM1555015
		3	Camapara	491	16P0328141	UTM1555741
QSMAS	5-7 years old	4	San Lorenzo	514	16P0328916	UTM1555231
		5	San Lorenzo	558	16P0328927	UTM1554693
		6	Gualmuraca	378	16P0330104	UTM1553618
QSMAS	>10 years old	7	Quezungual	819	16P0333189	UTM1558678
		8	Portillo Flor	683	16P0328974	UTM1556950
		3	Camapara	522	16P0328280	UTM1555656

* 1= Miguel Cruz; 2= Juan Mejía; 3= Lindolfo Arias; 4= Juan Sibrián; 5= Camilo Mejía; 6= Santos Vargas; 7= José L. García; 8= Bernarda Laínez

Measurements for the study on nutrient dynamics were carried out during three years, from April 2005 to December 2007, and included:(1) decomposition of and nutrient release from biomass of trees, shrubs, and annual crops, using the litterbag technique (Shanks and Olson 1961); (2) N mineralization (NH_4^+ and NO_3^- + NO_2^-), determined by mineralization of the whole soil (Anderson and Ingram 1993); (3) partitioning of soil total P following a shortened sequential P fractionation (Tiessen and Moir 1993, after Hedley et al. 1982); (4) size-density fractionation of soil organic matter (SOM) in the soil (Meijboom et al. 1995; Barrios et al. 1996); and (5) nutrient partitioning of crop biomass.

GHG fluxes including N_2O, CH_4 and CO_2 were determined using a closed chamber technique, with 16 sampling dates from July 2005 to July 2006. Global warming potential (GWP) was determined using CH_4 and N_2O fluxes, and C stocks in soil (soil organic carbon) and in tree biomass. GWP values were extrapolated to the region where QSMAS is practiced and were projected in time considering land use change. An emergy (a measure of the total energy used in the past to make a product or service) evaluation was conducted as in Diemont et al (2006) to quantify resource use and system sustainability, using data from plots and relationships (energy input per unit of energy output) reported in other studies.

Four farmers participated in trials for the determination and evaluation of recommendations generated by the Nutrient Management Decision Support System (NuMaSS) software, to improve efficiency of N fertilization in QSMAS. NuMaSS was developed by the Soil Management CRSP, and is a tool that diagnoses soil nutrient constraints and selects the appropriate remedial practices, based on agronomic, economic and environmental criteria, for location-specific conditions (Cahill et al. 2007). The amount of fertilizer N recommended was the balance between the total amount of N needed by the crop and the N acquired from the soil, plant residues and cover crops, with a subsequent adjustment for the fertilizer N use efficiency by the crop. Fertilizer recommended for NuMaSS was about 14% of the fertilizer traditionally applied by farmers in QSMAS' target region. The study included an economic analysis of the fertilizer costs and net return. Costs were calculated based on the current local prices of N in urea and P in triple superphosphate, for NuMaSS; and on the prices in each community for the N, P and/or K fertilizers traditionally used by farmers. Market value of yield was based on the current price of maize per hectare and the yield from each treatment. Net return was calculated as the difference in fertilizer costs and market value of yields.

The exploratory study conducted to provide understanding on how soil quality is perceived and valued (with emphasis on soil macrofauna as biological indicator) by local farmers, included: (i) semi-structured interviews; and information gathered from: (ii) participatory mapping of within-farm variation in soil type and quality; (iii) a workshop on local indicators of soil quality based in method outlined by Barrios et al (2006); (iv) observation (N. Pauli, PhD student); (v) reviews of consultants' reports; and (vi) other works conducted by PN15.

ES generated by QSMAS include at least food, water, firewood, C sequestration, resilience, residues for animal feeding, and nutrient cycling, and reduced global warming potential compared to the traditional production systems based in SB practice. The study performed on the potential payment for environmental services (PES) for QSMAS only included water availability (considering runoff, infiltration and storage), soil retention (for reduced erosion compared with SB system), and C sequestration in soil organic matter. Analysis was based on data available in 2007 and included some assumptions for not available data. Economic analysis of productivity was made based on two of the traditional crop associations practiced under QSMAS (relay maize-sorghum and common bean alone). Limitations for the analysis included: (i) data recorded for less than 5 years; and (ii) lack of information (rainfall and temperature) at micro-watershed level for a more precise quantification of water balances).

Results and Discussion

Milestone 2.1: QSMAS plant productivity, nutrient budget and gas fluxes quantified on contrasting farms

Crop productivity. Over the three years, average crop yields in maize showed higher productivity with the addition of fertilizer (1.63 t ha^{-1}), increasing production in 89.5% compared with no fertilization (0.86 t h^{-1}). In the fertilized systems, QSMAS >10 had the higher yields (1.76 t ha^{-1}) while the lowest were observed in QSMAS 5-7 and SB (1.56 and 1.55 t ha^{-1}, respectively). However, productivity in QSMAS decreased across time. Comparison of traditional systems of the same age, SB without fertilization and QSMAS <2 fertilized, this yielded twice the production of SB system (1.52 vs. 0.78 t ha^{-1}, respectively Figure 2.2). QSMAS yields were 20% higher than the average production of maize obtained in Honduras between 2000 and 2005, equivalent to 1.44 t ha^{-1} (FAOSTAT 2006).

For common bean, average crop yield of the three years was 0.51 t ha^{-1} and 0.37 t ha^{-1} with and without the addition of fertilizers, respectively, an increase of 37.8% as result of fertilization. With and without fertilization, the higher yields were obtained by QSMAS >10 (0.61 and 0.41 t ha^{-1}, respectively) while the lowest were observed in SB (0.36 and 0.32 t ha^{-1}). This low response to fertilization suggests that the regional landrace used has a low yield potential. Comparison of the traditional systems of the same age showed that QSMAS <2 years fertilized had a productivity 59.3% higher than SB system not fertilized (0.51 y 0.32 t ha^{-1}, respectively). Common bean yields in QSMAS plots were 18% lower than the average obtained in Honduras between 2000 and 2005, equivalent to 0.72 t ha^{-1} (FAOSTAT 2006).

Yields of maize in QSMAS plots are higher than the national average and more important, than the production obtained with the traditional SB system. Although they are relatively good given the natural conditions of infertile and shallow soils, they only reach half of the potential reported for the variety used under optimal conditions. In the case of common bean, yields are not better than the obtained with SB system and they are lower than the national average. In the case of maize, the main explanation is the low quality of the seed mainly due to limited sources in the market for the variety selected by farmers (released more than 20 years ago). Seed of better quality or even better, varieties with higher yield potential, combined with improved fertilization (mainly timing, splitting the supplementary N application) might result in significant increases of yields of this crop. In the case of common bean, undoubtedly the low response to fertilization and other production practices is attributed to the low yield potential of the variety used. This landrace is preferred by Honduran farmers along the border with El Salvador, their most important market, because its commercial type (small, red light) is markedly favored (demand and value) over other commercial types. Technicians of FAO have made attempts to introduce new improved varieties with higher yield potential, but as long as infrastructure do not facilitate the transportation of production to the local market (less demanding for color) farmers may continue use the less productive landrace.

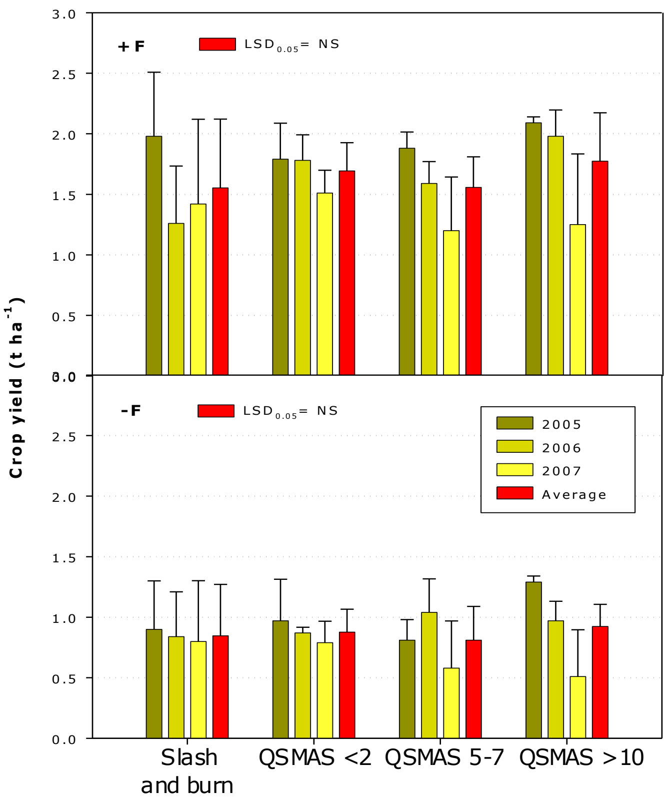


Figure 2.2: *Maize productivity in two production systems with (+F) and without (-F) the addition of fertilizers.*

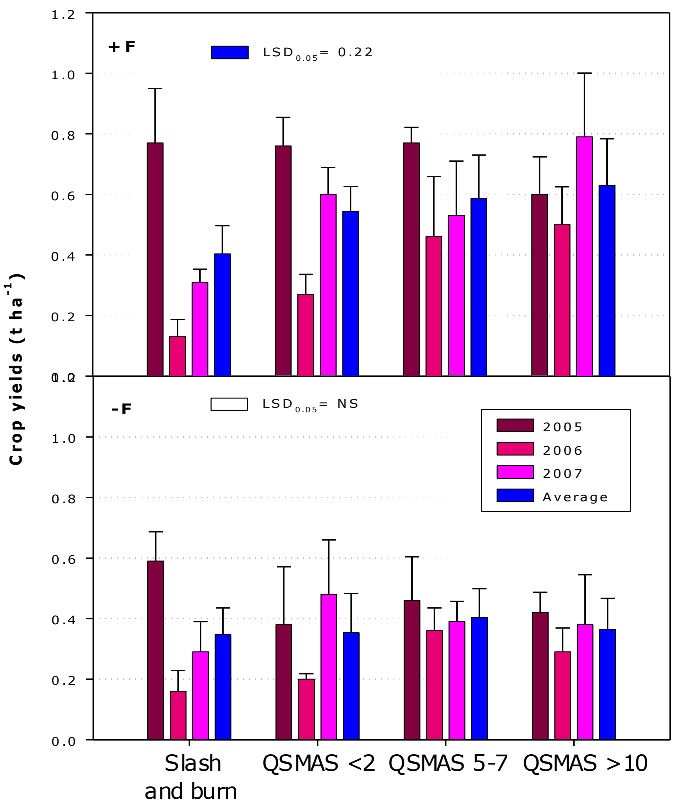


Figure 2.3: *Common bean productivity in two production systems with (+F) and without (-F) the addition of fertilizers.*

Study on nutrient dynamics. Total soil N content across the years showed a trend to decrease with time in the SB system while it increased significantly in QSMAS >10, with and without fertilization. The comparison of total N in SB system vs. QSMAS <2 (with a similar period under production) and SF, suggest that the use of SB can drive to a rapid reduction of the nutrients in the landscape while QSMAS maintains and even increases the pool of N. Over the 3 years, potential N mineralization (N-min) was also higher in QSMAS >10, although it was only different to the SF. The study on P dynamics showed no differences among land use systems in total P content across the years, although different trends were observed in SB and QSMAS, with SB showing an increase in the organic (Po) pool and QSMAS increasing its inorganic (Pi) pool. In terms of P availability, over the years the average size of P pools relative to total P were: available P (AP) 12% of total P, moderately available P (MAP) 29%, and residual (not available) P (RP) 59%. The RP pool tended to increase and MAP and AP pools tended to decrease over time in the SB system relative to SF, while QSMAS (average of <2 and >10 years old plots) exhibited the opposite tendency.

The similar behavior in N-min and P available pools among production systems is a positive finding, because it implies the following: (i) QSMAS is as good as SB as a source of N and P, even though in QSMAS their content is more a result of biologically mediated process than of an accelerated process that drives immediate availability of nutrients, such as burning; and (ii) QSMAS performs consistently over time, suggesting that this form of management may provide a sustainable source of N and P. Additionally, at similar rates of N-mineralization, the N balance in SB system is expected to be less positive than in QSMAS, considering that yearly SB has lower additions of N (no fertilization and fewer sources of biomass) and higher losses of N through burning (volatilization losses of ammonia and wind-related losses of ash) than QSMAS.

The participatory evaluation of the recommendations generated by NuMaSS to optimize fertilizer N use in QSMAS showed that, although yields and net return were higher with the traditional fertilization, the profit per unit of added fertilizer was much higher with NuMaSS ($13.36/kg fertilizer vs. $25.09/kg fertilizer, respectively). Farmers reported that they would continue to use QSMAS and the fertilizer recommendations of NuMaSS, that produces yields comparable to the traditional management but require lower fertilizer inputs.

Study on GHG fluxes, GWP, emergy and ecological footprint index. Greenhouse gas fluxes showed a seasonal behavior, with higher emissions during rainy season, from May to October. QSMAS and SF were CH_4 net sinks, with values of -102 mg CH4 m^{-2} $year^{-1}$ and -36 mg CH_4 m^{-2} $year^{-1}$, respectively (Figure 2.4). The only CH_4 net source was SB, with 150 mg CH_4 m^{-2} $year^{-1}$. All treatments were found to be N_2O and CO_2 sources, resulting from natural processes (SOM decomposition) and from management (fertilization). Soil variables that could explain differences in CH_4 fluxes were pH and susceptibility to compaction. In the case of N_2O, bulk density, total porosity and air permeability were the main soil characteristics.

QSMAS contributes to C sequestration, as shown in Figure 2.5. C stocks were higher in SF and QSMAS, with higher accumulation in SF for aboveground C (C in trees and shrubs) and in QSMAS >10 for belowground (soil organic) C. SB system presented higher annual losses of aboveground C, while young QSMAS plots (<2 and 5-7 years old) presented higher losses of belowground C.

QSMAS presented a much lower GWP (10.5 Mg Equiv. CO_2) than SB traditional system (40.9 Mg Equiv. CO_2) (Figure 2.6). SF had a very low GWP (1.14 Mg Equiv. CO_2). According to land use trends, when projecting GWP to the region where QSMAS is practiced and using a 20-year time horizon, it is estimated a decrease of 0.10 Tg Equiv. CO_2. Higher C stocks in soil and tree biomass indicate a gradual accumulation of C in SF and QSMAS >10. According to the emergy evaluation SF and QSMAS had less environmental impact than SB (highly affected by levels of soil erosion) as noted in the Environmental Loading Ratio, with values of 0.63, 0.14, and 0.02, respectively. The Ecological Footprint Index (1.02, 1.14 and 1.63, respectively) and the Emergy Sustainability Index (4124, 136 and 34.8, respectively), indicate higher of sustainability in QSMAS and SF.

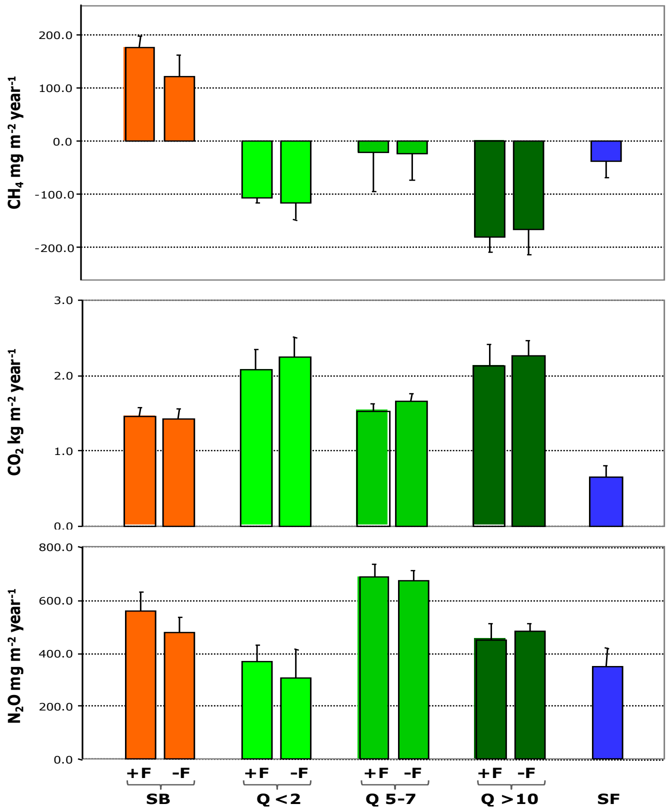


Figure 2.4: *Annual accumulated fluxes of GHG in five land use systems (SB=Slash and burn; Q= QSMAS; SF= Secondary forest) in Honduras. Bars represent standard deviation.*

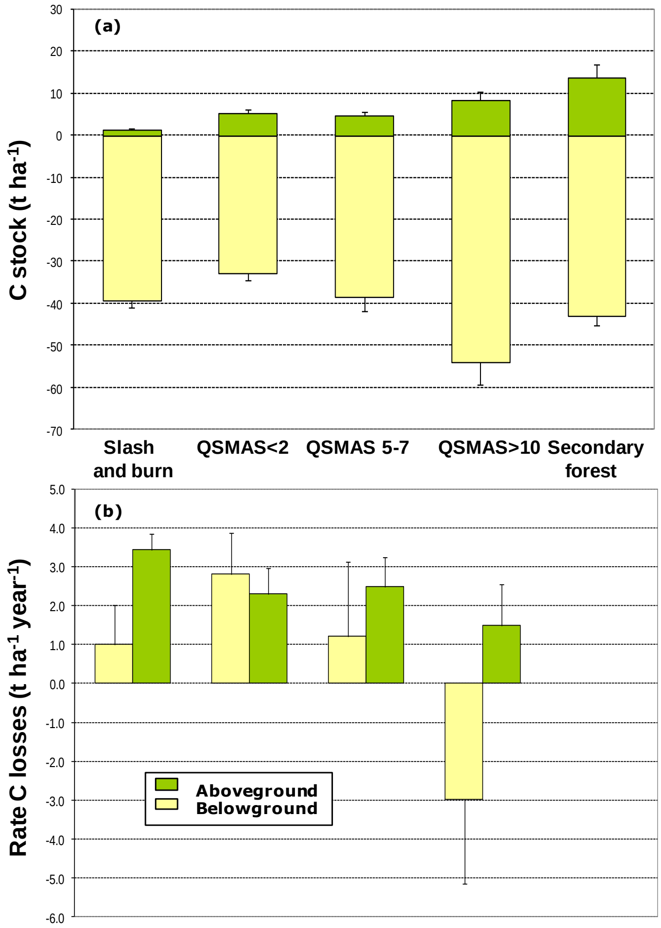


Figure 2.5: *Above and below ground stocks of C (a) and annual rate of C losses (b) in five land use systems in Honduras. In (b), SF is a control system and negative values represent increments of stocks. Bars indicate standard deviation.*

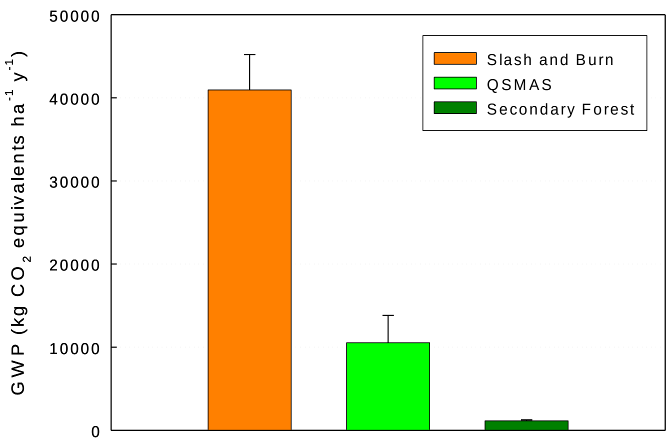


Figure 2.6: *Global Warming Potential (GWP) in a 20-year scenario of three land use systems in Lempira, southwest Honduras.*

Milestone 2.2: Soil-water interactions for crops and environmental services characterized

A group of common indicators were mentioned individually by farmers as 'positive' and 'negative', where positive indicators suggested that a particular plot of land is likely to be of good quality for growing crops, and negative indicators suggesting the opposite. Table 2.2 shows these pairs of positive and negative indicators, and the ranking assigned to these indicators. The most important indicator was the presence of certain species of trees and shrubs. The reasons were not necessarily related to any direct effects on crop growth, but rather as a function of their general utility on a parcel of land. The most highly valued trees were those that fulfilled multiple functions, including provision of timber, fruit, firewood, rapidly decomposing mulch, appropriate shade for crops and N fixation, although the most important factor was the economic value of these trees.

The second most important indicator of soil quality was the capability of the land to retain soil moisture through the summer dry period. As one of the farmers said, "When there is no water, there is nothing". In third place was whether the land was burnt or not burned. Soil structure (in terms of porosity and manageability) was the fourth most important indicator, and was related to the capacity of water and air to enter. Further, where there are no animals, the soil is often "squashed", which is not good for growing crops. Fifth place was occupied by the amount of litter at the soil surface, and also by the presence of macrofauna in the soil (particularly earthworms and scarab beetle larvae). About which plant species had the best type of leaves for mulching, some farmers said that some species were better because they decompose slowly and therefore help to retain soil humidity, while others maintained that the plants with leaves that decompose rapidly were better, as this increases the amount of organic matter in the soil. In equal sixth place were the color of the soil, and the infiltration capacity of the soil. In seventh place was the depth of the soil, followed by soil fertility level, the abundance of stones, the soil texture, presence of a hard layer in the soil, and in last place, slope. The relative unimportance of slope is perhaps to be expected, given that practically all of the available farming land in the zone lies on steep hillsides.

Potential for PES as a result of the use of QSMAS in the reference site is shown in Table 2.3. In plots under QSMAS, most valuable ES are attributed to water runoff and infiltration, followed by soil water storage, as source of ground water for the community and/or for irrigation. However, this potential PES may be underestimated since QSMAS generates ES not only at plot level but most importantly at landscape level (actual proportion in the reference site is 1 ha of QSMAS plot: 8.6 ha of secondary forest under natural regeneration, with no use of SB system).

Table 2.2: *Local indicators used by farmers as guide of soil quality, and ranks assigned by farmers to each indicator.*

'Positive' indicator	'Negative' indicator	Ranking
Plants*: *Cordia alliodora*, *Diphysa americana*, *Cecropia peltate*, *Gliricidia sepium*, *Lisolyma* sp.	Plants: *Miconia argentea*, *Luhea candida*	1
Moist soil in summer	Dry soil in summer	2
Not burned	Burnt	3
Porous, soft, easily managed soil	Compacted, hard soil	4
Soil with litter layer	Soil without litter layer	5
Earthworms, white grubs (scarab beetle larvae)	No soil animals	5
Black, brown soil color	Yellow, white color	6
Absorbs water easily	Water does not easily infiltrate	6
Deep soil (more than two handspans)	Shallow soil (less than two inches)	7
'Fertile'	'Sterile'	8
Not many stones	Many large stones	9
Loamy texture	Clayey texture	10
Yellow hardpan layer	White hardpan layer	11
Less steeply inclined	Steeply inclined	12

Table 2.3: *Economic value of some of the environmental services generated by Quesungual system. Candelaria, Honduras, 2007.*

Environmental Service	Amount (t ha^{-1})	Average price (US$ t ha^{-1})	Total (US$ ha^{-1})
Soil water storage[a]	55.0	17.5	962
Runoff and infiltration[b]	121.0	17.5	2,117
Reduction of sediments[b,c]	24.0	3.0	72
Soil carbon[d]	9.6	4.0	38
Total net environmental benefit			3,190

[a] 50% of the cost of potable water (m^3) in the reference site for QSMAS.
[b] During the wet season.
[c] Value of soil (m^3) in forestry systems in Nicaragua.
[d] Based on the price of one ton of C in the Latin American market.

Milestone 2.3: Influence of rainfall in crop productivity and water quality characterized

Average precipitation and temperatures (high and low) in the reference site of PN15 during the period of study can be observed in Figure 2.7. Crop water productivity was determined in 2007. In this year, average precipitation and evapotranspiration (after FAO 1998) were 1005 and 491 mm in the early part of rainy season (May) and 419 and 272 mm in the later part (Aug), respectively. In that year, precipitation was 1005 mm and evapotranspiration (after FAO 1998) was of and 272 in the early part of the rainy season and of 419 mm and 491 in the late part, respectively.

During the dry season SF had the highest infiltration (43.9 mm) and lowest runoff (1.6 mm). SB system showed the lowest infiltration (41.9 mm) and highest runoff (2.4 mm), while QSMAS 5-7 and QSMAS >10 years had higher infiltration (44.3 and 43.9 mm, respectively), and lower runoff (0.91 mm). SB again had the lowest infiltration (29.8 mm) and highest runoff (12.0 mm) during the rainy season. In contrast, QSMAS >10 years had the highest infiltration (38.5 mm) and lowest runoff (4.8 mm). SB had lower infiltration and higher runoff than QSMAS, during both the rainy and dry seasons.

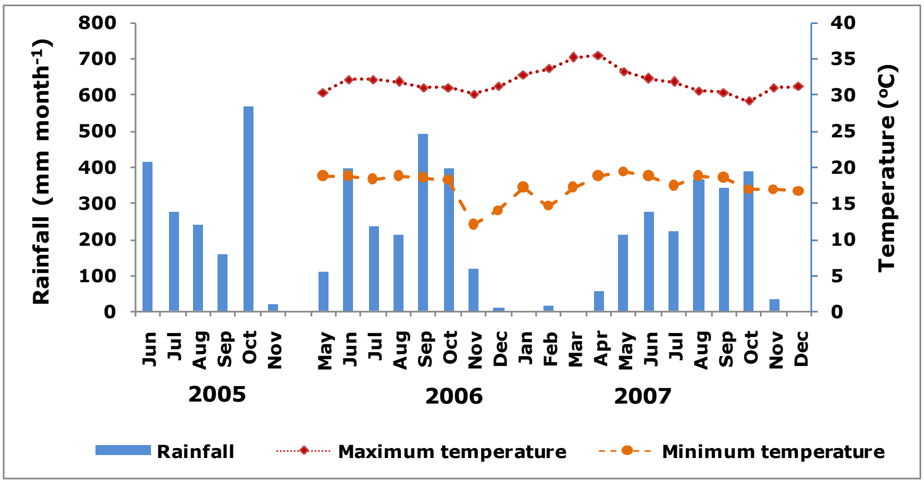


Figure 2.7: *Average precipitation, high and low temperatures during the period of study in the reference site of PN15.*

In 2007, precipitation and evapotranspiration (after FAO 1998) were 1005 and 491 mm in the early part of rainy season, and 419 and 272 mm in the later part, respectively. In the early part of the rainy season available soil water (0-40 cm) varied between 0.09 and 0.104 $m^3 m^{-3}$, with QSMAS <2 and QSMAS 5-7 and was 10 and 16% higher, respectively, than in SF (Figure 2.8). In the later part of the rainy season the amount of available soil water varied between 0.11 and 0.127 $m^3 m^{-3}$ in SB and QSMAS <2, respectively. The mean value of available soil water content (0-40 cm soil depth) in QSMAS systems (average of the three different ages) was significantly greater than that of the SB system, suggesting increased availability of water for crop growth. These improvements in QSMAS were related to changes in soil porosity due to increases in mesoporosity (30%) and macroporosity (19%), and decreased the soil bulk density. This increased the plant available soil water storage capacity and availability of water for crops in the dry season, and increased the capture of rainfall at the beginning of the rainy season.

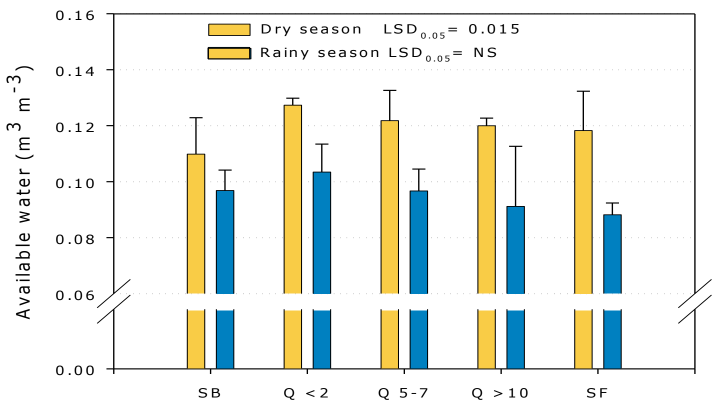


Figure 2.8: *Average available soil water content (0-40 cm) in the rainy and dry seasons of 2007.*

There was no interaction between land use system (LUS) and fertilizer treatment on crop water productivity (CWP, kg grain m^{-3}). CWP for maize was greatest in fertilized system of QSMAS <2 (0.48 kg grain m^{-3}) and least with QSMAS >10 (0.18 kg gain m^{-3}) (Figure 2.9). In plots with no fertilizer application, the highest CWP was observed with QSMAS <2 (0.26 grain kg m^{-3}) and the lowest with SB system (0.10 kg grain m^{-3}). In both fertilized and non-fertilized systems, CWP for common bean was greatest in QSMAS <2 (0.32 and 0.27 kg grain m^{-3}, respectively) and least with SB (0.10 and 0.07 kg grain m^{-3}). Fertilization increased CWP of (by 92%) and common bean (by 23%). These results may reflect adequate available soil water during the maize crop (from sowing to physiological maturity) in the early part of the rainy season, as precipitation was higher than evapotranspiration (ET). In the

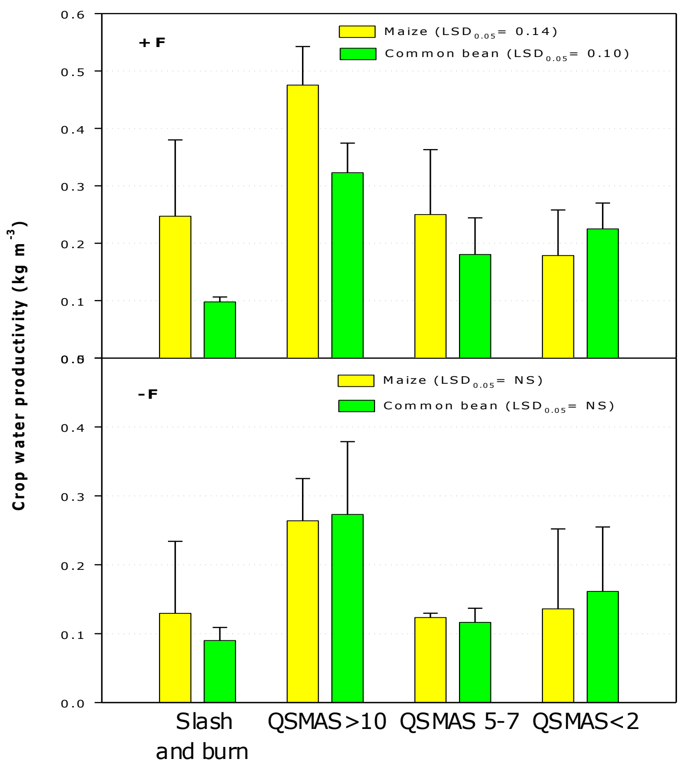


Figure 2.9: *Crop water productivity in two land use systems with (+F) and without (-F) the addition of fertilizers. Honduras, 2007.*

case of common bean, growth in the later (drier) part of the rainy season and available water content in the soil decreased from flowering to physiological maturity, with lower precipitation than ET and this resulted with a negative water balance. Under these conditions, QSMAS showed greater available water content in soil that resulted in greater grain yield and CWP.

Harvest index (HI), the relationship between crop yield and total dry weight or biomass, in maze with fertilizer was higher in QSMAS 5-7 (0.37) and SB system (0.34), while lower value was obtained by QSMAS >10 (0.27). However, these results are opposite to the crop yield observed in this crop (see Milestone 2.1). Without fertilizer, higher HI was obtained in QSMAS 5-7 (0.44) and lower in QSMAS >10 (0.20), which also had the lowest crop yield. In fertilized and no fertilized common bean, lowest HI was obtained by SB system (0.41 and 0.48, respectively), a result that was consistent with the lowest crop yield obtained by this land use system. Since in many grain crops HI is reaching its natural limit, substantial improvements in crop and soil management will be essential for increasing yields based on biomass production (Dobermann and Cassman 2002).

Water (or hydrological) balance, the comparison between the differences in soil water content, was calculated using both ET according to Hargreaves (Hargreaves and Samani 1985) and Penman-Monteith (FAO 1998). Water balance with ET according to Hargreaves showed higher water balances in QSMAS >10 fertilized and no fertilized, with values for maize of 364 (+F) and 425 mm (-F); and of 129 (+F) and 150 mm (-F) for common bean. Lowest values were obtained by SB fertilized (150 mm for maize and 58.0 mm common bean) and by QSMAS 5-7 without fertilization (148 mm in maize and 46.6 mm in common beans). Water balance with ET as in Penman-Monteith showed higher values when systems were fertilized in QSMAS <2 (254.5 mm for maize and 73.4 mm for common bean), and lower in SB system (29.5 mm in maize and -32.8mm in common bean). Without fertilization, higher values were obtained in QSMAS >10 (376 mm in maize and 104 mm in common bean) and the lower again in SB system (-189 mm in maize and -157 mm in common bean).

The highest soil loss occurred in 2005, and was markedly higher in SB followed by QSMAS and SF (Figure 2.10). The same trend was observed in 2006 and 2007, although differences were more remarkable in 2005 due to higher rainfall intensity and to the recent conversion of SB plots from SF that resulted in bare soil and therefore higher susceptibility to erosion. Total soil losses over the 3 years from SB were 5.6 times greater than from the three QSMAS treatments, and 22 times greater than from SF. Using the rainfall simulator, higher indices of soil erodibility were also observed with the SB system in both wet and dry seasons, while SF had the lowest indices. As a result, the SB system had the highest nutrient losses (kg ha^{-1}) of N (9.9), P (1.3), K (6.9), Ca (22.8) and Mg (24.2), while SF had the lowest losses (kg ha^{-1}) of N (1.7), P (0.2), K (1.2), Ca (2.6) and Mg (2.7).

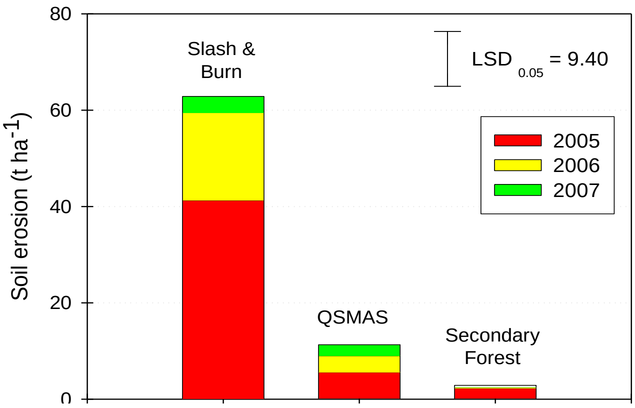


Figure 2.10: *Accumulated soil losses in three land use systems in 2005. QSMAS value is the average of three different ages.*

Nutrient losses due to soil erosion (N, P, K, Ca and Mg) and runoff (PO_4^-, NO_3^-, CL^-, and NH_4^+), were evaluated in 2007. Nutrient soil losses were significantly higher in SB system and lower in the SF. In QSMAS plots, nutrient soil losses increased across time (QSMAS>10 > QSMAS5-7 > QSMAS<2). Since nutrient losses were higher in fertilized systems, the progressive reduction in the efficient use of fertilizers may partially explain why farmers stop using QSMAS plots between 10 to 12 years of use. In the case of runoff water, higher nutrient losses were also observed in fertilized plots and in SB system and generally lower in QSMAS >10F. However, the averages were not statistically different.

Although there were no differences in the quality of runoff water from the different treatments, it was poorest in the SB system and better in QSMAS >10. SB system had the highest concentration (mg L^{-1}) of total P (2.30), PO_4^{3-} (0.29), NO_3^- (7.97) and NH_4^+ (0.70). QSMAS >10 had the lowest concentration (mg L^{-1}) of total P (0.18), PO_4^{3-} (0.25) and NH_4^+ (0.24), while QSMAS 5-7 had the lowest concentration of NO_3^- (6.13). Highest soluble solids (mg L^{-1}) was observed with QSMAS 5-7 (183) and lowest with QSMAS <2 (83.3). SF had values (mg L^{-1}) of 0.65 for P, 0.43 for PO_4^{3-}, 4.73 for NO_3^-, 0.92 for NH_4^+, and 25.0 for total soluble solids.

Conclusions

- Local indicators of soil quality are markedly related with the tree component of QSMAS, which in turn is thoroughly linked with water, C and nutrient cycling in the system. The importance of trees and shrubs include their functionality and economic value, confirming that their reduction (absolute number of individuals) across time is determinant of the productive life of a QSMAS plot.
- Preliminary analysis on PES showed that QSMAS has a high potential to generate additional sources of income to communities that decide to adopt the system (or its principles). However, a new analysis on PES including the whole watershed would be needed since QSMAS generates an important amount of ES at landscape level.
- Potential payment for the environment services provided by QSMAS at plot and landscape level may facilitate the adoption of the system (or other variants of conservation agriculture) and the process towards a communitarian commitment for the sustainable management of natural resources.
- Under experimental conditions, QSMAS is equally effective than SB traditional system for the production of maize, and more efficient to produce common bean. Undoubtedly, QSMAS performance is favored by management practices leading towards resilience, efficient nutrient cycling, improved crop water productivity, and increased and sustained C synthesis and accumulation.
- Compared with SB traditional system, QSMAS improves water availability for crop production while reducing soil and nutrient losses. The more dramatic effect is the increased productivity of water obtained by QSMAS in the later part of the bimodal rainy season, when rainfall is usually irregular (dry spells on key stages of crop development) or insufficient (shorter rainy season).
- Compared to SB system, global warming potential is markedly reduced in QSMAS as result of less emission of greenhouse gases and higher C capture. Other environmental services provided by the system at both, plot and landscape level, include reduced soil erosion, enhanced resilience, better soil and water quality and conservation of biodiversity.

Objective 3. To evaluate and document potential areas suitable to QSMAS

The main aim of this objective was to determine the potential areas in tropical and subtropical sub-humid regions where QSMAS will be both biophysically and socioeconomically suitable for adoption by small-scale farmers. Additionally, it was planned to validate the performance of QSMAS in two regions previously identified in Central America (Nicaragua) and South America (Colombian Andes).

Methods. The methodological approach included the performance of a site similarity analysis in order to determine extrapolation domains for QSMAS in similar agro-ecoregions; and the establishment of plots for the validation QSMAS in sites of Nicaragua and Colombia with major similarities and differences in comparison to the reference site.

Extrapolation Domain Analysis (EDA). The EDA is a method to identify the area of expected influence of a new technology or knowledge over broad geographic areas. The logic of the EDA is based on the expectation that sites with similar characteristics to reference sites are more likely to adopt than those that are different or unfavorable. Similarity is defined in terms of climate (patterns and variability of rainfall and temperature), landscape (land use) and socioeconomic (levels of poverty) characteristics, and estimated by comparison between the source and target climates. Favorability is determined by project specialists.

EDA uses the Homologue model (Jones et al. 2005) and Bayesian predictive modeling using Weights of Evidence (WofE). Homologue identifies areas with similar agro-ecological conditions. The model predicts, for each 18 km pixel in the tropics, the similarity with conditions in the pixels that contain the reference sites. Homologue bases climatic similarity calculations on classifications of more than thirty derivatives, including temperature, number of dry months and number of dry days. Bayesian model using Weights of Evidence identifies where it is likely to find areas with similar landscape or socio-economic conditions to those found in the reference site. In this case the pixel size is about 5 km. The critical factors are selected on the basis of what factors project scientists deem to be important and on the availability of data for global modeling at the desired scale.

The search for extrapolation domains uses the status of the selected critical factors found in reference sites. In this context, the diversity of the sets of reference sites will influence the identification of domains. However, the method is transparent and relies on the information provided by the project and is not influenced by strategies set by the modelers in sorting out the available information

The EDA approach was applied to identify where QSMAS seems likely or unlikely to be adopted within other regions at pan-tropical scale. The factors were chosen in consultation with PN15 project staff, and based on careful reading of information in PN15 proposal and reports and literature review to refine the understanding of the project purpose and context. QSMAS is a particular system that emerged as a response to critical biophysical and socioeconomic constraints, being favored by specific environmental characteristics of the location. The set of variables proposed for QSMAS in the search for extrapolation domains are the following:

- Poverty (2 US$/day) (Thornton et al. 2002)
- Climate (length of dry season) (Jones et al. 2005)
- Slope (From SRTM data, Jarvis et al. 2006)
- Water availability (proximity to water sources, Lehner et al. 2004)

- Access (Nelson 2006)
- Land Cover (tree cover from GLCF 2008)

Erosion, agriculture and livestock productivity, agricultural subsistence systems, land tenure, soils type and community and institutional participation/support were also considered, but not used mainly because most of the information was not available and/or the lack of operability of the models at the scale needed.

Poverty was chosen as the factor to guarantee that predicted domains contain areas with similar socio-economic characteristics of the reference sites. Homologue areas for QSMAS reference sites include the length of dry season. For slope high-resolution digital elevation models from the Shuttle Radar Topography Mission (SRTM) data were used (e.g., soil erosion and soil shallowness). Water availability was estimated considering the distance to any watercourse or water body. Access was used as a proxy for the type of agricultural systems and productivity levels. At a later stage, project staff suggested the inclusion of land cover with a particular emphasis on forest cover. Data from the Moderate Resolution Imaging Spectroradiometer (MODIS) of NASA on forest canopy cover were used. PN15 staff supplied data on the location of 109 project pilot sites (QSMAS plots), most of them in the surroundings of Candelaria.

Validation of QSMAS in Nicaragua and Colombia. QSMAS prototypes were established in two validation sites: (1) La Danta watershed of Calico (Black River) basin, in the municipality of Somotillo (13°2'0" N, 86°55'0" W), department of Chinandega, north-west Nicaragua; and (2) the municipality of Suarez (N 2º57', W 76º42'), Cauca River Upper Catchment, department of Cauca, south-west Colombia (Figure 3.1). These sites were selected based on similar or different biophysical and socioeconomic conditions, as shown in Table 3.1. There were also important variations on the approach followed by PN15 to share the management practices used in QSMAS with the farmers participating in the validation efforts. The similarities and differences among validation sites are of high importance to understand the performance of the system in both sites and the acceptance and willingness for adoption for local farmers.

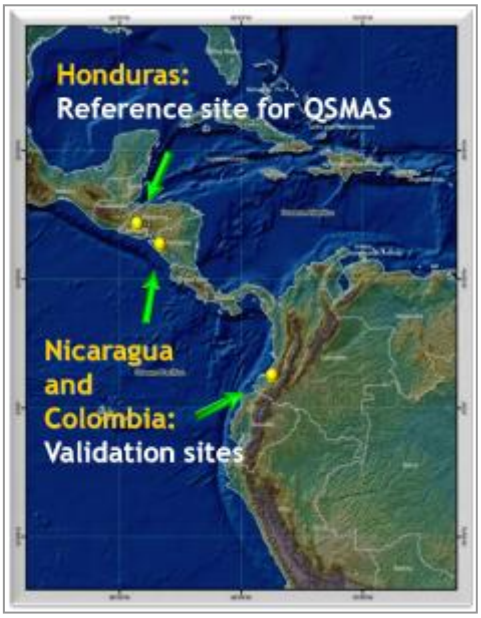


Figure 3.1: *Location of the reference and validation sites of QSMAS.*

In Nicaragua the activities started in April 2005, when 12 small-scale Nicaraguan farmers from 4 municipalities together with two technicians and two researchers from INTA visited Candelaria, the reference site in south-west Honduras where QSMAS is practiced as an alternative to traditional slash and burn (SB) system. The visiting farmers had an opportunity to witness the establishment of QSMAS plots by Honduran farmers and local high school students, to see QSMAS plots under exploitation, and to hear the perceptions of local farmers about the multiple benefits from the use of QSMAS as an alternative production system to SB agriculture. Back in Nicaragua, these and other farmers and technicians participated in training on QSMAS, to prepare them for the validation of the system. In May of 2005, two of the most involved Honduran farmers visited

Nicaragua to provide training on the establishment of QSMAS plots for validation. The watershed La Danta was selected based on the following characteristics: (i) a situation of food insecurity; (ii) similar climatic characteristics compared to the reference site in Honduras; and (iii) predominance of hillsides with secondary forest in the process of degradation. Participating farmers were selected using the following criteria: (i) land tenure (ownership of the property); (ii) accessibility (for data recording and field visits); and (iii) commitment to follow instructions for the establishment and management of QSMAS.

Initial field activities included an inventory of local vegetation in order to obtain information on the vegetation composition existing in the watershed and use this to provide recommendations for the potential use of tree and shrub species in QSMAS, based on the criteria of predominance and economic (actual and possible use) value. Research activities were planned to evaluate QSMAS performance compared to the SB system and to secondary forests (SF) as reference treatments. Six validation plots (900 m^2 per plot) were established in farmers' fields for the evaluation of four land use systems: (1) traditional SB; (2) management of crop residues; (3) QSMAS; and (4) demarcated areas of secondary forests (SF). Basic grain crops of maize and common beans were established to measure and compare differences among land use/production systems for treatments 1 to 3.

Consistently with the traditional practice, establishment of SB system had a different management compared with subsequent management over the years. In 2005 the system was established through the complete slashing of tress and shrubs, the extraction of firewood and the uniform burning of the remaining dried material throughout the plot. Since plots have a significant reduction on biomass production, in 2006 and 2007 native biomass was slashed and piled to be burned

Table 3.1: *Main biophysical and socioeconomic characteristics of the validation sites of QSMAS compared with the reference site in Honduras.*

Characteristics	Similarities	Differences
Biophysical (agro-ecosystem)	• Agriculture based on the use of slash and burn practice. • Limited productivity and sustainability (low crop water productivity and soil fertility, high soil erosion) • Temperature (annual mean around 27 °C) • Main staples (basic grains): maize and common bean • Intensive cattleranching • Soils: mainly Entisols • Slopes: 30-50%	• Annual precipitation: - Nicaragua: 1400-1600 mm - Colombia: 1900-2100 mm • Length of dry season: - Nicaragua: 6 months (Nov-Apr) - Colombia: 3 months (Jun-Aug) • Altitude: - Nicaragua: 100-300 masl - Colombia: 1000 masl • Secondary forests: - Nicaragua: present and diverse (more than 45 spp.) - Colombia: very limited with low diversity (less than 10 spp.) • Soil quality: - Nicaragua: adequate fertility - Colombia: low fertility and low pH
Socioeconomic	• High poverty • Food insecurity	• Main productive activity: - Nicaragua: agriculture - Colombia: gold mining

in isolated sites within the plots. Plots including management of crop residues and QSMAS were similarly managed during the three years, with the fertilization of maize and common bean crops and the distribution of crop residues shortly before the cropping season. In addition, QSMAS included the partial, selective and progressive slash and prune of trees and shrubs; and the homogeneous distribution of the resulting biomass and naturally fallen litter, simultaneously with crop residues and throughout the cropping season. In all systems weeds were controlled by manual and/or chemical means; integrated pest management was used for the control of diseases and insects.

Maize (local landrace 'Usulutan') and common bean (var. 'INTA Rojo') were established and managed following the standard timing, spatial arrangement (42,436 plants ha^{-1} for maize and 83,333 plants ha^{-1} for common bean) and management practices used in the region for the production of these basic grains using relay intercropping system. In the plots including management of crop residues and QSMAS fertilizer was applied at planting at the level of 21 kg N ha^{-1} and 23 kg P ha^{-1} for each crop, using diammonium phosphate (18% N and 46% P_2O_5); and a complement of 30 kg N ha^{-1} around 25 days after planting (DAP) for maize, using urea (46% N).

In the validation plots, methodology included soil sampling for physical and chemical characterization of soil, and field measurements of resistance to penetration and susceptibility to erosion. Field sampling was performed using three test pits in each system and sampling of soil at 0-5, 5-10, 10-20 and 20-40 cm depths. Samples were analyzed in soils physics and chemistry laboratories at CIAT. Soil physical determinations included: bulk density (Bd), real density (Rd), soil moisture, soil moisture retention curves, saturated hydraulic conductivity (Ks), susceptibility to compaction, total porosity and others. Soil chemical characteristics included: pH, organic matter (OM), available phosphorus (P), exchangeable calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), aluminum (Al), cationic exchange capacity (CEC), and micronutrients. In the field, productivity of maize and common bean was evaluated over three cropping seasons, from 2005 to 2007.

Univariate and multivariate analyses were carried out for variables on soil physical and chemical characteristics and crop yields, using SAS software for statistical analysis and with $\alpha = 0.05$ significance level.

In Colombia the activities started in June 2007, with the visit to Suarez of staff from CIPASLA and CIAT to discuss with local farmers and authorities of an agricultural school, about the possibilities of establishing the validation plots. The municipality of Suarez was selected due to the following characteristics: (i) use of SB as a traditional production system; (ii) predominance of hillsides susceptible to erosion; (iii) situation of food insecurity; and (iv) easy access of field sites for monitoring progress. Selection of farmers was based on: (i) the existence of a secondary forest of at least 1 ha area; (ii) production of basic grains (maize and common bean); and (iii) accessibility of the farm.

Initial field activities included a systematic vegetation inventory to obtain information on the existing vegetation composition in the selected farms and to use this information to provide recommendations for the management of QSMAS validation plots. Establishment of the validation plots was done by local farmers with the guidance of PN15 graduate students that are very familiar with the system. Research activities were planned to evaluate QSMAS agroecological performance compared with both the SB system and SF as reference treatments. Three validation plots (average 9,265 m^2 per plot) were established in farmers' and communal fields for the evaluation of two production systems with two variations: (1) traditional SB (i.e. without addition of fertilizers); (2) SB with fertilization and pH amendment to reduce aluminum toxicity; (3) traditional QSMAS (i.e. with the addition of fertilizers) complemented with pH amendment; and (4) QSMAS without fertilization. Demarcated areas of secondary forests (SF) were used as a control.

Both systems were established shortly before the cropping season. In the case of SB system it consisted of the complete slashing of trees and shrubs, the extraction of firewood and the uniform burning of the remaining dried material throughout the plot. QSMAS plots were established through the partial, selective and progressive slash and prune of trees and shrubs; and the homogeneous distribution of the resulting biomass and naturally fallen litter. In both systems weeds were controlled by manual and/or chemical means; integrated pest management was used for the control of diseases and insects.

Twenty days before planting crops, dolomitic lime (20% Ca, 10% Mg) was applied in two of the plots for the adjustment of pH and to lower aluminum saturation. Maize (var. 'ICA V-305) and common bean (var. 'Calima') were established and managed following the spatial arrangement (30,000 plants ha^{-1} for maize and 60,000 plants ha^{-1} for common bean) and management practices used in the region for the production of these basic grains (multiple cropping). Fertilization was preformed based on soil analysis of each farm and specific nutritional requirements of each crop. For maize, requirements of 120 kg N ha^{-1}, 80 kg P ha^{-1} and 100 kg K ha^{-1} were supplied by applying diammonium phosphate and potassium chloride (60%K_2O) after ten days of planting (100% of P and K), complemented with urea (46% N) at 30 days after planting. For common bean, requirements of 20 kg N ha^{-1}, 30 kg P ha^{-1} and 30 kg K ha^{-1} were supplied by applying diammonium phosphate and potassium chloride at planting.

Methodology included soil sampling for physical and chemical characterization of soil, and field measurements of resistance to penetration and susceptibility to erosion. Field sampling was performed using two pits in each system and sampling of soil at 0-5, 5-10, 10-20 and 20-40 cm depths. Samples were analyzed in soil physical and chemical laboratories at CIAT. Physical determinations included: texture, Bd, Rd, soil moisture, moisture retention curves, saturated hydraulic conductivity (Ks), susceptibility to compaction, resistance to penetration, porosity distribution, total porosity and others. Chemical characteristics (six samples per plot, 20 cm soil depth) included determination of pH, OM, available P (Bray-2) and S, exchangeable Ca, K, Mg, Na, Al, CEC, and micronutrients including boron (B), iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn). In the field, productivity of maize and common beans was evaluated in one cropping season (August 2007 to February 2008).

Univariate analyses were carried out for variables on soil physical and chemical characteristics and crop yields, using SAS software for statistical analysis and with $\alpha = 0.05$ significance level.

Results and Discussion

Milestone 3.1: Maps of similar areas elaborated

Favorability maps produced by Homologue and WofE were combined to identify potential QSMAS extrapolation domains (ED) where areas with a probability higher than zero are intersected. Probabilities of intersecting areas were calculated as averages of the posterior probability from WofE and probability value from Homologue. Potential areas were then classified in ten different classes with probabilities ranging from 0.1 to 1.0; and then intersected with population (data from CIESIN 2005) and area maps to generate statistics by probability class on the potential number of people impacted by QSMAS. This provided a figure of the current population living in the EDA areas, or the 'target population'. ED area and population for QSMAS depended on the probability level chosen. The collaborators insisted on the caution for use of the results, even though they are more a representation of expert knowledge than of prediction.

Results are presented in Table 3.2 for those countries in three continents that presented 50% or more of similarity to the field plots in the reference site. The bivariate map generated display the probability value contributed primarily by climatic factors and then by socio-economic and landscape features in a single map (spatially where and why a similarity occurs) (Figure 3.2). This map of the ED areas for QSMAS shows that the main constraints on identifying extrapolation domains are either in the climatic homologues as in the socio economic variables. Given the number of variables, probability values tended to be low. However, significant locations in Brazil, El Salvador and in the Democratic Republic of Congo were found. Cameroon and Nigeria also showed important areas. Further details of where QSMAS seems to be relevant and extrapolated can be found by analyzing carefully the graphs, tables and the bivariate map (e.g. zoomed map for Latin America, Figure 3.3) generated.

Table 3.2: *Pan-tropical areas in different countries that were identified as suitable for targeting QSMAS in Latin America, Africa and Asia based on site similarity analysis.*

Continent	Country	Area (km^2)
Latin America	El Salvador	106,000
	Honduras	44,000
	Brazil	2,384,000
	Costa Rica	19,000
	Mexico	25,000
	Nicaragua	10,000
	Venezuela	2,000
	Guatemala	1,000
Africa	Cameroon	55,000
	Democratic Republic of Congo	75,000
	Nigeria	51,000
	Guinea	3,000
	Malagasy Republic	1,000
Asia	Myanmar	25,000
	Laos	11,000
	Thailand	3,000
	Indonesia	1,000
	Vietnam	1,000

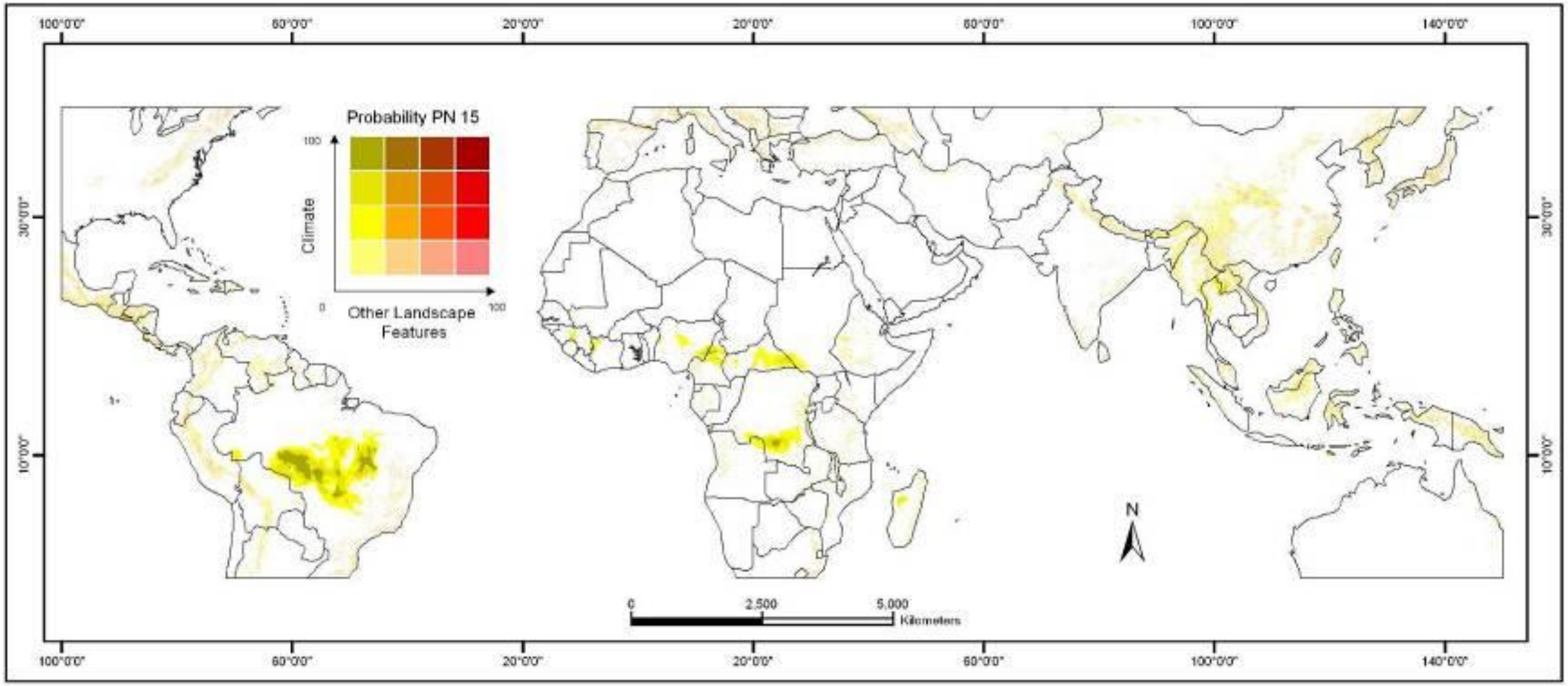


Figure 3.2: *Bivariate map showing influential critical group of factors for QSMAS across the Pan tropical world.*

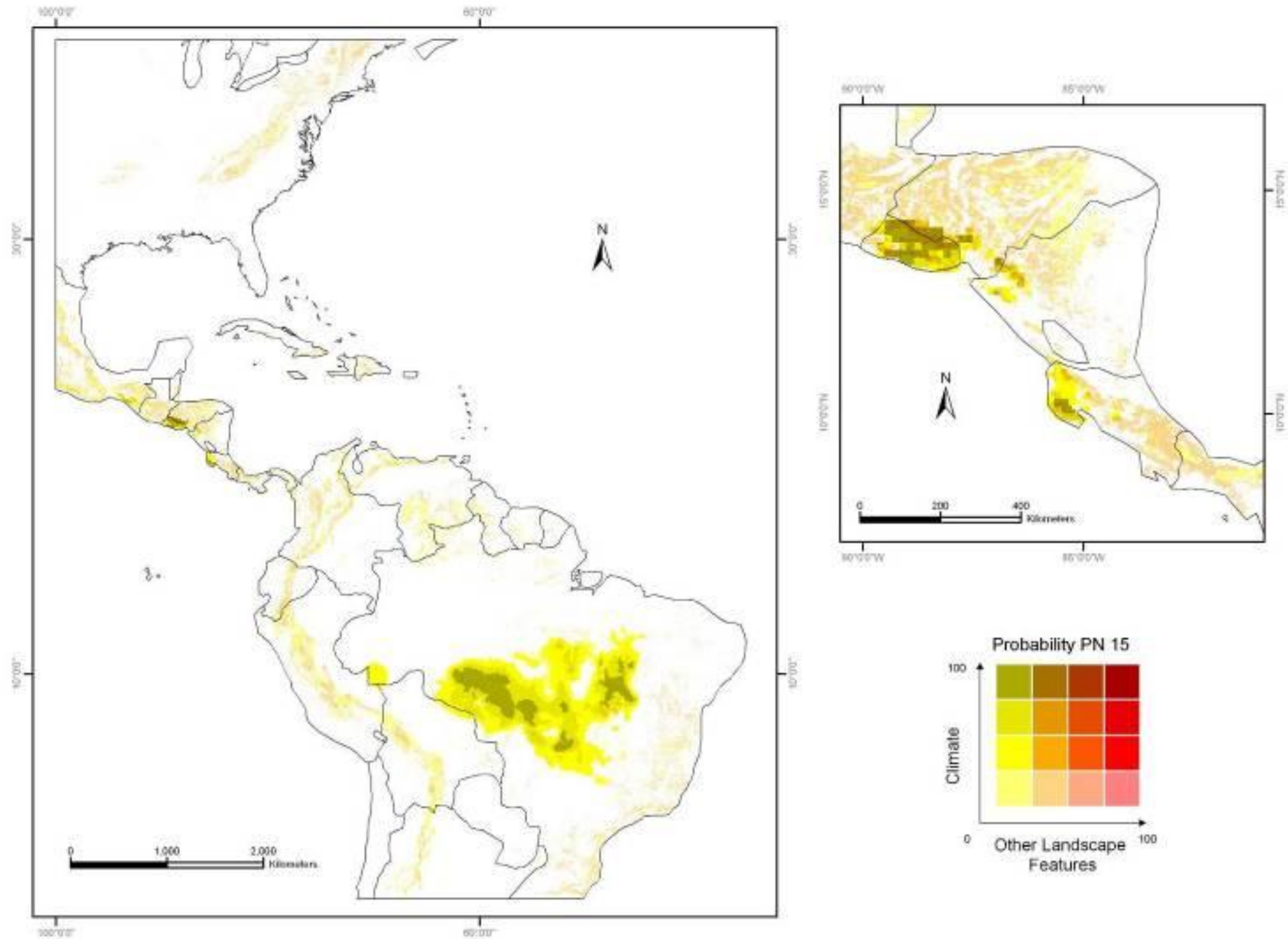


***Figure 3.3:** Bivariate maps showing influential critical group of factors for QSMAS across the American continent.*

Milestone 3.2: A prototype of QSMAS established in Nicaragua with the participation of local community

The vegetation inventory showed that secondary forests in La Danta watershed are composed of 47 species of 18 botanical families. Out of these, 22 species of 14 families have a good potential to be included in QSMAS plots based on provision of socioeconomic and environmental benefits (Table 3.3). After three years of the establishment of the validation plots, results showed that physical properties like texture, Bd, Rd and total porosity, has a similar behavior in all the land use systems tested. Mean values of Bd, Rd, total porosity, susceptibility to compaction and residual porosity were on allowable limits, with Bd around 1.3 g cm^{-3}, Rd near 2.6 g cm^{-3}, total porosity above 52%, susceptibility to compaction around 87% and residual porosity around 13%, indicating that these soils were less susceptible to compaction (texture is loam), have a good aeration and do not restrict root development. In general, soils in La Danta watershed have high availability of Ca, Mg and K, and high CEC, confirming the good level of fertility in these soils.

In relation to Ks, QSMAS and crop residues have no problem in accepting rains equal or greater than 11.1 cm h^{-1}, and have no restrictions with rainfall below 10 cm h^{-1}. The traditional SB system and the SF presented restrictions in rainfall larger than 5.5 cm^{-1} h, indicating that rainfall exceeding this value will result in runoff and erosion. Rainfall simulator test showed that QSMAS had the lowest runoff with 3.98 mm in a simulation of 30 min, while the SB system presented the highest rate with 14.7 mm. Secondary forest had the lowest soil loss with 21.3 g m^{-2}, and the SB system the highest with 35.1 g m^{-2}.

Average production of maize was as follows (Figure 3.4a): in 2005 cycle, 1237 kg h^{-1} in SB system, 1212 kg h^{-1} in crop residues, and 1111 kg h^{-1} in QSMAS, with the traditional system presenting greater results. In the cropping seasons 2006 and 2007 production in the SB system were very similar with a slight decrease (8%), while increasing in crop residues system (51% and 63%, respectively) and QSMAS (25% and 67%, respectively). For common bean, average production in 2005 was 1017 kg h^{-1} with crop residues, 957 kg h^{-1} in QSMAS and 621 kg h^{-1} in the traditional SB system (Figure 3.4b). In 2006 and 2007 cropping seasons, average production in SB system decreased 12% and 4%, respectively, while increased in crop residues system (25% and 19%, respectively) and QSMAS (45% and 55%, respectively). Average yields from 2005 and 2006 resulted in higher net benefits in QSMAS (US$2,008 ha^{-1}), followed by crop residues (US$1,594 ha^{-1}) and SB system (US$1,095 ha^{-1}).

In terms of farmer acceptance of QSMAS, in 2006 INTA reported that farmers validating QSMAS were already practicing the system within their farms but outside the validation plots. At the same time, other farmers in the region were also establishing QSMAS plots as a result of a farmer-to-farmer dissemination. In June 2007, INTA reported that they are looking for additional resources in order to promote the system in other sub-humid regions of Nicaragua. Unfortunately this couldn't be accomplished due to a long process of institutional restructuring at INTA. In August 2007, the 1st Regional Workshop of Farmers Practicing QSMAS was held in Somotillo with participation of farmers and technicians from Honduras and Nicaragua. Farmers shared their positive experiences together with a few valid concerns about the system. Among the many reflections, probably the most important was expressed by a Nicaraguan farmer: "*I know there is still much to be improved and learned but we already took the most important step--that is, not to use slash and burn*" (García and Poveda 2007).

Table 3.3: *Forest species (with agronomic and economic potential) that were included in QSMAS plots in La Danta watershed, Somotillo, Nicaragua.*

Nº	Scientific name (family)	Potential use[a]
1	*Cordia alliodora* (Boraginaceae)	1, 5, 7, 10, 16, 20, 22
2	*Lysiloma divaricatum* (Mimosaceae)	7, 12, 13, 19
3	*Hymenae caurbaril* (Caesalpinaceae)	7, 10, 12, 13, 16, 19, 21
4	*Guazuma ulmifolia* (Sterculiaceae)	1, 5, 6, 8, 11, 16
5	*Albizia adinocephala* (Mimosaceae)	7, 8, 19, 23
6	Genízaro[b]	1, 5, 7, 11, 16, 19, 20
7	*Albizia caribea* (Mimosaceae)	5, 7, 19
8	*Birsonima crassifolia* (Malpighiaceae)	6, 7, 8, 10, 16, 17, 19
9	*Cordia bicolor* (Boraginaceae)	7, 10
10	*Diphisa robinioides* (Fabaceae)	7, 12
11	*Stemmadenia donnell* (Apocynaceae)	8, 19
12	*Enterolobium ciclocarpun* (Mimosaceae)	1, 5, 12, 14, 16, 20
13	*Bursera simarouba* (Burceraceae)	15, 16, 21
14	*Tabebuia crysanta* (Bignonaceae)	4, 7, 8, 12, 16, 19
15	*Schizolobium parahybum* (Caesalpinaceae)	3, 12, 14, 16
16	*Eugenia salamensis* (Myrthaceae)	7, 8, 16
17	*Karwinskia calderonii* (Rhamnaceae)	7, 19
18	*Muntigia calabura* (Elaeocarpaceae)	7, 15
19	Palanca[b]	8, 10, 17
20	*Lonchocarpus phlebifolius* (Fabaceae)	8, 18, 19
21	*Senna skinneri* (Caesalpiniaceae)	2, 7, 12, 14
22	*Switenia humilis* (Meliaceae)	5, 7, 9, 13, 16, 20

[a]1= agroforestry; 2= barriers; 3= beams; 4= bridges; 5= carpentry; 6= charcoal; 7=construction; 8= firewood; 9= floors; 10= food; 11= forage; 12= furniture; 13= handicrafts; 14= industry; 15= live fences; 16= medicine; 17= ornamental; 18= for making plow; 19= posts; 20= reforestation; 21= resin; 22= source of pollen; 23= wood; 24= yoke.
[b] Local name (scientific name is unknown).

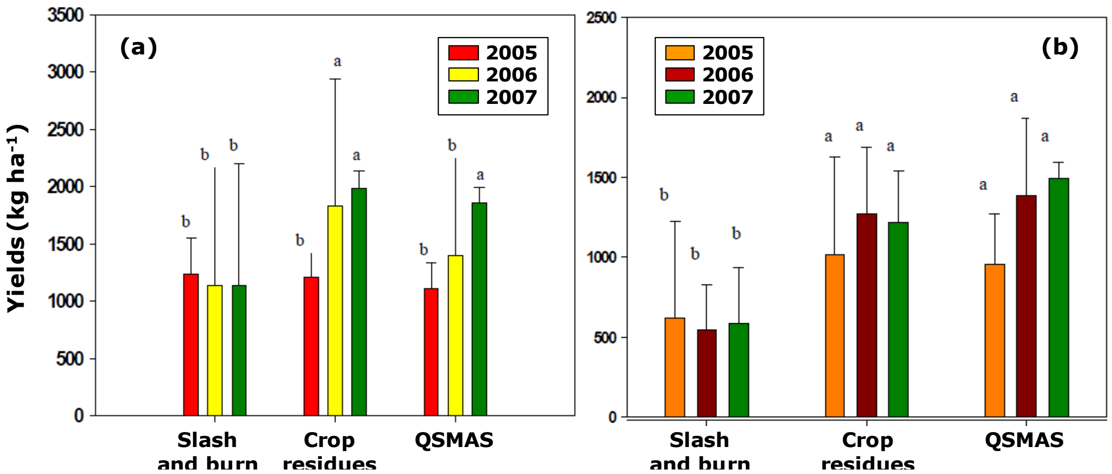


Figure 3.4: *Yields of maize (a) and common bean (b) in experimental plots including three different production systems. La Danta watershed, Somotillo, Nicaragua.*

Milestone 3.3: A prototype of QSMAS established in Colombia with the participation of local community

The vegetation inventory in Suarez showed that composition of secondary forests is poor in terms of variability (8 species of 7 families) and number of individuals. One of these species, *Miconia granulose* (Melastomataceae), is known for being a pioneer species for ecosystems that are in the process of recuperation. In addition, 90% of the individuals were in the stage of early growth (stem diameter at breast height <5 cm). These observations confirm that the region has been exposed to the processes of degradation of natural vegetation and according to local farmers this was driven by the extensive use of slash and burn agriculture and cattleranching.

Mean values of Bd, total porosity and porosity distribution, and general conditions for water availability and root development, were not affected by the production systems, but by the characteristics of the farms (soil quality) and by soil depth. Although this was the first cropping season, important variables such as susceptibility to compaction (critical values ≥87%) were affected by the production system and management practices, varying from 98.1% in SB fertilized (0-5 cm) to 80.7% in QSMAS not fertilized (20-40 cm). In general, soils in the validation plots are acidic and with good content of OM. However, high variations among farms were observed for most elements (Table 3.4). Out of the three farms, only one (corresponding to "La Salvajina dam") showed a good level of soil fertility.

Grain yields were markedly affected by the addition of fertilizers but not by the production systems (figures 3.5 and 3.6). Again, high variations observed in grain yields were mostly due to differences in the quality of soils of the validation plots and their response to nutrients.

In relation with farmer acceptance of QSMAS, this activity of validation was welcomed by local farmers and authorities since they are aware of the environmental degradation that the region had suffered for years as a result of the extensive use of unsustainable agricultural practices. Unfortunately, extreme biophysical and socioeconomic conditions such as the difficulties to find appropriate farms (e.g. nonexistence of secondary forests and low soil fertility including deficiency of some essential elements) and the high dependency on gold mining, limited the actual and potential impact of QSMAS in the region.

Table 3.4: *Chemical analysis of soils from the validation plots. Suarez, Colombia, 2007.*

Farm*	pH	OM ($g\ kg^{-1}$)	P Bray II ($mg\ kg^{-1}$)	Al	K	Ca	Mg	CIC	S	B	Fe	Mn	Cu	Zn
				cmol kg^{-1}					mg kg^{-1}					
1	4.69	46.1	0.73	2.65	--	0.07	0.04	13.5	61.9	0.14	67.9	1.7	0.56	0.6
2	4.65	73.7	2.75	4.60	0.11	0.23	0.12	19.6	45.1	0.31	37.6	4.2	0.44	1.0
3	5.01	77.2	4.36	0.91	0.24	5.17	2.58	28.5	47.4	0.38	13.1	74.4	2.12	2.4

*1 = Agricultural college; 2 = Vicente Mosquera; 3 = Salvajina dam

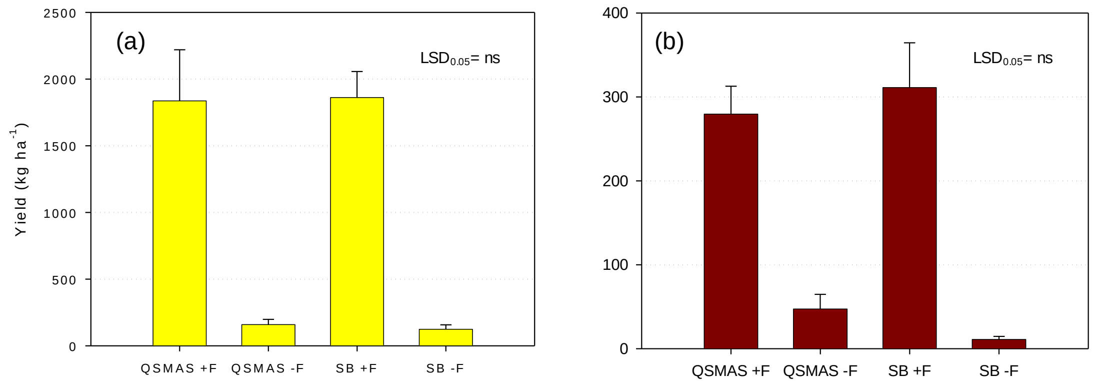


Figure 3.5: *Yields of maize (a) and common bean (b) in experimental plots including two different production systems and two levels of fertilizer application. Bars represent standard deviation. Cauca, Colombia.*

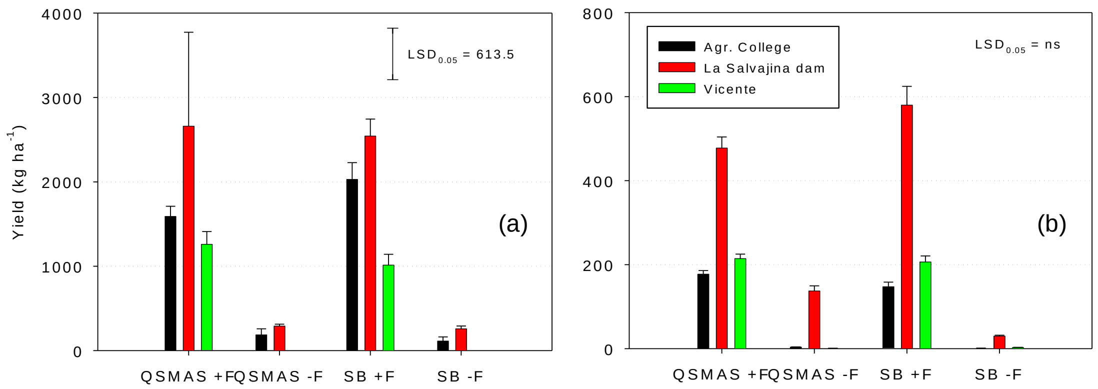


Figure 3.6: *Yields of maize (a) and common bean (b) in experimental plots including two different production systems and two levels of fertilizer application. Bars represent standard deviation. Cauca, Colombia.*

Conclusions

EDA:

- Work on EDA showed good expectations of potential impact for QSMAS in a number of countries in Latin America, Africa and Asia. However, the obtained results are limited to the availability of data from the reference and target sites in tropical regions.
- Adoption beyond reference sites is not a simple process to be determined from basic data. Nevertheless, the proposed EDA can be used as a means to explore what major factors could induce or restrict wider adoption.

Validation in Nicaragua:

- Results suggest that the use of *QSMAS* may increase the productivity and profitability in the maize-common bean intercropping commonly used in Central America, especially when compared to the traditional SB production system.

- Major driving factors on QSMAS acceptance in Nicaragua include INTA's[5] initiative to replace SB practice; farmer-to-farmer exchange of knowledge as an excellent tool to promote and disseminate QSMAS as an alternative to SB; and the perception of farmers on the multiple benefits of QSMAS compared with SB.
- This experience indicates that changing from SB to QSMAS is not that difficult for farmers since they appreciate the multiple economic and environmental benefits from the system.

Validation in Colombia:

- Although no differences were observed among grain yields of SB system and QSMAS, this experience suggests that farmers are conscious of the negative impacts caused by the use of SB system and that they are open to try new practices to replace it.

General:

- Practicing SB system by smallholders in sub-humid hillsides implies burning, soil losses due to erosion, yield decline over time leading to shifting cultivation. Introduction of QSMAS as an alternative to SB system helped farmers to overcome these major limitations.
- For farmers to realize further benefits from QSMAS there is need for intensification and diversification of the system with high value components (livestock and fruit crop options). This will involve access for smallholders to credit and markets. Enabling policies are needed for designing payments for environmental services (PES).

[5] INTA was already promoting technologies leading to more sustainable agriculture by promoting the use of crop residues as a part of a no-till system to replace SB and by managing natural resources at watershed level.

Objective 4. To develop tools for dissemination, adaptation and promotion of the QSMAS management strategies

Dissemination of QSMAS through PN15 activities was crucial to learn from the adaptation processes incorporating local innovations. Collaboration with local consortia, universities and NARES was essential for conducting research activities and validation of QSMAS in Nicaragua and Colombia.

QSMAS was promoted in the reference site as an alternative to the traditional practice of slash and burn (SB system). Therefore, it was necessary to analyze the impact of QSMAS compared with the SB system that is still predominant among small-scale householders in the Pan tropical world. Since the biophysical impact was studied under Objective 2, this Objective was focused on the social and economic impacts of QSMAS in Honduras as result of replacing the SB system.

Methods

Professionals and students from Central America were identified to conduct these studies focused to answer specific questions raised in the project's proposal. Additionally, students from universities of the United States, Switzerland and Australia received support to conduct studies that complemented the information generated by PN15. In all target sites, PN15 partners assigned human and capital resources to collaborate in different activities of research and validation of QSMAS.

The evaluation of the socioeconomic impact of QSMAS in the reference site was executed in the second semester of 2007. The methodology used consisted of: (i) the participatory identification of a set of indicators to capture the benefits of QSMAS from different stakeholders at different scales (household, communities, local organizations, researchers and policy makers); (ii) a field survey conducted to collect this information; and (iii) the validation of results with the stakeholders. The study also included a cost-benefit analysis comparing QSMAS profitability in 1999 and 2007. An additional workshop was conducted in May 2009, including among its objectives to identify the most significant changes that different stakeholders perceived to be the result of the massive adoption of QSMAS in the reference site. This information was complemented with the results of the application of the DDP approach used to analyze QSMAS context in Objective 1 (pages 10 and 11).

Results and Discussion

Milestone 4.1: Building capacity for economic (yields, labor) and environmental (soil and water quality) monitoring

A total of sixteen professionals conducted graduate (6) or undergraduate (10) studies with the total or partial support of PN15. Among the 16 total students 7 (44%) were female students. The list of students with details on their degree and main achievement is provided in the CPWF-PN15 Completion Report Proforma.

Out of the 15 resulting theses (two students worked together on one dissertation), 12 (80%) were conducted in Honduras and 4 (20%) in Nicaragua. Six (40%) were related with water and soil losses at plot or watershed scales; two (13.3%) with natural vegetation; two (13.3%) with soil fauna; and one with nutrient dynamics, greenhouse gases, edaphic characterization, pests and diseases and validation of QSMAS (6.6% each, for a total of 33.3%). Four theses included information on grain yields (3 in Honduras, 1 in Nicaragua), and one (conducted in Honduras) incorporated the component on labor inputs.

Milestone 4.2: Use existing MIS consortium in Central America and CIPASLA in Colombia and NGO networks to adapt and promote the QSMAS

Validation of QSMAS in Nicaragua was possible mainly due to the collaboration of INTA through MIS Consortium (see Objective 3). Field activities were conducted for almost four years, from April 2005 to December 2008, although during 2008 activities were reduced due to logistic and economic limitations as a result of administrative changes at INTA. Even though only 6 farmers participated on the validation of the system in Somotillo village, about 70 additional smallholders of the community started using the system in their own plots and more than 90% of the community stopped using slash and burn system[6]. INTA organized field trips and workshops to promote the system among farmers and technicians from other communities.

As a member of MIS consortium, the UNA-Nicaragua collaborated with INTA through the research activities of two undergraduate theses students. These theses were instrumental on the characterization of the validation site and management of forest component within the validation plots.

Training and exchange workshops were executed on an annual basis, with the active participation of farmers and technicians from INTA, UNA-Nicaragua and CIAT.

In Colombia, validation activities were conducted by CIAT in collaboration with CIPASLA consortium. Unfortunately, important limitations including identification of suitable sites, security and shortage of matching funds from the partner affected the starting of this activity (delayed for two years). The site selected was the best given the security concerns in the region. This experience was of high value on the development of strategies for future efforts on the validation of QSMAS (included in the guide for its validation).

UNAL-Palmira collaborated with PN15 through partial supervision of four theses studies at graduate level (2 PhD and 2 MSc) including the most complete one for the study of water dynamics in the system. Internal seminars were instrumental for sharing information with the academic community, regarding the system *per se* and the specific studies.

FAO was a key partner for realizing research activities in Honduras, with significant contribution in terms of logistics (from selection of farms and involving farmers in field activities to sharing offices and storage facilities) during most part of the project duration. While promoting the system in the reference site, during visits to PN15 experimental plots, FAO shared with technicians and decision makers from different countries the research activities and results of the project.

Two new partners incorporated through MIS and PN15 activities were the Soil Management CRSP and ARIDnet. Results of the validation of NuMaSS software promoted by the Soil Management CRSP resulted in important recommendation to improve the efficiency of fertilization in maize. The results of one workshop

[6] Information compiled during an additional study funded by CPWF Impact and Innovation and executed in May 2009.

guided by ARIDnet group provided new insights on the processes that lead to QSMAS dissemination in the reference site, and on the future of the system as an option to confront desertification and facilitate rehabilitation of degraded soils in sub-humid regions.

Milestone 4.3: Document impact of QSMAS compared to other agricultural systems

According to stakeholders (farmers, technicians, professors and local authorities), most of the changes resulted from the dissemination of Quesungual system in the reference site corresponded to socioeconomic conditions (Table 4.1). The main social impact was food security achieved by every economic strata of the community, initially through the production of basic staples. Once this condition was reached householders could consider other opportunities and options to improve their livelihood, according to their economic possibilities. These included increasing production areas and/or improving yields and quality of production through better soil productivity and input supply. Resilience and productivity of the system permitted a sustainable production beyond subsistence levels and therefore allowed and promoted diversification at household level (mainly home gardens and some livestock and minor species) through linkages to local markets.

Impact of QSMAS as income source was different depending on the economic strata. For the poorest householders, QSMAS appeared to be more important for food security and as a source of employment. A second more visionary (or economically capable) stratum was additionally benefited by diversifying production with livestock, commercial activities (e.g. sale of inputs), and/or with other sources of employment (i.e. education, carpentry and construction). This group was benefited with the linkages to local markets (which are in large extent visited by Salvadorian customers) through basic grain surpluses and the relative diversification resulted from the use/benefits of QSMAS. The highest economic stratum was capable to acquire land in the last ten years, for livestock production. For this group, the main benefits derived from QSMAS were increased capacity building and organization.

The cost/benefit analysis comparing QSMAS with SB system showed that Quesungual system was more profitable (Table 4.2). However, comparison of data from 1999 and 2007 suggest that the production of basic grains with QSMAS was reaching a steady state of profitability, and that it could be threatened by significant raises on the costs of inputs (i.e. fertilizers and herbicides) and labor.

Important indicators such as education and health were indirect benefits from the dissemination of QSMAS. This is particularly clear for education, since the level of education among adults (that were in school age more than 20 years ago) was differentiated by strata. It was found to be similar among children despite the economic capacity of their families. Among the main social benefits derived from the adoption of QSMAS were the environmental services, since they had an impact on the wellbeing of families and communities.

The result of these studies confirmed both the magnitude and diversity of impacts summarized by Ayarza and Wélchez (2004), as a result of QSMAS dissemination in one of the more depressed regions in Honduras.

Table 1.1 (page 11) presents the comparison of human, environmental and biophysical drivers and key factors affecting land degradation and land improvement as result of the predominant use of QSMAS and SB systems in the reference site, respectively. The information showed that contrary to SB system, based on local knowledge, QSMAS effectively addressed the key slowly changing biophysical variables (e.g. soil quality and forest cover) by increasing the stability over time of the quickly changing biophysical (e.g. soil moisture availability) and socioeconomic (e.g. income diversification with firewood and tree-crop production) variables.

Table 4.1: *More significant changes perceived by different stakeholders as result of the promotion and adoption of QSMAS in Candelaria, south-west Honduras.*

Changes	Group†		
	1	2	3
Biophysical environment			
Improved environment (air) quality (less contamination)	*		*
Improved quality of soils	*		
More forestry resources	*		
Better climatic conditions			*
Socioeconomic conditions			
Food security and sovereignty of every stakeholder	*	*	*
Better education	*	*	*
Improved health and health related services	*	*	*
Improved organizational capacity (including women)	*	*	*
Projects of potable water (better amount and quality of water)	*	*	*
Reduced size of families (birth control)	*	*	
Better infrastructure to access communities	*	*	
Improved access to markets to acquire inputs and sale products (e.g. El Salvador)	*	*	
Improved capacity building (e.g. management of water, health care, legislation)	*	*	
Local financial systems	*		*
Increased capacity to manage natural resources (soil, water, vegetation and fauna)	*	*	*
Better use of inputs	*		
Reduced mortality among women and kids	*		
Reduced mortality of animals (cattle and minor species)	*		
Self employment		*	
Diversified use of trees and wood		*	
Land use planning (at both community and field levels)		*	
Basic sanitation		*	
Improvement of personal care		*	
Improved economic conditions			*
Diversification of production			*
General change on people's attitudes			*
Policies			
Regulations for exploitation of forests			*
Law against alcohol consumption		*	
The best changes: implementation of law against burning, more rainfall, consciousness on the sustainable management of natural resources, participation of the whole group of stakeholders		*	*
The most difficult: to create consciousness among people to generate significant changes	*		

† Group 1= experienced farmers practicing all the principles of QSMAS; Group 2= experienced farmers practicing most of the principles of QSMAS, and young farmers; and Group 3= local authorities, professors and technicians.

Table 4.2: *Comparative economic analysis of Quesungual and slash-and-burn systems for the production of maize (and sorghum as animal feed). Candelaria, Honduras, 2007.*

Production System	Cost (US$ ha^{-1})	Net revenue (US$ ha^{-1})	Other income sources[b]	Total income (US$ ha^{-1})	Net income (US$ ha^{-1})	B/C
Slash and burn – 1999[a]	267.57	222.22	22.49	244.71	-22.86	0.91
QSMAS – 1999[a]	279.37	317.76	25.93	343.69	64.32	1.23
QSMAS – 2007	418.22	642.48	108.47	750.94	332.73	1.80

[a] Source: Deugd 1999.
[b] Included firewood and crop residues

Similar biophysical and socioeconomic benefits to the ones presented in this report can be appreciated with other agroforestry systems, such as the Sahelian Eco-Farm evaluated in Africa by CPWF-PN5 ("*Enhancing Rainwater and Nutrient Use Efficiency for Improved Crop Productivity, Farm Income and Rural Livelihoods in the Volta Basin*" (Pasternak et al. n.d.).

Conclusions

- The development of research capacity in the target area of PN15 through PhD, MSc and BSc student theses was instrumental to: (i) complete other research objectives of the project; (ii) promote the system through results from student theses; and (iii) improve the capacity of the region to conduct and report on field and laboratory research activities.
- Participatory experimentation (Honduras) and validation (Nicaragua and Colombia) was fundamental for understanding and promoting QSMAS, and to learn from farmers with different level of expertise on the management of the system.
- The evolution of Quesungual system towards a diversification by including high value market oriented fruit and vegetable crops and also livestock production may facilitate to reach higher profits while reducing risks and contributing to QSMAS' sustainability.
- Further analysis of the impact must include local laws affecting variables allegedly influenced by QSMAS, such as technologies (e.g. new crops and other productive activities), linkages to markets, education, capacity building and poverty alleviation.
- The increased scarcity of water and higher demand for food and biofuel while conserving biodiversity, require the development of innovative crop production strategies that can simultaneously restore degraded landscapes. Through a careful adaptation, QSMAS can be used by local governments and development organizations to benefit from these ecosystem services.

A note of caution on QSMAS adaptation and dissemination

Even though agroforestry systems have been recommended for more than two decades as an effective production technology to achieve food security and environmental quality, they have not been sucessfully adopted by small scale farmers in developing countries. Although PN15 has generated valuable information to adapt QSMAS to other tropical regions, it is important to include a note of caution on this practice.

Adaptation of QSMAS may not always result with multiple benefits as reported from the experiences in reference and validations sites. This is because of a number of preconditions needed for the system to be adopted by farmers (Figure 3.7):

1. **Communities:** QSMAS is a validated feasible option to SB system. However, if communities are not convinced on the need to change their traditional production systems, the apparent increased labor required for QSMAS (which only occurs in the first season during the establishment of the plots) may contribute to its rejection. Organizations promoting QSMAS must share with stakeholders (i.e. local authorities, institutions, organizations and leaders) all the key information on the system and try to get the commitment needed to support its adaptation.

2. **Organizations:** QSMAS generates benefits in the short, medium and long terms (around 3, 5 and 10 years, respectively). If stakeholders expect to obtain in the short term the set of benefits reported in this and other documents, efforts to adapt QSMAS may be abandoned. Strategies to improve rural livelihoods based on QSMAS must define realistic achievements according to the system's potential and the biophysical and socioeconomic contexts of each target site. Medium to long term benefits may require strategic alliances to give continuity to the process of adaptation and further dissemination. Specially recommended are organizations addressing similar objectives of development, food security, and management of natural resources.

3. **Topography:** QSMAS has a dramatic effect on reducing soil erosion on hillsides. On flat areas, this important benefit may not be noticeable by farmers.

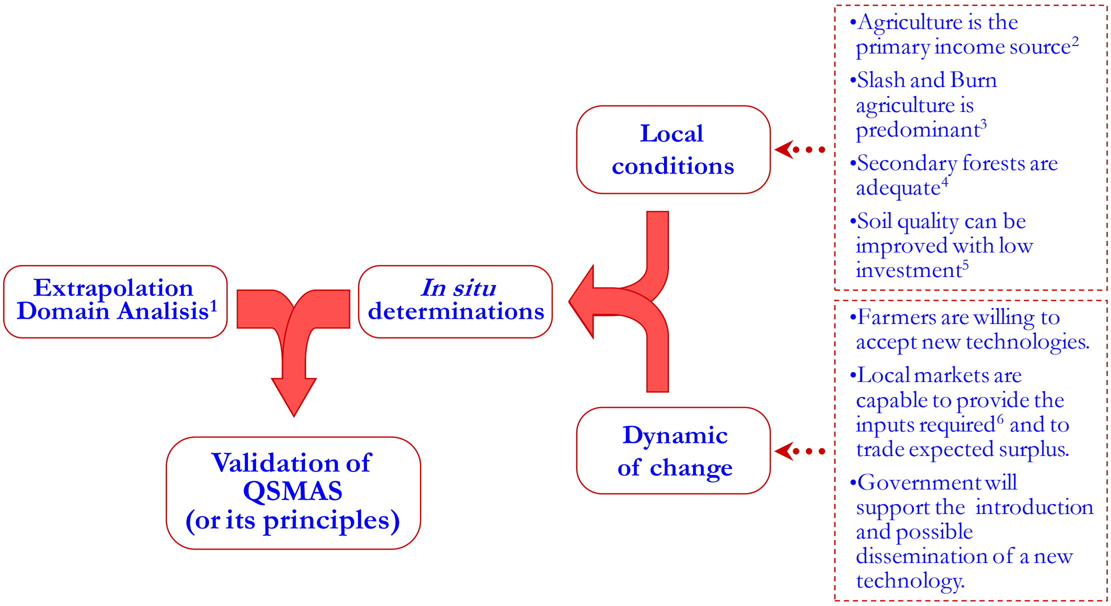
4. **Rainfall pattern:** QSMAS will improve water availability to plants in sub-humid regions with a long (up to six months) dry season and when irregularity (dry spells) or insufficiency (shorter rainy season) of rainfall occurs. Significant increases on crop water productivity will not be achieved when water is not limiting production.

5. **Vegetation:** QSMAS management is based on the conversion of naturally regenerated secondary forests into productive plots. Although it is possible to establish the system while the landscape is still in the process of regeneration, longer term needed to realize benefits may cause rejection of the system by farmers.

6. **Edaphic limitations:** QSMAS requires efficient fertilizer applications, which forms part of one of its four key management principles. Smallholders practicing SB agriculture usually do not apply fertilizers hence the adoption of this practice implies a significant economic and cultural effort. If correction of nutritional limitations in the soil requires significant amounts of fertilizers or amendments, farmers would rather choose to continue using their traditional practices.

7. **Linking to markets:** farmers managing QSMAS plots require inputs (mainly fertilizers) and possibilities to trade expected surpluses. Lack of any of these will result on failure of the potential agronomic and economic benefits of the system and undoubtedly, on its rejection by farmers.

Figure 3.7: *Decision support system for QSMAS adaptation and dissemination.*



[1]SSA based on relevant climate, topography, landscape and socioeconomic characteristics. Since SSA is in process of validation, sites with favorable conditions for the adaptation of QSMAS may have been omitted; [2]Agriculture represents around 80% of household income; [3]Practiced by at least 80% of the farmers; [4]Extension are similar to average production fields and predominant species are capable to recover (branches and biomass) after severe yearly pruning; [5]No limiting constraints such as extreme acidity or deficiency of essential nutrients; [6]Mainly amount and quality of inorganic fertilizers.

2 OUTCOMES AND IMPACTS

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
(1) Scientific community, policy makers and extension institutions	They can use the knowledge generated by PN15 on QSMAS, and the experience gained by PN15 partners on the system's validation.	They can use QSMAS as a model production system to be used by resource poor farmers for the sustainable management of natural resources to prevent and reverse soil degradation, improve food and economic security, and enhance the whole water cycling.	PN15 conducted a number of studies demonstrating the biophysical (crop-water productivity, water cycling, nutrient cycling, greenhouse gas fluxes, erosion and vegetation) and socioeconomic benefits of the use of QSMAS by smallholders in the reference and validation sites. During the four years, PN15 have shared information on methodologies and results with different stakeholders. Efforts are being made to generate additional scientific publications. Project outputs 1, 2, 3 and 4 were involved for these activities.	Scientists and policy makers are already interested on the experience of QSMAS in Honduras and in Nicaragua.
(2) Resource poor farmers from the validation site of QSMAS in Nicaragua (Somotillo village)	They stopped using slash and burn agriculture replacing this technology with QSMAS.	(i) They realized that it is possible to produce annual crops (maize and common bean) and forestry products (e.g. firewood and timber) using more sustainable technologies; and (ii) they improved their knowledge on the use of forest species.	PN15: (i) facilitated the application of the farmer-to-farmer mechanism of dissemination by organizing visits of farmers and technicians from Nicaragua to the reference site in Honduras, followed by a visit by Honduran farmers to Nicaragua to provide training on QSMAS management through the establishment of validation plots; and (ii) organized two workshops for the exchange of experiences of farmers and technicians on QSMAS. Project outputs 2, 3 and 4 were involved for these activities.	One community of Nicaragua (Somotillo) is no longer using the traditional slash and burn system and around 60% of the farmers already adopted QSMAS to produce basic grains
(3) Resource poor farmers from the reference site of QSMAS in Honduras	They improved their capacity to participate and contribute to research and outreach	(i) They developed new knowledge and experience on the establishment and management of experimental	PN15: (i) worked with farmers on the planning and execution of research activities; and (ii) brought visitors (farmers, technicians and officers of	A team of at least 8 farmers (including one female) with improved

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
(Candelaria village)	activities.	plots; and (ii) they acquired skills for communication and improved their confidence to share information with other farmers and technicians.	international institutions) to know the system and hear from users about the benefits from its adoption, and research activities. Project outputs 2, 3 and 4 were involved for these activities	capacity to contribute to the management of field experiments and shared information on QSMAS.
(4) INTA /CENIA (NARS, Nicaragua)	INTA is including QSMAS among the technologies being promoted as an option for small-scale farmers in drought-prone areas.	INTA's awareness of QSMAS benefits at agronomic, environmental and socioeconomic levels.	(i) Partnership with MIS consortium facilitated the knowledge of QSMAS to INTA and other partners; and (ii) INTA has been promoting technologies leading to more sustainable agriculture by including the use of crop residues as a part of a no-till system to replace SB and by managing natural resources at watershed level. Project outputs 2, 3 and 4 were involved for these activities	Besides adoption in Somotillo, INTA planned to evaluate QSMAS with 300 more farmers in similar regions of Nicaragua (it was not possible because of lack of funds).
(5) Students of different levels (BS, MSc and PhD)	They improved their academic qualifications and acquired knowledge on QSMAS management and processes.	Students acquired: (i) general knowledge of agroforestry systems as an alternative to slash and burn systems for food production; and (ii) new specific knowledge and expertise on the planning and reporting of research activities related with each particular study.	PN15: (i) funded with tuition and fees for the education of two professionals at MSc level and two at PhD level; and (ii) collaborated through support on field activities and scientific advice of other 15 students (2 were at PhD and 13 were at BS level). Output 4 was involved for these activities.	19 professionals from 5 countries and 2 continents improved their academic qualifications (4 PhD, 2 MSc and 12 BS).
(6) Staff (researchers and officers) from partner R&D institutions	They are considering agroforestry and other technologies based on local knowledge for additional research and/or use for development.	They are giving a higher value to local knowledge, participatory research and/or QSMAS, based on the interaction with PN15 team.	Promotion of QSMAS through: (i) visits to the reference and validation sites in Central America; and (ii) implementation of research activities for academic purposes. Project outputs 2, 3 and 4 were involved for these activities .	At least one NARS (INTA) and two organizations of international cooperation (FAO, IDRC).
(7) Academic institutions	They are including in their academic research	They are giving a higher value to agroforestry and other forms of	Promotion of QSMAS through: (i) visits to the reference and validation sites in Central America	At least 3 academic partners of MIS

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
	activities, work on agroforestry and other types of conservation agriculture, and applying research methodologies used in PN15.	conservation agriculture; and to the different methodologies applied in theses studies of PN15.	(CA); and (ii) implementation of research activities for academic purposes. Project outputs 2, 3 and 4 were involved for these activities	consortium and two universities outside the Central American region.
(8) PN11 ('Rice landscape management for raising water productivity, conserving resources and improving livelihoods in upper catchments of the Mekong and Red river basins') staff	Dr. Benjamin Samson reported that after the exchange of experiences with PN15, PN11 started conducted trials in Lao PDR to compare soil losses in burned (traditional production system) and unburned plots.	Information shared of results on the biophysical benefits of using QSMAS instead the traditional systems based on slash and burn	Biophysical evaluations conducted by PN15 on soil-water dynamics included measurement of soil and nutrient losses through erosion. Since the preliminary extrapolation domain analysis suggested south-east Asia as potential region for QSMAS adaptation, PN15 participated in Theme 1 (Crop Water Productivity Improvement) sponsored travel grants to advocate and assist cross-learning between complementary CPWF projects. Project outputs 2, 3 and 4 were involved for these activities.	PN11 research team in Lao PDR established plots with and without the traditional slash and burn practice to compare soil losses through erosion.

Of the changes listed above, which have the greatest potential to be adopted and have impact? What might the potential be on the ultimate beneficiaries?

The change with higher potential to be adopted and have impact is the adoption of QSMAS in the validation site in Nicaragua. The change with major potential to have impact is the use of QSMAS and similar techniques of conservation agriculture in new research projects, through the interest of scientists and young researchers that are familiar with these technologies because of their participation in PN15.

In both cases the potential beneficiaries would be resource-poor smallholders (and their communities) in drought-prone tropical hillside agroecosystems, by achieving food security and improving the availability of resources; and downstream users through higher amounts of water of improved quality. Additional impacts include reduction in global warming potential by eliminating burning.

What still needs to be done to achieve this potential? Are measures in place (e.g., a new project, on-going commitments) to achieve this potential? Please describe what will happen when the project ends. INTA requires additional funds to promote the adaptation and further adoption of QSMAS in other suitable ecoregions of Nicaragua. INTA and the UNA-Nicaragua are already committed to join efforts on the preparation of proposals with this objective in collaboration with CIAT through MIS consortium. Researchers may need additional information on the results of the project (including the extrapolation domain analysis as reference) to identity target regions and search for strategic partners to collaborate on the preparation of full proposals for new projects focused on the adaptation of QSMAS or its principles for improving food security and ecosystem services in other similar agroecoregions in the tropics.

Each row of the table above is an impact pathway describing how the project contributed to outcomes in a particular actor or actors. Which of these impact pathways were unexpected (compared to expectations at the beginning of the project?) The high acceptance and early dissemination of QSMAS in Nicaragua was an unexpected outcome, since the initial plan only included the validation of the system. Why were they unexpected? How was the project able to take advantage of them? The plan was to apply a participatory approach to validate QSMAS. It included the exchange of experiences among farmers from the reference and validation sites, which ultimately was a key element on the transfer of the technology. For PN15 this implies that the dissemination of the system may be facilitated (in terms of time and effort required) by the mechanism of farmer-to-farmer once the pioneer group of farmers visualized the benefits from the system.

What would you do differently next time to better achieve outcomes (i.e. changes in stakeholder knowledge, attitudes, skills and practice)? Use improved mechanisms to monitor the progress of activities under responsibility of partners and mainly, to receive reports on advances and achievements. Be more aggressive on sharing the knowledge generated (through research) or compiled (by revision of secondary information) with organizations focused on research for development.

3 INTERNATIONAL PUBLIC GOODS

PN15 applied different traditional and participatory research methodologies to: (i) acquire knowledge on the technologies used in QSMAS; (ii) understand the decision making process of farmers practicing the system; (iii) evaluate the positive and negative results of the management of QSMAS, compared with other land use systems; and (iv) elucidate the principles that define its management.

These international public goods (IPG) are useful for scientists, researchers, students, NARES, and NGOs to conduct research activities in other land use systems and to apply the knowledge generated in similar agroecoregions.

3.1 Tools and Methodology

3.1.1 Production technologies

Knowledge on the management of QSMAS and on the decision making of farmers practicing the system was acquired through: (i) working with farmers experimented (more than five years) on the management of the system; and (ii) information collected for its economic analysis. The information was included in the management section of the guide for the validation of QSMAS (at the moment in final stages of preparation).

3.1.2 Research methodologies

The most significant IPG resulted from the research activities conducted by the project is the integrated knowledge generated on the performance of QSMAS compared with the two alternative land use systems that are common in the region. These are the slash and burn traditional production system (to determine the relative pros and cons if it is replaced by QSMAS) and the secondary forest (to determine the magnitude of changes in the landscape as a result of QSMAS adoption).

This knowledge was mainly generated by combining a number of methodologies for the study of water and nutrient dynamics, soil quality and greenhouse gas fluxes from QSMAS. Study on water dynamics included the assessment of: (i) infiltration, runoff and soil water availability according the methods described in the TSBF Manual of Methods (Anderson and Ingram, 1993); (ii) water infiltration and runoff, through the use of a rainfall minisimulator (Cobo, 1998); and (iii) susceptibility to erosion by the use of erosion plots. Soil losses were determined through the comparison of the indices of soil erodibility K-USLE and Ki-WEPP, corresponding to the Universal Soil Loss Equation (Wischmeier and Smith 1978) and to the Water Erosion Prediction Project (Nearing et al. 1989), respectively. Crop water productivity was calculated using the crop yield and soil water data and by estimating the evapotranspiration according to the method of Penman and Monteith (FAO 1998).

Study on nutrient dynamics included: (i) determination of decomposition and nutrient release from biomass of trees, shrubs and the two annual crops, maize and common bean (Wieder and Lang 1982), using the litterbag technique (Bocock and Gilbert 1957); (ii) N mineralization to measure the potential conversion of organic N into inorganic forms available for plant uptake (Anderson and Ingram 1993); (iii) soil P dynamics to measure the size of different pools with varying levels of availability, following a sequential fractionation technique (Tiessen and Moir 1993, after Hedley et al. 1982); and (iv) size-density fractionation of soil organic matter (SOM) as indicator of potential functional activity of SOM (Meijboom et al. 1995; Barrios et al. 1996).

The study on greenhouse gas fluxes included the determination of: (i) N_2O, CH_4 and CO_2 fluxes using a closed chamber technique (Rondón, 2000); (ii) Global Warming Potential using CH_4 and N_2O fluxes, and C stocks in soil and in tree biomass (IPCC 1996; IPCC 2001); and (iii) emergy evaluation that included Ecological Footprint Index and Sustainability Index (Diemont et al. 2006).

3.2 Project Insights

3.2.1 Management principles

The set of technologies responsible for the success of QSMAS can be synthesized in the form of four basic principles that contribute synergistically to the superior performance of the system: (1) No slash & burn, through the management (partial, selective, and progressive slash & prune) of natural vegetation; (2) Permanent soil cover, through the continual deposition of biomass from trees, shrubs and weeds, and through crop residues; (3) Minimal disturbance of soil, through the use of no tillage, direct seedling, and reduced soil disturbance during agronomic practices; and (4) Efficient use of fertilizer, through the appropriate application (timing, type, amount, location) of fertilizers.

3.2.2 Farmers' decision making

Since management of QSMAS is based on principles, application (mainly timing and intensity) of the practices related to them depends on the individual criteria of each farmer. PN15 staff achieved a better understanding of the decision making of farmers to execute these practices, information that was also included in the guide for the validation of the system.

3.2.3 Needs for improvement

In the reference site in Honduras, QSMAS had reached a steady state of profitability which can be threatened by significant rises on the costs of inputs (e.g. fertilizers). As a result, the evolution of the system towards intensification and/or diversification including high value market oriented fruit and vegetable crops and also integration with livestock production, is strongly suggested to reach higher profits while reducing risks and contributing to the system's sustainability. Additional sources of income for farmers practicing QSMAS could be through the payment of environmental services, given the multiple benefits that the system can generate for improving livelihoods and reducing the ecological footprint.

3.3 Data

PN15 organized databases with the primary information generated through five multidisciplinary theses studies (three of PhD, two of MSc), and the impact study. Additionally, PN15 created a database (EndNote 6.0) with secondary information on QSMAS (mainly in Spanish). Compiled additional literature regarding the project's main topics studied (water and nutrient dynamics, greenhouse gas fluxes and systems agronomy) can be found in theses databases (bibliographies).

The databases corresponding to the thesis studies will be useful for further analyses, especially for multivariate analysis integrating data from the studies on water and nutrient dynamics and greenhouse gas fluxes to generate publications for *peer reviewed* journals and book chapters; and for the modeling of QSMAS.

4 PARTNERSHIP ACHIEVEMENTS

Value added to science, outcomes and/or impact was achieved through new partnerships developed as a result of PN15 activities:

- The partnership with MIS consortium favored the capacity building of four professionals at graduate level and ten undergraduate students from the target region in Latin America, which can enhance research competitiveness of regional NARES and their eligibility as strategic partners for designing and implementing research projects in the region.
- The integrated research approach used in the project was instrumental in attracting advanced research organizations from Australia, the US and Switzerland to participate in joint research looking at the linkages between land management options in space and time, soil biodiversity and function and water quality and soil losses.
- The interaction with the CPWF Impact Assessment Project facilitated the definition of impact pathways of PN15. Additionally, support from this team allowed the execution of an additional study to evaluate the adoption of QSMAS in the reference site and the validation site in Nicaragua, and to determine the feasibility of QSMAS as an option to improve food security, agricultural profitability and environmental services under rainfed agriculture in the Andes as target regions for CPWF - Phase II (analysis of information and preparation of report in progress).
- The interaction with Theme 2 of CPWF has facilitated to explore the potential benefits of QSMAS through the payment for environmental services (PES) in Central America through a special project funded by SDC-Switzerland.
- The collaboration with the Basin Focal Projects (BFP) team of CPWF permitted to conduct the site similarity analysis and to define the extrapolation domains for the adaptation of QSMAS in other parts of the tropics with similar biophysical and socioeconomic conditions.
- The focus of the project on the characteristics of the system and its effect on landscape attracted ARIDnet Consortium to use QSMAS as a case study to test the Dryland Development Paradigm (DDP) to understand desertification/rehabilitation processes in sub-humid regions. This collaboration is documented in an article published by the journal, SCIENCE.

5 RECOMMENDATIONS

Research for development activities of PN15 indicate that QSMAS (or the application of its principles) is an option for improving the welfare of smallholders in sub-humid tropical areas. Recommendations for its improvement and dissemination in new regions include the following:

5.1 Recommendations for Research

The need for further research on Quesungual system (or on the application of the principles responsible for its agroecological performance) includes:

1. Filling knowledge gaps at system level:
   - Development of strategies to increase crop water productivity through improvement of current practices and/or intensification-diversification of production; and evaluation of alternatives to the use of herbicides and optimization of fertilization.
   - Evaluation of its resilience and profitability when integrated with livestock and fruit trees.
   - Assessment of its contribution as part of a farming system (small scale); as part of a multifunctional landscape of watersheds (large scale), including hydrological cycle.
   - Evaluation of its potential to recover degraded soils.
2. Strategies to scaling up and scaling out of QSMAS:
   - Validation-dissemination (linked to capacity building) in similar sites in the tropics.
   - Development of drought insurance linked with the use of the system.
   - Assessment of payment for environmental services (PES) at landscape level linked to the use of the system.

3. Generation of PES through improving landscape function for:
   - Services related to water
   - C sequestration and mitigation of greenhouse gas emissions
   - Soil quality and resilience (even to natural disasters)
   - Conservation of biodiversity
   - Recovery of degraded soils
   - Ecotourism

5.2 Recommendations for Extension

Key information generated by PN15 can be used to facilitate the adaptation of QSMAS (or its principles similar to conservation agriculture) in other regions. This include: (i) the application of the principles behind the successful performance of the system; (ii) the knowledge of technologies of management associated with the principles; (iii) the identification of sites where Quesungual system has possibilities to succeed (extrapolation domain analysis based on its biophysical and socioeconomic contexts in the reference site); and (iv) the experiences on QSMAS validation. Strategies may be needed for the introduction of the system where the social, economic and biophysical environment are not favorable for agroforestry based systems.

Additional considerations for the decision making on the adaptation of the system include:

- A target site: farming communities moving towards a situation of land degradation and/or vulnerability to climate change due to the extensive use of

slash and burn agriculture (but still have areas under secondary forests) or other technologies.
- A strategic partner: an institution/organization working in development and including food security as a key part of its agenda.
- A strategy enabling people to work together for mutual benefit.
- A financial mechanism for key inputs (i.e. fertilizers)
- Storage facilities and/or a market capable to sell the expected surpluses.
- A regional–national goal for improving the sustainability of agroecosystems while enhancing their functionality.

5.3 Recommendations for Policies

Policy implications for achieving wider impacts of QSMAS include enabling:
- Regional–national-local goal to protect the sustainability of agroecosystems while enhancing their functionality.
- Local agricultural and developmental extension systems.
- Incentives to communities to adopt more sustainable and environmentally friendly production practices.
- Financial mechanisms to facilitate adoption of proposed changes.
- Physical infrastructure to sustain productivity gains.
- PES.

5.4 Recommendations for Institutions

- Use of knowledge generated by PN15 of CPWF to achieve a better knowledge and understanding of Quesungual system may facilitate its evaluation as an option to improve food security under conditions of vulnerability.
- Although the management of the system must be adapted to local conditions and traditions, it must be defined around the application of its basic principles and if necessary, of other principles of conservation agriculture.
- Participatory approaches must be part of the whole process of adaptation.
- If QSMAS is going to be adapted as part of a short term project (i.e. 3 years or less), special attention must be paid to the capacity building of local organizations that can continue the effort of dissemination.
- Potential PES including environmental services from QSMAS at plot and landscape level may facilitate the adoption of QSMAS (or other variants of conservation agriculture) and the process towards a communitarian commitment for the sustainable management of natural resources. However, this requires the execution of complementary studies (mainly on water dynamics including sub-soil water) to better estimate the hydrological balance for the region.
- QSMAS may be part of a strategy towards reaching a progressive welfare, through the accomplishment of objectives at different terms. In the short term (~3 years), this may include elimination of slash and burn and/or other drivers to land degradation, initial recovery of secondary forests and biodiversity, improvement of the services related to water, and achievement of sustainable food security through productivity and resilience to climate change. In the medium term (~5 years) it may comprise diversification and linkages to markets, significant recovery of secondary forests and biodiversity, and use of the experience for replication in similar environments through the farmer-to-farmer mechanism of dissemination. In the long term (~7 years) it may include a significant dissemination and adaptation strategy, and the recognition of changes towards environmentally friendly technologies at community level through mechanisms of PES.

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Poster papers

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Appendix A

Ayarza, M.A. and L.A. Wélchez. 2004. *Drivers effecting the development and sustainability of the Quesungual Slash and Mulch Agroforestry System (QSMAS) on hillsides of Honduras*. In International Water Management Institute, Comprehensive Assessment "Bright Spots" Project, Final Report, 187-201. The Quesungual Slash and Mulch Agro-forestry System (QSMAS) is considered to be a Bright spot of improved land and water management for sub-humid hillside agroecosystems affected by severe seasonal drought periods. This system has contributed to improve livelihoods of more than 6,000 farmer households in the Lempira Department, Honduras. It is based on an improved indegenous technology that manages dispersed native trees in cropping fields through periodic pruning. Competition between plant communities is kept low while provision of plant residues for soil cover and nutrient cycling is maintained favoring soil moisture conservation and fertility maintenance. Annual crops and pastures are planted on no-burned fields with zero tillage/direct planting operations. This system has enabled farmers to increase crop yields and reduce labor inputs associated with weed control. Besides gains in crop improvement, the widespread adoption of the system is associated with strong community participation in the development and promotion of the system; the implementation of local policies to avoid use of fire for agricultural purposes; and incentives to promote the overall welfare of the community. In addition a key element in the success of QSMAS has been diversification of farming systems once household food security has been achieved. This has enable farmers to produce crop and animal products for local markets thereby generating enhanced incomes. There are a number of positive elements associated with the adoption of this improved land management system including; the acknowledgement by poor farmers of the importance in careful management of natural resources to effect improved food security and wellbeing; a longterm commitment is required by all parties for this Bright spot to develop; access to credit can also be used as a tool in promoting improved land and water management; local support systems are important to drive intensification and diversification processes; and a continuous process of facilitation and capacity building is required for the successful scaling up and out of NRM strategies. It has become evident that reduced labor availability may become factor influencing the intensification and diversification processes. Family labor is decreasing due to the greater number of children attending school and the continuous out migration of young people to the main cities in Honduras and USA. It is plausible that the QSMAS can be transferred to other regions of the world facing similar land and water resource issues and that this should be encouraged.

Baquera, N., Herrick, J.E., and M. Ayarza. 2006. *Determining vegetation coverage and changes in land use under the Quesungual slash and mulch agroforestry system.* Paper presented at the Annual Meeting for the Ecological Society of America, August 6-11, in Memphis, Tennessee. Land use throughout history has changed to suit the needs of the people, but just as the needs of the people have changed so should the methods employed to cultivate the land. As of 1985 producers in the municipality of Candelaria in the Department of Lempira in Honduras have been applying a locally developed method known as the Quesungual Slash and Mulch Agroforestry System (QSMAS). Candelaria is an area composed of slopes that commonly exceed 45 degrees, which results in high erosion rates from cultivated fields. The QSMAS is an alternative to traditional slash and burn management, which requires extensive periods of time for recovery and contributes to soil erosion. The three main characteristics that distinguish the QSMAS from other traditional methods are the elimination of annual burning to allow accumulation of crop residue, management of native trees to provide a partial canopy that encourages rapid forest regeneration during fallow, and zero tillage in order to maintain soil structure and high mulch coverage. QSMAS provides the ability to reduce the time required by land to recover under fallow, which in turn may reduce the amount of land that exceeds land degradation thresholds. An extensive amount of research has been done to understand the dynamics of the system at the plot level however; little research has analyzed the extent of adoption and the change in tree coverage due to adoption. The objectives of this project are 1) develop methodology to monitor the changes in land cover and land use through remote sensing imagery, and 2) apply these methods and ground-based measurements in a pilot study to quantify land coverage and land use in an area near the municipality of Candelaria. Preliminary analysis indicates difficulty in distinguishing parcels within the same region of Silvopastoral and those applying the QSMAS system.

Castro, A., Rivera, M. Ferreira, O., Pavón, J., García, E., Amézquita, E., Ayarza, M., Barrios, E., Rondón, M., Pauli, N., Baltodano, M.E., Mendoza B., Wélchez, L.A., Cook, S., Rubiano, J., Johnson, N., and I. Rao. *Proceedings of the Workshop on Increasing Water Productivity of Rainfed Cropping Systems* (in press). *Is the Quesungual System an option for smallholders in dry hillside agroecosystems?*. Paper presented at the Workshop on Increasing the Productivity and sustainability of Rainfed Cropping Systems of Poor, Smallholder Farmers, September 22-25, in Tamale, Ghana. The Quesungual Slash and Mulch Agroforestry System (QSMAS) is a smallholder production system with a group of technologies for the sustainable management of vegetation, water, soil and nutrient resources in drought-prone areas of hillside agroecosystems of the sub-humid tropics. QSMAS integrates local and technical knowledge and provides resource-poor farmers with an alternative to the non-sustainable, environmentally unfriendly slash and burn (SB) traditional production system. The main objective of this study was to determine the key principles behind the biophysical resilience of QSMAS and its capacity to sustain crop production and alleviate water deficits on steeper slopes with risk of soil erosion. Activities included the evaluation of QSMAS performance compared to the traditional SB system in terms of water dynamics (including crop water productivity), nutrient dynamics, and greenhouse gas fluxes (including global warming potential). Results indicate that the application of the four principles behind QSMAS productivity and sustainability (no slash-and-burn, permanent soil cover, minimal disturbance of soil, and improved fertilizer practice), has positive effects on the soil-plant-atmosphere relationships, soil quality, and on landscape and the environment. Validation in Nicaragua and Colombia underpin the potential of QSMAS to enhance support for livelihoods in vulnerable rural areas in sub-humid tropics.

Fonte, S.J., Barrios, E., and J. Six. 2008. *Earthworms, soil fertility, and organic matter dynamics in the Quesungual agroforestry system of western Honduras*. Paper presented at the Annual Meeting for the Ecological Society of America, August 3-8, in Milwaukee, Wisconsin. The Quesungual slash-and-mulch agroforestry system of western Honduras has been put forth as a sustainable alternative to traditional slash-and-burn agriculture for the tropical dry forest zones across Central America. This system forgoes burning and utilizes native tree species interspersed with annual crops to stabilize hillsides, promote soil fertility, and conserve vital soil moisture. Although this system has been readily adopted among farmers in the region, the mechanisms behind the Quesungual system's success remain poorly understood. The research presented here aims to better elucidate soil organic matter dynamics and earthworm communities in the Quesungual system via comparisons with slash-and-burn agriculture and secondary forest in a replicated field trial. The Quesungual and slash-and-burn treatments were further subdivided into plots receiving standard fertilizer applications (N-P-K) or no inorganic nutrient additions. Earthworms were hand-sorted for each of the experimental plots in July of 2007 and returned to the lab for weighing and identification. Soils were collected in both 2006 and 2007 and fractionated into macroaggregates (>250 µm), microaggregates (53-250 µm), and the silt and clay fraction (<53 µm) by wet-sieving. Macroaggregates were further separated into coarse particulate organic matter (> 250 µm), microaggregates within macroaggregates (53-250 µm), and macroaggregate-occluded silt and clay (<53 µm). All fractions and bulk soils were analyzed for total C and N, while bulk soil was additionally analyzed for available P (Olsen P). Results indicate that earthworm numbers and biomass are considerably lower under slash-and-burn agriculture than under the Quesungual system or secondary forest ($P = 0.02$ and $P = 0.03$; respectively), with the largest populations found under the fertilized Quesungual plots. For the 2006 sampling, P availability was highest in the Quesungual plots receiving inorganic fertilizer additions ($P < 0.01$), despite equivalent additions of mineral P in the fertilized slash-and-burn treatment. The influence of management on soil structure, as well as C and N distribution, appears to be less pronounced than for P and earthworm populations. Our findings thus indicate that Quesungual system receiving fertilizer additions seems to be the most advantageous for the management of soil fertility and fauna.

Pauli, N. 2008. *Environmental influences on the spatial and temporal distribution of soil macrofauna in a smallholder agriforestry system of western Honduras.* PhD diss., University of Western Australia (http://theses.library.uwa.edu.au/adt-WU2008.0142).
This thesis presents the findings of an investigation of the spatial and temporal distribution of soil macrofauna at multiple scales within smallholder agriforestry fields in a remote, mountainous area of western Honduras. Since 1990, smallholder farmers in the study area have switched from traditional slash-and-burn agriculture to a form of slash-and-mulch agroforestry based on cultivating maize, beans and sorghum amongst dispersed trees. The principal objective was to examine the influence of the slash-and-mulch agricultural system on soil macrofauna abundance, biomass and community composition, and relate soil macrofauna distribution patterns to environmental variables. The initial stage of the research comprised transect-based sampling of soil macrofauna and biophysical variables in four common land uses of the study area. All four land uses (secondary forest, young milpa (agriforestry), mature milpa, and pasture) supported abundant, diverse and heterogeneous soil macrofauna communities, with few notable differences in soil macrofauna distribution among land uses. The most abundant soil macrofauna taxa were termites, ants, earthworms and beetles. Of the 'explanatory' environmental variables that were measured (including land use and selected soil properties, vegetation characteristics and topographic variables), those that had the strongest relationships with soil macrofauna abundance were land use, tree density and soil organic matter content. The second stage of the research was spatially-orientated and used stratified sampling based on within-field differences in farmer-defined soil type, as well as grid-based sampling of soil macrofauna surface activity. There was substantial within-field variation in soil type and topography, which was related to distribution patterns of at least one agriculturally-important soil macrofauna taxon. Earthworm activity was higher in areas of fertile soil and lower slope positions. At a finer scale, there was a positive spatial correlation between tree distribution and earthworm casting activity. The final phase situated the biophysical research in the local socio-economic context through participant observation and interviews with farmers. The results of the three phases of the study were incorporated into an original conceptual model of the relationships

among soil macrofauna and environmental variables in the study area across multiple spatial scales and along a chronosequence of land use changes. Specific pointers are provided for further research on the role of soil fauna in influencing soil structure, nutrient cycling and pest species abundance, and for further investigating local knowledge and the socio-economic and cultural drivers of land use change.

Reynolds, J.F, Stafford Smith, D.M., Lambin, E.F., Turner, B.L., Mortimore, M., Batterbury, S.P.J., Downing, T.E., Dowlatabadi, H., Fernández, R.J., Herrick, J.E., Huber-Sannwald, E., Jiang, H., Leemans, R., Lynam, T., Maestre, F.T., Ayarza, M., and B. Walker. 2007. *Global Desertification: Building a Science for Dryland Development*. Science (316):847-851. In this millennium, global drylands face a myriad of problems that present tough research, management, and policy challenges. Recent advances in dryland development, however, together with the integrative approaches of global change and sustainability science, suggest that concerns about land degradation, poverty, safeguarding biodiversity, and protecting the culture of 2.5 billion people can be confronted with renewed optimism. We review recent lessons about the functioning of dryland ecosystems and the livelihood systems of their human residents and introduce a new synthetic framework, the Drylands Development Paradigm (DDP). The DDP, supported by a growing and well-documented set of tools for policy and management action, helps navigate the inherent complexity of desertification and dryland development, identifying and synthesizing those factors important to research, management, and policy communities. (**Special note:** Millions of rural poor in the subhumid and semi-arid regions of Guatemala, Honduras, Nicaragua, and El Salvador face severe food deficits and poor opportunities for generating income to improve their livelihoods. The Quesungual Slash and Mulch Agroforestry System (QAS) was developed as a development strategy to improve rural livelihoods in the Lempira Department, Honduras, and has now been adopted by more than 6000 farmer households. This alternative to slash-and-burn agriculture builds strongly on local knowledge to deliver a doubling in crop yields and cattle-stocking rates and considerable reduction in costs associated with agrochemicals and labor, as well as much improved resilience to droughts and cyclones thanks to enhanced landscape waterholding characteristics. To examine the QAS in the context of the DDP framework, an ARIDnet workshop (13 to 20 November 2005)—involving 20 natural and social scientists working in conjunction with local communities and decision-makers—conducted a systematic analysis of long-term sustainability in the Candelaria region of Lempira. An analysis of findings showed that increased rates of soil erosion associated with inappropriate management practices in southern Honduras and northern Nicaragua can push these hillside agroecosystems across hydrologic thresholds (principle 3 in Table 2, i.e., P3; P1 to P5 and ki-1 to ki-5 refer to principles 1 to 5 and key implications 1 to 5, respectively, in Table 2) when coarse-textured surface horizons are lost. Intervention costs rise nonlinearly (ki-3) for both biophysical (soil profile development) and socioeconomic reasons (more-motivated farmers emigrate in early stages of yield decline) (P1, ki-1). The QAS, based on local environmental knowledge (P5), effectively addresses the key slow biophysical variables (soil depth and forest cover) by increasing the stability over time of the fast biophysical (soil moisture availability) and socioeconomic variables (income is diversified with fuelwood and tree-crop production) (P2). The system is supported by an extensive set of government and nongovernment relationships at multiple levels (P4, ki-4). The DDP analysis, and the development of related conceptual models, helped workshop participants identify the key factors and processes addressed by the QAS (P5)).

Wélchez, L. A., Ayarza, M., Amézquita, E., Barrios, E., Rondón, M., Castro, A., Rivera, M., Rao, I., Pavón, J., Ferreira, O., Valladares D., and N. Sánchez. 2008. *No-burn agricultural zones on Honduran hillsides: Better harvests, air quality, and water availability by way of improved land management*. In: Agriculture and rural development: Sustainable land management source book, The World Bank, Washington, DC, USA, 78-82.
Hillsides are an important agro-ecosystem in the tropics and subtropics. Traditional slash-and-burn practices, widely used in the hillside areas of Central America, have been a driving force in agricultural expansion and landscape degradation. Farmers in a village called Quesungual, Honduras, developed a slash-and-mulch system and eliminated the burning. This was the origin of the Quesungual Slash-and-Mulch Agroforestry System (QSMAS). With support from the Honduran government and the Food and Agriculture Organization (FAO) of the United Nations, a process to validate the system that involved the active participation of farmers was initiated. Farmers practicing QSMAS can produce sufficient maize and beans to meet their household needs and sell the excess in local markets. In addition, innovative farmers are intensifying and diversifying this system by using vegetables and market-oriented cash crops, as well as raising livestock. QSMAS demonstrated a high degree of resilience to extreme weather events, such as the El Niño drought of 1997 and Hurricane Mitch in 1998. Permanent cover protects the soil from raindrop impact and crust formation, while minimizing surface evaporation. In addition, surface residues favor nutrient recycling, improve soil fertility, and could result in higher carbon storage in soils. The success of QSMAS is a reflection of a community based learning process in which local people and extension service providers share ideas and learn together. At the landscape level, QSMAS has contributed to the conservation of more than 40 native species of trees and shrubs. Newer QSMAS farms (two to five years old) serve as sinks for methane with low emission levels of nitrous oxide. These results help mitigate climate change.

FINAL REPORT

- **Capacity building –** please provide the details of all the capacity building activities in your project in the format given below.

Category	Name	Achievements
Bachelors students	Denis Valladares (2005)[1] Naman Sánchez (2005)[1] Marco Morales (2006)[2] Noemi Baquera (2006)[3] Mario Pineda (2006)[2] Lester M. Talley and Tomas R. Gutiérrez (2007)[4] Maynor Hernández (2007)[2] Agustina Calero (2007)[4] Geo Galbusera (2007)[5] Ursina Galbusera (2007)[5]	Determination of soil losses through erosion in the experimental plots in Honduras. Determination of biomass accumulation applying allometric equations on three species of trees of importance in secondary forests of the reference site in Honduras. Inventory of pests and diseases in maize and common bean in the experimental plots in Honduras. Comparison of vegetation coverage and land use using satellite imagery and ground truthing information in the reference site in Honduras. Determination of soil losses through erosion in the experimental plots in Honduras. Inventory of vegetation in secondary forests and determination of its potential use in the validation site in Nicaragua (joint thesis). Determination of soil losses through erosion in the experimental plots in Honduras. Edaphic classification of soils in the validation site in Nicaragua. Determination of soil losses through erosion in the validation plots in Nicaragua. Determination of the relationship between land use and water amount and quality at watershed scale in the reference site in Honduras.
Masters students	Jellin Pavon (2008)[6] Oscar Ferreira (2008)[6]	Characterization of soil physic-chemical quality and susceptibility to erosion in validation plots in Nicaragua Determination of greenhouse gases fluxes, global warming potential and emergy evaluation in the experimental plots in Honduras
PhDs	Mariela Rivera (2008)[6] Natasha Pauli (2008)[7] Aracely Castro (2009)[6] Steven Fonte (2009)[8]	Determination of water dynamics and identification of soil-plant factors for enhancing crop water productivity in the experimental plots in Honduras Determination of environmental influences on the spatial and temporal distribution of soil macrofauna in experimental plots in Honduras Determination of the dynamics of nitrogen and phosphorus in the experimental plots in Honduras Determination of the dynamics of earthworms, soil fertility, and organic matter in the experimental plots in Honduras
Post docs	NA	
NGOs	NA	
NARES	Daniel García[9] Oscar Poveda[10]	Improved capacity for the establishment and management of experimental plots, sampling and processing of samples, and on the recording of information. Improved capacity for the establishment and management of experimental plots, sampling and processing of samples, and on the recording and management of information. Improved capacity to conduct and report results from research (including participatory approaches) activities in different areas (soil water, soil quality, yields, vegetation inventory)
Farmers	**Honduras:** Lindolfo Arias, Miguel Cruz, José Lino García, Bernarda Laínez, Camilo Mejía, Juan Mejía, Juan Sibrián, Santos Vargas **Nicaragua:** Gerónimo Aguilera, Felipe Álvarez, Ismael Olivas, Ernesto Pineda , Roberto Pineda, Santos A Zúniga **Colombia:** José Lenid Gómez, Vicente Mosquera	Improved capacity for the establishment and management of experimental plots Enhanced capacity to share research activities with visitors in experimental (Honduras) and validation (Nicaragua and Colombia) plots Enhanced capacity to teach other farmers and technicians (even from other countries) to establish and manage QSMAS plots.
Scientists	Edgar Amezquita Miguel Ayarza	Gained knowledge on principles for management of agroforestry systems Quantified the livelihood and environmental benefits of QSMAS

	Edmundo Barrios Marco Rondón Idupulapati Rao	Realized the potential benefits of farmer to farmer exchange of the technologies
Others (identify)	Edwin García[11] Odvin Ayala[11]	Improved capacity for planning, establishment and management of experimental plots, sampling and processing of samples, and on the recording and management of information. Improved capacity to conduct and report results from research (including participatory approaches) activities in different areas (soil water, water quality, soil nutrients, greenhouse gas emission, yields, vegetation inventory) Improved understanding on the establishment and management of experimental plots, sampling and processing of samples, and on the recording of information.
Future needs	Edwin García[11]	Studies of MSc, with a thesis focused on the adaptation of Quesungual system to Andean regions with different elevations above the sea level, with a view on both subsistence and high value crops.

[1]National School of Forest Sciences-Honduras; [2]University of Agriculture-Honduras; [3]University of Texas-El Paso; [4] University of Agriculture-Nicaragua; [5]Swiss College of Agriculture; [8]National University of Colombia-Palmira campus; [7]University of Western Australia; [8]University of California-Davis; [9]Lempira Extension System (SEL, in Spanish); [10]Technicia of INTA-Nicaragua; [11]Technicians of CIAT-Honduras.

Data collection storage and sharing – please provide details of all data collected/acquired by your project in the format given below.

Please note that under the Project Agreement (standard clauses), that all data collected by your project is to be made freely available as an international public good. We are keen to ensure that data is shared as widely as possible both within the CPWF and to the wider community. If you want to discuss this issue please contact Mir Abdul Matin, Project Manager, Integrated data and Information System (IDIS) on m.matin@cgiar.org

Please send all data collected/acquired by your project in CD/DVD and provide description in the format given below. If you don't have data on any of the types mentioned below, leave it blank. In case of data collected on any types not mentioned please add the type and use similar format (e.g title, country, basin, time period, data source, use/distribution restriction, file name etc.) Please add any supplementary/additional comment you would like to mention on any data set. You will be contacted by IDIS in case any further clarification is required on any of the supplied data set.

1. Secondary data

1.1 Time series data on water and climate:

Title of the data set	Country[1]	Basin	Number of station	Time period (From–To)	Data source	Restriction of distribution /use	Data files (Names of files) *
Water and climate							
Climatic variables	Hon	Lempa River UW	N/A	2006-07	Weather stations	No	Weather_stations-Hon.xls
Crop water productivity	Hon	Lempa River UW[2]	N/A	2007	Experimental plots (Thesis M. Rivera)	No	Crop_productivity-Hon.xls
Erosion susceptibility and water quality	Hon	Lempa River UW	N/A	2005-07	Experimental plots (Thesis M. Rivera)	No	Erosion-Hon.xls
Evapotranspiration	Hon	Lempa River UW	1, 2 & 3	2006-07	Experimental plots (Thesis M. Rivera)	No	Evapotranspiration-Hon.xls
Biophysical characterization and yields							
Soil physical and chemical characterization, soil moisture and hydraulic conductivity	Hon	Lempa River UW	N/A	2005-07	Experimental plots (Thesis M Rivera)	No	Soil-Hon.xls
Nitrogen, phosphorus and soil organic matter dynamics	Hon	Lempa River UW	N/A	2005-07	Experimental plots (Thesis A. Castro)	No	Nutrient_dynamics_N_P_SOM-Hon.xls
Litter accumulation and decomposition, and nutrient release	Hon	Lempa River UW	N/A	2005-07	Experimental plots (Thesis A. Castro)	No	Litter_dynamics-Hon.xls
Greenhouse gas fluxes	Hon	Lempa River UW	N/A	2005-06	Experimental plots (Thesis O. Ferreira)	No	Greenhouse_gas-Hon.xls
Soil physical and chemical characterization, vegetation inventory, edaphic characterization and grain yields	Nic	Calico Watershed	N/A	2005 & 2007	Experimental plots (Thesis J. Pavón)	No	Soil_Yield-Nic.xls
Soil physical & chemical characterization, vegetation inventory and grain yields	Col	Cauca River UC	N/A	2007	Experimental plots	No	Soil_Yield-Col.xls
Soil macrofauna (SM)							
SM & land use and season variables	Hon	Lempa River UW	N/A	2004	Different land use systems (Thesis N. Pauli)	Yes[3]	PAULI_Ch2_data.xls.
SM & landscape variables	Hon	Lempa River UW	N/A	2004	Different land use systems	Yes	PAULI_Ch3_data.xls

					(Thesis N. Pauli)		
SM activity & landscape variables	Hon	Lempa River UW	N/A	2005	Different land use systems (Thesis N. Pauli)	Yes	PAULI_Ch4_data.xls
SM activity & fertility	Hon	Lempa River UW	N/A	2005	Different land use systems (Thesis N. Pauli)	Yes	PAULI_Ch5_data.xls
Farmers perceptions on soil, environment and macrofauna	Hon	Lempa River UW	N/A	2004	Different land use systems (Thesis N. Pauli)	Yes	PAULI_Ch6_interviewdatamatrix.xls
Socioeconomic benefits of QSMAS							
Impact of QSMAS in the Reference Site	Hon	Lempa River UW	N/A	2007	Survey	No	QSMAS-Soioeconomic_Hon.xls
Publications on QSMAS							
Literature on QSMAS	Hon	Lempa River UW	N/A	1996 to 2008	FAO, CIAT, MIS Consortium, ARIDnet Consortium, Soil Management CRSP	No	QSMAS_literature.enl

[1] Country: Hon= Honduras; Nic= Nicaragua; Col= Colombia
[2] Lempa River UW= Lempa River Upper Watershed; Calico Watershed= Calico (Rio Negro) Watershed; Cauca River UC= Cauca River Upper Catchment
[3] Permission from Natasha Pauli (natasha_pauli@yahoo.com.au , npauli@graduate.uwa.edu.au) is required.

* Data files should contain station wise time series data, list of stations with station name, station id (if applicable), country, state, district and geographic position of stations (x,y,z)

Example: Daily stream flow/Monthly average rainfall

1.2 Statistical data on socio-economy, demography, agriculture, water, climate and environment

Title of the data set	Country	Basin	Number of location	Time period	Data source	Restriction of distribution/use	Data files (Names of files)*

*Data files should include actual data, list of locations including (country, state, districts…), field descriptions including name, unit of measurement, code lists (if contains coded value)

Example: District wise population by age group / State wise crop production and yield by crops

1.3 Base GIS data on administrative boundary, transportation, hydrography, infrastructure, soil, land use, topography)

Layer name	Description	Geographic coverage	Format (vector, raster)	Feature type (polygon, line, point)	Data source	Source scale	Data provider (name address, e-mail)	Restriction of distribution/use	Data files (names of files)*

*Data files should include geometry file, projection file, description of field including name, unit of measurement, code list (if coded).

Example: District boundary of China / Detailed soil type

1.4 GIS data on socio economic, demography, water, agriculture, climate, land, environment and disaster)

Layer name	Description	Geographic coverage	Format (vector, raster)	Feature type (polygon, line, point)	Data source	Source scale	Data provider (name address, e-mail)	Restriction of distribution/use	Data files (names of files)*

*Data files should include geometry file, projection file, description of field including name, unit of measurement, code list (if coded).

Example: District wise population density map / Crop suitability map

1.5 Satellite image

Title	Geographic coverage	Type of satellite	Resolution	Time period	Data source	Restriction of distribution/use	File names

2. Processed data

List any manipulated data processed under your project (e.g. Land use map generated from satellite images, projected yield and production, interpolated rain fall etc.)

Data set title: Extrapolation domain analysis of QSMAS
Description: Maps, tables and figures projecting sites (regions and countries) were QSMAS can be adapted based on similarities with the reference site in Honduras
Purpose: Identify regions where QSMAS has possibilities to be adopted to improve rural welfare.
Geographic coverage (country, basin): Pan tropical world
Resolution (in case of raster data):
Original data used: Biophysical and socioeconomic variables from the reference site and the pan tropical world
Process description (process used for manipulation): Analysis using the Homologue model (Jones et al. 2005) and Bayesian predictive modelling using Weights of Evidence (WofE).
Access/use restriction: Yes (permission from J. Rubiano is required)
Data file name: To be provided by Jorge Rubiano (CPWF-BFP staff)

3. Primary data

For each survey include the following:

Title of the survey: Identification of socioeconomic benefits from the use of Quesungual system in Honduras (in Spanish)
Objective of the survey: To evaluate the socioeconomic effects of QSMAS on families that have adopted the system and to identify associated changes on their wellbeing.
Time period: Oct. 2007
Location (country, area): Candelaria, Honduras
Method of data collection: Survey
Number of samples: 50 smallholders
File names (Data files, questionnaire, list of survey location, supplementary information*) QSMAS-Soioeconomic_Hon.doc (survey) and QSMAS-Soioeconomic_Hon.xls (database)

Supplementary information includes code sheets, field description including name, unit of measurement, reference to questionnaire section, code list (if coded)

4. IP Audit Compliance

Please specify the IP audit compliance with the data described in section 1,2 and 3. Add the data item included in the IP audit document in the following table with corresponding SL of data.

Description of Third Party IP – what is it?	Source of Third Party IP – where did it come from?	Owner of Third Party IP – who's owns it?	IP Rights Owned by Third Party – what kind of IP rights does the owner have?	Status of Third Party IP Rights – do you have a legal right to use it?	SL (add the SL used to describe the data set in section 1,2,3)

- **Student Thesis** – please provide details of student thesis work accomplished through your project – for both completed and forthcoming work.

Type	Title	Published / Expected Date	Authors
PhD. Thesis	Environmental influences on the spatial and temporal distribution of soil macrofauna in a smallholder agriforestry system of western Honduras	Feb. 2008	Natasha Pauli[1]
PhD. Thesis	Determination of the water dynamics in Quesungual agroforestry system and identification of soil-plant factors for the improvement of crop-water productivity	Dec. 2008	Mariela Rivera[2]
PhD. Thesis	Dynamics of nitrogen and phosphorus in Quesungual Slash and Mulch Agroforestry System	Jul. 2009	Aracely Castro[2]
PhD. Thesis		Jul. 2009	Steven Fonte[3]
MSc. Thesis	Greenhouse gases fluxes, global warming potential and emergy evaluation of Quesungual agroforestry system in southern Lempira, Honduras	Apr. 2008	Oscar Ferreira[2]
MSc. Thesis	Application of the principles of Quesungual slash-and-mulch agroforestry system in Nicaragua: characterization of soil physical and chemical characteristics and susceptibility to erosion in La Danta, Somotillo	May. 2008	Jellin Pavón[2]
BS. Thesis	Influence of Quesungual Agroforestry System on erosion and water quality	Dec. 2005	Denis Valladares[4]
BS Thesis	Accumulation of aerial biomass and nutrient concentration in three broad leaf species of Quesungual system	Dec. 2005	Namán Sánchez[4]
BS. Thesis	Floristic study of forest species and its potential use for the establishment of the Quesungual Agroforestry System in La Danta watershed, Somotillo, Chinandega	Feb. 2006	Lester M. Talley and Tomas R. Gutiérrez[5] (joint thesis)
BS Thesis	Determination of vegetation coverage and changes in land use under the Quesungual system	Dec. 2006	Noemi Baquera[6]
BS Thesis	Characterization of the density population of insect pests and diseases in Quesungual Agroforestry System (SAQ)	Dec 2006	Marco Morales[7]
BS Thesis	Influence of Quesungual Agroforestry System on erosion and water quality	Dec 2006	Mario Pineda[7]
BS Thesis	Influence of Quesungual Agroforestry System on erosion and water quality	Dec 2007	Maynor Hernández[7]
BS Thesis		Dec. 2007	Geo Galbusera[8]
Internship Report (p. 18).	Water production and quality at watershed level: comparison of three land uses – Quesungual agroforestry system, silvopastoril system and secondary forest– in Lempira, Honduras.	Dec. 2007	Ursina Galbusera[8]
BS. Thesis	Detailed study of soils on hillside areas based on toposequences in the watershed La Danta, Somotillo, Chinandega	Jun. 2008	Agustina Calero[5]

[1]University of Western Australia; [2]National University of Colombia-Palmira campus; [3]University of California-Davis; [4]National School of Forest Sciences-Honduras; [5]University of Agriculture-Nicaragua; [6]University of Texas-El Paso; [7]University of Agriculture-Honduras; [8]Swiss College of Agriculture.

Communication Activities – please provide details of all communication activities in the format given below.

Type	Where held	When held	Who aimed at	Outcome
Project Management Meetings				
Planning meeting	Managua, Nicaragua	Nov. 2004	MIS partners in Nicaragua	Definition of Somotillo as validation site in Nicaragua and definition of experimental procedures
Planning meeting	Santa Lucía, Honduras	Feb. 2005	MIS partners	Definition of research activities, protocols and methodologies
Planning meeting	Managua, Nicaragua	Nov. 2005	MIS partners in Nicaragua	Work plan for validation
Planning meeting	Palmira, Colombia	Nov. 2005	Scientists and students of PN15 at CIAT	Work plans for thesis studies
Planning meeting	Palmira, Colombia	Jul. 2007	Theme 2 team and scientists and staff of PN15 at CIAT	Definition of products expected from the assessment of payment for environmental services
Planning meeting	Palmira, Colombia	Jul. 2007	CIPASLA and PN15 staff at CIAT	Agreement for collaboration on the validation of QSMAS in Colombia
Planning meeting	Palmira, Colombia	Sep. 2007	PN15 staff at CIAT	Management of validation plots of QSMAS in Colombia
Planning meeting	Palmira, Colombia	Oct. 2007	PN15 staff at CIAT	IDEM
Planning meeting	Palmira, Colombia	Nov. 2007	PN15 staff at CIAT	IDEM
Planning meeting	Palmira, Colombia	Jan. 2008	PN15 staff at CIAT	Harvest in validation plots in Colombia
National Seminars / Conference / Workshops				
Workshop on the validation of NuMaSS software (	La Ceiba, Honduras	May. 2006	PN15 staff collaborating with the validation of NuMaSS	Plan for the management of trials
XIII Colombian Congress of Soil Science	Bogota, Colombia	Oct. 2006	Scientists, academic community, representatives of government and the private sector with interest in the areas	Plans and preliminary results shared and discussed with stakeholders
91st Ecological Society of America (ESA) Annual Meeting		Aug. 2006	Scientific and academic community	Shared knowledge generated by N. Baquera's thesis
Workshop on the validation of NuMaSS software	Yojoa Lake, Honduras	May. 2007	Farmers, technicians of local institutions and local government authorities	Update of results and planning for future activities

Type	Where held	When held	Who aimed at	Outcome
93rd ESA Annual Meeting	Wisconsin, USA	Aug. 2008	Scientific and academic community	Shared knowledge generated by S. Fonte's thesis
XIV Colombian Soil Science Congress	Villavicencio, Colombia	Oct. 2008	Scientists, academic community, representatives of government and the private sector with interest in the areas	Results shared and discussed with stakeholders
Regional Seminars / Conference / Workshops				
2nd Workshop of the CPWF	Nairobi, Kenya	2005	CPWF community	Plans and preliminary results shared
1st Annual Workshop of the MIS partners working on Quesungual System	Santa Lucía, Honduras	Feb. 2005	Scientists, technicians and students participating in PN15	IDEM
LI Annual Meeting of the Central American Cooperative Program for the Improvement of Crops and Livestock (PCCMCA)	Panama, Panama	May. 2005	Researchers from Central America	IDEM
2nd Annual Workshop of the MIS partners working on Quesungual System	León, Nicaragua	Feb. 2006	Scientists, technicians and students participating in PN15	Progress (activities, preliminary results of research and validation) shared with partners, and budget for execution of the on-going / pending activities planned.
IV meeting RUPSUR, climatic variability and change	Cali, Colombia	Nov. 2006		Shared knowledge generated by O. Ferreira's thesis
LIII Annual Meeting of the Central American Cooperative Program for the Improvement of Crops and Livestock (PCCMCA)	Antigua Guatemala, Guatemala	Apr. 2007	Scientific community in the Central American region	Shared knowledge of QSMAS system and benefits and of PN15 research activities and results
3rd Annual Workshop of the MIS partners working on Quesungual System	Yojoa Lake, Honduras	Jun. 2007	Scientists, technicians and students participating in PN15	Progress (activities, preliminary results of research and validation) shared with partners, gaps to deliver the expected outputs identified, and budget for execution of the on-going/pending activities planned.
1st Regional Meeting of farmers practicing QSMAS	Somotillo, Nicaragua	Aug 2-3. 2007	Farmers and technicians participating in the project; and farmers and technicians in suitable areas for QSMAS	Exchange of knowledge, experiences and opinions on the management and results obtained to date.
Andean Forum on Water and Food	Bogota, Colombia	Jan. 2008	CPWF community,	Shared knowledge

Type	Where held	When held	Who aimed at	Outcome
			and other stakeholders	of QSMAS system and benefits and of PN15 research activities and results
Andean Panorama on Water Environmental Services	Manizales, Colombia	Feb. 2009	CPWF community, stakeholders in the Andean region	Knowledge on advances on knowledge, actions and policies on the payment for environmental services
Quesungual System forum on salutation to the World Food Day	Managua and Leon, Nicaragua	Apr. 2009	Academic community of the UNA-Nicaragua, NGOs in Nicaragua, farmers and technicians participating in PN15	Shared knowledge of QSMAS system and benefits and of PN15 research activities and results
International Seminars / Conference / Workshops				
IV Forum Africa-Latin America of Intraregional Cooperation on Combat to Desertification	Tunisia	Nov. 2004	Researchers from Africa and Latin America	Socialization of QSMAS in African countries
International Symposium of Land Degradation and Diversification	Uberlandia, Brazil	May. 2005	Researchers from all over the World	Socialization of QSMAS
CPWF Knowledge Sharing Week	Colombia, Sri-Lanka	Aug. 2005	CPWF community	Exchange of knowledge and experiences
18th World Congress of Soil Science	Philadelphia, USA	Jul. 2006	Scientific community on soils	PN15 activities and preliminary results shared with the SSS community
Impact pathways (CPWF) workshop	Palmira, Colombia	Oct. 2006	CPWF community in the Andean Region	Knowledge shared and discussed with stakeholders
1st International Forum on Water and Food	Vientiane, Lao PDR	Nov. 2006	CPWF community	PN15 plans and preliminary results shared
XVII Latin-American Congress of Soil Science	Guanajuato, Mexico	Sep. 2007	Researchers from Latin America	IDEM
Annual Conference of the North-South Centre of the ETH Zurich and EAWAG on: Water for development: Prospects for integrated water resources management.	Zürich, Switzerland	Jun. 2008	Researchers from all over the World	IDEM
Workshop on "Increasing Water Productivity of Rainfed Cropping Systems"	Tamale, Ghana	Sep. 2008	CPWF community	PN15 main results shared with CPWF community
2nd International Forum on Water and Food	Ethiopia	Nov. 2008	CPWF community	IDEM
World Water Week	Stockholm, Sweden	Aug. 2009	Scientific community working on water for food	PN15 main results will be shared
Farmer Group Meetings / Workshops / Training Sessions / Demonstrations				
Local indicators of soil quality	Candelaria, Honduras	Oct. 2004	Local farmers of the reference site and PN15 staff	Knowledge of local indicators of soil quality
Farmer-to-farmer exchange of experiences	Candelaria, Honduras	Apr. 2005	Farmers and technicians from	Plan to validate QSMAS in

Type	Where held	When held	Who aimed at	Outcome
			Honduras and Nicaragua	Nicaragua
Planning meeting	Somotillo, Nicaragua	May. 2005	Farmers from San Dionisio and Somoto, Nicaragua	Plan of activities to establish demonstration plots of SAQ
Demonstration of establishment and management practices by Honduran farmers in validation plots in Nicaragua	Somotillo, Nicaragua	May. 2005	Farmers from Honduras and validating QSMAS in Nicaragua	Practical demonstration of tree pruning and management of mulch
Land degradation workshop http://www.biology.duke.edu/aridnet/ wkshop_quesungual/quesungual_home.html	Lempira, Honduras	Nov. 2005	Scientists and students of ARIDnet consortium and PN15	Analysis of dynamics behind QSMAS adoption and of the system as an option to mitigate desertification
Meeting with farmers to plan activities	Candelaria, Honduras	Apr. 2005	Farmers and technicians participating in the project	Plan of activities
Meeting with farmers to plan activities	Candelaria, Honduras	Apr. 2006	Farmers and technicians participating in the project	IDEM
Meeting with farmers to plan activities	Candelaria, Honduras	May. 2007	Farmers, technicians and students participating in the project	Update of results and planning for pending activities
Meeting with farmers to present final results on PN15 and validation of NuMaSS	Candelaria, Honduras	Dec. 2007	Farmers and technicians participating in the project	Main results synthesized and shared and discussed with stakeholders
Workshop on land degradation in soils of semiarid regions of America: the case of Coquimbo http://www.biology.duke.edu/aridnet/ wkshop_chile/chile_program.htm and http://www.slideshare.net/pabloneco/el-drylands-development-paradigm-y-la-prov-del-limar-presentation	Limari, Chile	Sep. 2008	Scientists from South America and ARIDnet consortium	Sharing of the Dryland Development Paradigm analysis on QSMAS
Field Visits to Project Partners				
Interviews with farmers to compile information for the evaluation of the socioeconomic impact	Candelaria, Honduras	Apr. 2007	Local authorities, farmers, householders and PN15 staff and collaborators in Central America	Preliminary information to confirm secondary data and the design of surveys to be applied
Field visit to experimental plots	Candelaria, Honduras	Jun. 2007	Staff from FAO and the Netherlands Partnership Programme (FNPP) project “Forests and Climate Change in Central America”	Sharing of the system principles and benefits derived from it’s use, and of research activities and relevant results
Field visit to experimental plots	Candelaria, Honduras	Jun. 2007	PN15 scientists and students	Review of research advances

Type	Where held	When held	Who aimed at	Outcome
				and pending activities and corresponding plan of action.
Field visit to experimental plots	Candelaria, Honduras	Jul. 2007	Drs. Urs Scheidegger and Sandra Contzen (Swiss College of Agriculture)	Review of research activities (U. Galbusera) and identification of additional studies.
Field visit to plots for the validation of NuMaSS	Candelaria, Honduras	Jul. 2007	Authorities and farmers of Guarita municipality, southern Lempira, Honduras	Activities on fertilization synthesized and shared
Field visit to experimental plots	Candelaria, Honduras	Aug. 2007	Authorities and farmers of La Unión municipality, southern Lempira, Honduras	Sharing of the system principles and benefits derived from it's use, and of research activities and relevant results
Field visit to experimental plots	Candelaria, Honduras	Aug. 2007	Authorities and students of ESNACIFOR, Honduras	IDEM
Field visit to validation sites in Colombia	Cauca, Colombia	Feb. 2008	E. Humphreys and A. Huber-Lee (CPWF theme leaders), A.C. Castro (CONDESAN), N. Pauli (Univ. of Western Australia), R. Vivas and C. Benavides (CIPASLA), PN15 at CIAT and local collaborators	Knowledge of QSMAS system and review of validation activities.
Field visit to production plots	Candelaria, Honduras	Apr. 2008	FAO projects in Honduras	Sharing of QSMAS principles and benefits derived from it's use, and of research activities and relevant results
Field visit to production plots	Candelaria, Honduras	May. 2008	FAO, UNCCD, FIDA	IDEM
Field visit to production plots	Candelaria, Honduras	Sep. 2008	PINCHES and CARE, Nicaragua	IDEM
Other Key Communication Activities				
Meeting with authorities of the Reference Site	Candelaria, Honduras	2004	Local authorities	Explanation of activities to be conducted by PN15
Annual Meeting – MIS consortium	León, Nicaragua	Feb. 2006	Consortium partners	Share advances and planning of activities
World Food Day	Candelaria, Honduras	Oct. 2006	Community of the reference site	Sharing of activities and

Type	Where held	When held	Who aimed at	Outcome
				results
Meeting	Palmira, Colombia	Oct. 2006	S.Cook (CPWF-BFP Coordinator) and t. Oberthür (Land Use Project Coordinator)	Sharing knowledge on QSMAS and of PN15 activities and results
Science Council at CIAT	Palmira, Colombia	Oct. 2006	CIAT community	Sharing of activities and results
Annual Review Meeting of the FAO - Lempira's Extension System	Tegucigalpa, Honduras	Dec. 2006	FAO officers and technicians	Sharing of activities and results
Meetings with local collaborators on the validation of the NuMaSS	Candelaria, Honduras	Mar. & May. 2007	Authorities and farmers collaborating with the validation of NuMaSS	Update of activities and planning for the execution of research activities
External Program and Management Review (EPMR) – CIAT and 1st CIAT's Knowledge Sharing Week	Palmira, Colombia	May. 2007	Scientific community of CIAT	Sharing knowledge on QSMAS and of PN15 activities and results
Workshop to define outputs to include in a proposal to be prepared by FAO-Honduras in a new project for the development of the Lempira region	Intibucá, Honduras	May. 2007	Technicians of FAO, local government authorities, representatives of government institutions	Sharing of research activities and impact of QSMAS
Presentation of the Report: "Analysis of the process of rural development in the south of Lempira using the DDP conceptual model of desertification: study of Quesungual case"	Tegucigalpa, Honduras	Jun. 2007	Mr. Mateo Molina (Officer IBD), policy makers, technicians and academic community from local universities	Sharing of findings on the sustainability of QSMAS and its potential use to recover degraded areas
Presentation of research results to authorities of municipalities in the southern region of Lempira	Candelaria, Honduras	Jul. 2007	Local authorities and farmers	IDEM
Meeting with students and authorities of the ITC-Candelaria	Candelaria, Honduras	Aug. 2007	40 students and professors of the local high school	Shared knowledge generated by U. Galbusera's study
Presentation of research results to evaluator of FAO-Lempira Extension Service	Candelaria, Honduras	Oct. 2007	Local authorities and farmers	Sharing knowledge on QSMAS and of PN15 activities and results
Presentation of the impact analysis	Candelaria, Honduras	Nov. 2007	Local authorities, technicians and farmers	Validation of results from the impact study as result of QSMAS adoption
Presentation of recommendation of fertilization based on the validation of NuMaSS software	Candelaria, Honduras	Nov. 2007	Local authorities, technicians and farmers	Recommendation to improve efficiency on the use of fertilizers
Presentation of a summary of the background and advances of the project	CIAT HQ, Palmira, Colombia	Nov. 15th. 2007	Dr. Maarten de Groot, Water and Environment Regional Specialist, Program Support Unit – CIDA/ACDI,	Interest of Canadian institution for the dissemination of QSMAS in other regions of

Type	Where held	When held	Who aimed at	Outcome
			and Dr. Axel Schmidt, Regional Coordinator of CIAT for Central America and the Caribbean	Honduras
Set of slides with highlights of QSMAS Set of slides on PN15-QSMAS	Mozambique, Africa Rome, Italy	Dec. 3-7. 2007 Feb 2008	Participants – AGM of CGIAR Prepared for presentation of Dr. A. Huber-Lee to the CPWF Steering Committee	Knowledge of QSMAS system and benefits IDEM
Visit A. Castro (PhD student) to target areas of PN11 in Lao PDR and Vietnam, including presentations summarizing QSMAS contexts and benefits and advances on research of PN15 (Travel Grant funded by CPWF-Theme 1).	Target sites of PN11 in Lao PDR and Vietnam	Feb. 2008	CPWF-PN11 staff and national collaborators (three researchers of Lao PDR and more than 20 in Vietnam)	Trip report and a paper for the CPWF bi-monthly Newsletter Edition 27, Aug/Sept 2008
2nd CIAT's Knowledge Sharing Week	Palmira, Colombia	May. 2008	Scientific community of CIAT	Sharing knowledge on QSMAS and of PN15 activities and results
Presentation of results of research activities (lead by UC-Davis)	Candelaria, Honduras	Sep. 2008	Local authorities, professors, technicians and farmers	Sharing of results from the studies on water and nutrients dynamics and greenhouse gas fluxes
3rd CIAT's Knowledge Sharing Week	Palmira, Colombia	May. 2009	Scientific community of CIAT	Sharing knowledge on QSMAS and of PN15 activities and results
Presentation of research methodologies and results at the UNAL-Palmira	Palmira, Colombia	Nov. 2005 Jun. & Nov. 2006 Jun. & Nov. 2007	Scientists, professors, and students involved in the project	Sharing knowledge on QSMAS and of thesis activities and results
Videos / DVDs / Plays / Songs / Oral Material Produced / Newspaper Articles / Radio Presentations / Television				
MIS Consortium Informative Bulletin (No. 1)	N/A	Jan. 2005	MIS community and partners	Sharing activities and results
MIS Consortium Informative Bulletin (No. 2)	N/A	Jan. 2005	MIS community and partners	Sharing activities and results
MIS Consortium Informative Bulletin (No. 3)	N/A	Mar. 2006	MIS community and partners	IDEM
MIS Consortium Informative Bulletin (No. 7 and 8)	N/A	Jun. 2007	MIS community and partners	IDEM
CPWF bi-monthly newsletter readers	N/A	Aug-Sep. 2007	MIS community and partners	IDEM
CPWF bi-monthly newsletter readers	N/A	Aug-Sep. 2008	MIS community and partners	IDEM
Television (reporters from BBC-London)	Lempira, Honduras	Feb. 21. 2007	General public	Dissemination of research activities and impact of QSMAS
Video – 1st Workshop of farmers practicing QSMAS in Honduras and Nicaragua (Network of Communicators from	Somotillo, Nicaragua	Aug. 2007	Population of Candelaria, farmers and technicians in	Recording of the exchange of experiences and

Type	Where held	When held	Who aimed at	Outcome
Candelaria, Honduras)			suitable areas for QSMAS	opinions on the management and results obtained, and of interviews with farmers
"Agriculture, Transformation and Business" (technical-scientific publication of the College of Agronomists of Honduras).	Tegucigalpa, Honduras	Apr. 2008	College of Agronomists of Honduras	Dissemination of research activities and impact of QSMAS

FINAL REPORT

- **Status of expenditure and receipts to date (US$)** - please provide your final expenditure status in the format given below. Note: there are 3 tables a) Expenditures , b) Receipts and c) Matching Funds. <u>In addition to this information an audited statement of expenditure will be required.</u>

a) Expenditures

				COST IN US DOLLARS		
Pro	Budget Item Code			TOTAL BUDGET	EXPENDITURES TO DATE	BALANCE AVAILABLE
	CONTRIBUTED FUNDS					
	1	MATCHING FUNDS		754,800	754,800	-
	RESOURCES REQUESTED FROM THE CHALLENGE PROGRAM ON WATER AND FOOD					
	2	PERSONNEL RENUMERATIONS, TRAVEL AND ACCOMODATION				
	2.1		PERSONNEL COSTS			
	2.1.1		Project Leader	87,592	86,993	599
	2.1.2		Principal investigators (International)	-	-	-
	2.1.3		Principal investigators (National)	-	-	-
	2.1.4		Consultants	-	-	-
	2.1.5		Support Staff	72,973	74,400	(1,427)
	2.2		TRAVEL AND ACCOMODATION			
	2.2.1		Project Leader	11,435	12,729	(1,294)
	2.2.2		Principal investigators (International)	12,000	11,621	379
	2.2.3		Principal investigators (National)	-	-	-
	2.2.4		Consultants & Support Staff	17,866	15,719	2,147
	2.2.5		Other project participants	-	-	-
	3	RESEARCH OPERATIONAL COSTS				
	3.1		EQUIPMENTS			
	3.1.1		Office equipment	2,181	2,181	-
	3.1.2		Laboratory equipment	5,732	5,734	(2)
	3.1.3		Field equipment	8,143	8,141	2
	3.1.4		Other equipment	1,767	1,767	-
	3.2		COMMUNICATION COSTS AND CONSUMABLES			
	3.2.1		Communication expenses	10,800	10,715	85
	3.2.2		Office supplies	14,200	14,624	(424)
	3.2.3		Laboratory supplies	48,508	48,509	(1)
	3.2.4		Field research supplies	39,100	39,244	(144)
	3.2.5		Other services (please specify)	69,779	70,310	(531)
			Freight Services			
			Contract Service Labour			
			Service Telephone and Fax			
			Repair and Maintenance Including Cars			
			Rent Services			
			Publication/Reports			
			Mail/Postage Services			
			Notary Services			
			Email and Internet			
			Life Insurance			
			Vehicle Obligatory Insurance			
			Bank Fees			
			Photocopies/Duplications			
			Cleaning Service			
			Official Vehicle			
			Water/Sewerage System			
			Services and Data Management Services			
		TOTAL OF 2 & 3		402,076	402,687	(611)
	4	MISCELLANEOUS				
	4.1		CONTINGENCY (3%)	15,000	15,206	(206)
	4.2		OVERHEADS	88,640	88,510	130
	4.3		Others (please specify)	249,084	248,397	687
			Support to Partners			
		TOTAL REQUESTED FROM THE CPWF		352,724	352,113	611
	GRAND TOTAL			754,800	754,800	-

b) Receipts

1	Total project budget (a)		$754,800
2	1st tranche payment received	$51,453	
	2nd tranche payment received	$77,181	
	3rd tranche payment received	$128,633	
	4th tranche payment received	$123,133	
	5th tranche payment received	$123,134	
	6th tranche payment received	$14,585	
	7th tranche payment received	$118,341	
	8th tranche payment received	$94,672	
3	Total funds received to date (b)		$731,132
4	Balance of budget remaining (a - b)		$23,668

c) Matching Funds

Name of Institute	Type of support	Amount (if applicable)	Is this as agreed, or are there deviations	Was there any risk to the project if a deviation
IWMI		$731,132		

11. CPWF ASSESSMENTS *

Assessment *	Basin Coordinator				Theme Leader			
	1	2	3	X	1	2	3	X
Did the Project contribute quality outputs towards Basin and Theme priorities?								
Have you verified the progress and dissemination reported?								
Did the Project work according to its plan?								
Did the Project sufficiently focus on CPWF objectives?								
Did the Project demonstrate a new research approach in the spirit of CPWF?								
Were provisions for stakeholder and end user involvement adequate?								
Were provisions for addressing gender issues adequate?								
Were provisions for addressing environmental issues adequate?								

* Assessment: (1) Good: a high standard of work; (2) Adequate: an acceptable standard of work, but improvements are possible; (3) Inadequate: this aspect of the project is not up to standard and must be improved; (X) Not known.

RECOMMENDATION TO CPWF SECRETARIAT: SATISFACTORY / UNSATISFACTORY / TERMINATE

Feedback Comments from the Theme Leader to be provided to the Project Leader.
Feedback Comments from the Basin Coordinator to be provided to the Project Leader.

Note: the space available here for comments is not meant to be restrictive – use as much space as necessary