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Changing human–ecological relationships and drivers using the Quesungual agroforestry system in western Honduras

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Abstract

Development of sustainable agricultural production systems in the tropics is challenging in part because the local and external conditions that affect sustainability are constantly in flux. The Quesungual agroforestry system (QSMAS) was developed in response to these changing conditions. The history and potential future of the QSMAS provide an opportunity to consider the factors affecting small-scale agricultural production systems on marginal lands throughout the world. We evaluated the QSMAS in Honduras in the context of the five principles of the Drylands Development Paradigm (DDP) during three periods: pre-QSMAS, QSMAS adoption and the future. The first two periods provided lessons that could be relevant to other regions. The QSMAS system in Honduras must continue to evolve, if long-term benefits are to be realized. We conclude that while the DDP was a useful framework for systematically identifying the critical drivers and processes determining the sustainability of QSMAS in Honduras, it is ultimately no more able to predict the future than the collective knowledge of those who choose to apply it. The DDP, however, can facilitate the integration and application of knowledge.

Key words: agroforestry, Quesungual, QSMAS, Drylands Development Paradigm, DDP, Honduras, sustainability, interdisciplinary

Introduction

Population growth and agricultural frontier expansion using slash-and-burn practices in the forested hillsides of subtropical to tropical areas have resulted in extensive reduction of forest cover, and increased runoff and soil erosion throughout the world and especially in Central America[1–4]. The resulting loss of soil productivity and biodiversity has exacerbated rural poverty, particularly in steepland areas that make up 78% of the total area of Central America[5]. For the past 25 years, reversing land

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degradation and increasing agricultural output have been a priority of numerous research and development projects. These efforts, while well-intentioned, have been mostly ineffective because of incomplete, poor understanding of the complex interactions between social, ecological, institutional, economic and policy factors that lead to land degradation and limit recovery[6].

The Quesungual agroforestry system (QSMAS) has been adopted since 1992 by thousands of farmers and helped many of the poorer farmers in the hillside region of Lempira, Honduras to achieve food security, while improving soil and water conservation[7]. This slash and mulch-based system combines selective thinning and pruning of native tropical forest vegetation with planting of annual crops (maize, sorghum and beans) and/or improved grasses with no burning, zero tillage/direct planting and spot fertilization. Compared to slash-and-burn, this system maintains permanent soil cover improving soil and water conservation. Since farmers use different criteria for selecting specific trees to thin and/or retain, the widespread adoption of the QSMAS system has resulted in a diverse landscape mosaic of tree cover. This helps conserve the deciduous tropical forest, which is often cited as one of the most highly threatened ecosystems in the world, now covering a small fraction of the area it dominated prior to European colonization[8]. Farmers in other regions of Latin America also practice variations of slash-and-mulch, including some in high-rainfall areas of Ecuador's Amazon Basin[9] and Costa Rica[10].

The widespread adoption of the QSMAS has been driven by observed increases in crop yields associated with the moderate use of fertilizers, better crop varieties, improved soil water availability[11] and significant reduction in costs associated with agrochemicals and labor[12]. In addition to increasing annual crop production, the improved capacity to capture, retain and slowly release water has allowed QSMAS farmers to escape devastating losses during droughts and hurricanes such as the severe El Niño drought in 1997. In 1998, after the devastating Hurricane Mitch in Central America, farmers practicing this system reported less soil, water and crop losses compared to those practicing the traditional slash-and-burn agriculture[13].

The evolution of the present day QSMAS provides a unique example of the integration of local environmental knowledge with national and international expertise through stakeholder cooperation[14]. While much international focus has been directed toward slash-and-burn approaches[15–17], there is little information on slash-and-mulch by comparison[18]. Although QSMAS is a potential model for developing sustainable agroforestry systems in other parts of Latin America and the world, its adoption by others is limited by a lack of a detailed, systematic analysis of the key biophysical and socio-economic drivers and variables involved. Furthermore, in order to establish guidelines for the QSMAS approach, input from all stakeholders is required. Guidelines for implementing the QSMAS need to include provisions for unanticipated consequences of adopting this technique, as well as the effects of potential changes in markets and environmental conditions[19].

Our general objective was to describe the QSMAS as practiced in the steeplands of western Honduras (Lempira) in the context of the principles of the Drylands Development Paradigm (DDP)[18]. We used the principles of the DDP to identify some of the critical socio-economic and biophysical factors causing land degradation[20] in Lempira and to evaluate the long-term sustainability of the QSMAS. Specifically, we (1) defined the socio-economic and biophysical conditions associated with the development of the QSMAS, (2) identified the factors that led to QSMAS adoption and (3) anticipated future challenges to the sustainability of the QSMAS.

Key Biophysical Characteristics of Lempira

The Lempira region is located in the southern part of Honduras close to the border with El Salvador (Fig. 1). It has an area of 2177 km^2 and is an important component of the Lempa River watershed, which provides nearly 60% of hydropower consumed by El Salvador. Soils of the region are predominantly Entisols with slopes greater than 30%, are shallow and acidic ($pH < 5.1$) with low soil organic matter content and available phosphorus[21] and have a gravely or stony loamy sand texture[22]. Although stones in the soil profile (which accounts for 30–50% of total soil volume in the 0–30 cm depth) reduce soil water holding capacity, surface stones can reduce runoff and erosion by dispersing the kinetic energy of raindrops and slowing overland flow[23,24]. The average annual temperature varies from 17 to 25°C. Annual precipitation ranges from 1400 to 2100 mm in the 600–900 m range of elevation, where the QSMAS is practiced. The rainy season extends from early May to the end of October. During the dry season from early November to late April, strong winds blow from the North and the enhanced evapotranspiration rates cause severe water deficits until the onset of rains.

Key Socio-economic Characteristics of Lempira

With limited support from the Honduran central government, Lempira is relatively isolated from the rest of Honduras due to a poor infrastructure of roads. It has a total population of about 110,000 inhabitants, and is considered to be one of the poorest regions of the country. Remittances from relatives working in the US constitute an important source of supplemental income for many families[25].

Farms are generally small; 80% are less than 5 ha[21] and only 25% of farmers own their land[26]. The rest are allowed to farm common lands without a formal land title. Seventy-five percent of the farmers grow maize and beans as subsistence crops with traditional slash-and-burn, generally producing very low yields (600–800 kg/ha maize and

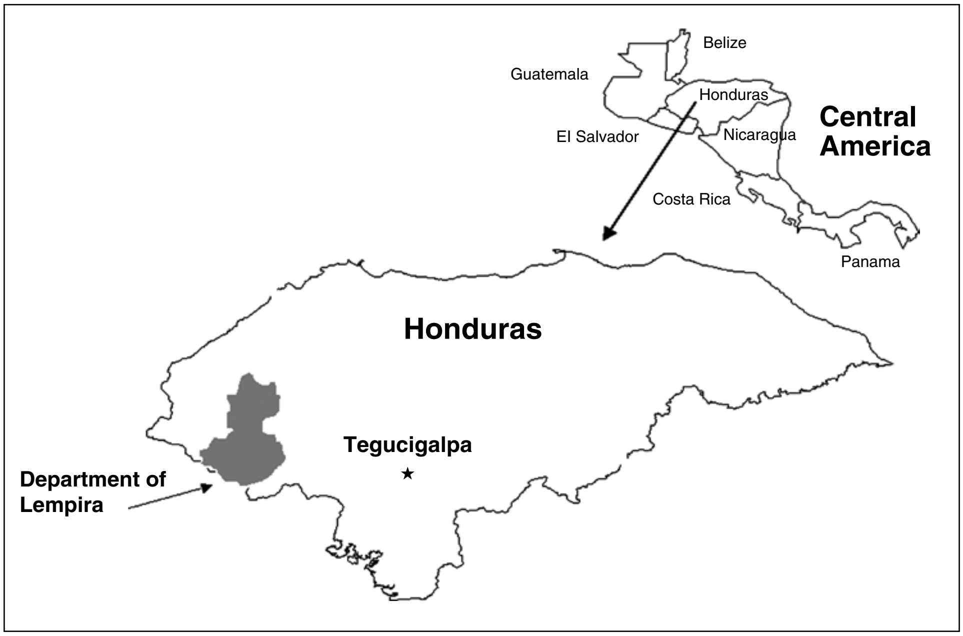

Figure 1. Location of the study area in the Lempira region in Honduras, Central America.

300 kg/ha beans), and many households also raise chickens, pigs and some cattle. Some farmers allow livestock to graze crop residues at the beginning of the dry season. Local food markets in Lempira are limited and are poorly integrated with the rest of Honduras. Basic grain production is primarily for self-consumption and local delivery, although cross-border trade with El Salvador, which is the most densely populated and industrialized country in Central America, is rapidly increasing. Local labor is also limited, but informal labor exchange within Lempira is a common practice and seasonal migration takes place in the northern coffee-producing areas.

Assessing QSMAS

From 15 to 20 November 2005, an international team of 16 biophysical and social scientists, students, extension specialists, development workers and other stakeholders conducted a workshop in the Lempira region to conduct an analysis of the QSMAS within the context of the five principles of the DDP:

1. Human–environmental systems are coupled, dynamic and co-adapting, so that their structure, function and interrelationships change over time.
2. A limited suite of '*slow*' variables are critical determinants of human–environmental system dynamics.
3. Thresholds in key slow variables define different states of human–environmental systems, often with different controlling processes; thresholds may change over time.
4. Coupled human–environmental systems are hierarchical, nested and networked across multiple scales.
5. Maintenance of up-to-date, local environmental knowledge is the key to functional co-adaptation of human–environmental systems.

Although the DDP has its roots in the desertification literature[18,27], we believe its principles are relevant to all rural human–environmental systems in Latin America.

This case study was jointly organized by the Consortium for the Integrated Management of Soils of Central America (MIS) and ARID*net*, an international research network that is testing the robustness of the DDP via multiple case studies of land degradation throughout the Americas. The goals of ARID*net* include facilitating field-level interactions between researchers, local stakeholders (farmers, land owners and developers) and decision-makers (details available at URL: http://www.biology.duke.edu/aridnet/).

In addition to background information from published and unpublished literature on the QSMAS, the workshop team conducted numerous interviews of scientists, development workers, community leaders and farmers living in and near the town of Candelaria, where the QSMAS has been widely adopted. In order to better understand the factors associated with the adoption of the QSMAS, interviews were also completed in the vicinity of the neighboring town of Guarita, where slash-and-burn agriculture continues to be practiced. In 2006, 16 additional individuals were interviewed to obtain further details on specific topics, provide clarifications where needed, and to obtain additional information to address gaps in our knowledge.

Our evaluation was completed in two phases. The first phase involved all workshop participants and immediately followed the completion of the on-site interviews. Working groups with biophysical and socio-economic expertise were formed to systematically apply the key concepts of the DDP in order to evaluate: (1) the extent to which QSMAS is potentially reversing land degradation in the area, (2) to identify the key biophysical and socio-economic variables associated with the evolution and success of the QSMAS and (3) to consider the extent to which the QSMAS will likely be an effective approach to limit land degradation and promote recovery given current farming trends in Lempira.

In the second phase, selected representatives of each working group refined this analysis to specifically cover three periods: *pre*-, *post*- and *future*-QSMAS. The *pre*-QSMAS period (1970–1990) represented a retrospective analysis focused on the conditions that led to the development of the QSMAS, the *post*-QSMAS period (1990–2006) covered the years since adoption of QSMAS to the present and the *future*-QSMAS period considered some of the most likely future challenges to the persistence and sustainability of the QSMAS in the Lempira region.

The QSMAS is a complex and dynamic system that consists of a suite of unique adaptive management systems being applied and modified by individual farmers. While this diversity makes generalizations more difficult, they also help explain the evolution of the QSMAS and point to its potential value in other parts of the world. In Table 1, we summarize the results of the application of the five principles of the DDP to each of three periods (*pre*-, *post*- and *future*-QSMAS).

Pre-QSMAS (1970–1990)

During the 1970s, the Department of Lempira experienced a rapid expansion of agricultural activities influenced by human and environmental drivers (DDP Principle 1): increasing population size (growth rate of 3% per year), migration from neighboring regions (including from El Salvador) and high poverty (90% of population lived on less than two dollars per day, 64% suffered of malnutrition and 90% were illiterate)[27]. Thousands of poor farmers practiced subsistence agriculture on more than 20,000 ha of communal forests using slash-and-burn farming. The extensive deforestation and overexploitation of these forests led to increased soil erosion (as much as $109\,\mathrm{Mg\,ha^{-1}\,yr^{-1}}$)[11], reduced soil cover and decreased soil fertility and water holding capacity (DDP Principle 2), causing decreased food production (maize 500–800 kg/ha, beans 200–300 kg/ha and sorghum 400–700 kg/ha)[13]. In time, these factors drove production systems past a threshold beyond which they were not able to meet household needs for food (one family of eight people consumes 1500 kg maize and 400 kg beans per year) and were no longer resilient to droughts and soil fertility decline (DDP Principle 3). Isolation, poor health and education services and weak social organization triggered further land degradation and extensive migration of locals to urban areas and elsewhere in search of work (DDP Principle 4).

In the 1980s, the Honduran government initiated a program to solve the food crisis by introducing improved crop varieties and subsidizing inorganic fertilizers and herbicides for Lempira farmers. During this period, the use of chemical fertilizers and herbicides increased from 25 to 80% considering all farms[28]. Nevertheless, despite intensive promotion of this program by the government, it had limited success because of the lack of access by most farmers to capital and technical assistance (DDP Principle 5). Moreover, the practice of this type of agriculture on slash and burned fields often further promoted soil and water losses.

Post-QSMAS (1990–2006)

After the devastating effect of a severe drought in 1987, the Honduran government and FAO jointly pursued a new strategy in Lempira to both reduce poverty and to increase crop production, while promoting restoration and conservation of native tropical deciduous forest[26].

The QSMAS emerged as a product of a community-based learning process in which local indigenous knowledge pertaining to no burning, slashing, mulching and pruning of native forest vegetation was combined with technical knowledge (use of spot fertilization, improved crop varieties and zero tillage/direct planting) (DDP Principle 5). Local residents (e.g., farmers and teachers at the technical schools) and local government authorities worked together with development agencies to evaluate, adapt and integrate new and existing practices and knowledge to develop the QSMAS. The key guiding principle was to maintain adequate soil cover throughout the year. This was achieved through a variety of practices, including tree pruning and using crop residues as mulch, minimizing or eliminating tillage, and introducing improved seeds and targeted fertilizer applications[12]. As a result, on-farm maize and bean yields increased 54 and 66%, respectively[13] (DDP Principle 2). A recent report of a study conducted by scientists of the Centro Internacional de Agricultura Tropical (CIAT)—Tropical Soil Biology and Fertility (TSBF) Program comparing slash-and-burn with QSMAS plots of increasing age (2–10 years of use) confirmed the improved capacity of QSMAS to retain soil and water[22]. According to this study, soil loss in slash-and-burn plots was five times greater than in QSMAS plots. Water loss by runoff was 25–60% greater in slash-and-burn plots than in QSMAS plots. Conversely, water infiltration in QSMAS plots was 15–30% greater than in slash-and-burn plots.

Although the adoption process of QSMAS was initially driven by short-term increases in crop yields at the farm level, its widespread adoption by thousands of farmers can be explained on the basis of a complex interaction with three main drivers of development[29]:

1. *Collective action* to focus on capacity building of local and regional organizations to support small farmers and improve education (DDP Principle 2).
2. *Technological change* to increase the resilience of local and regional production systems (DDP Principle 3).
3. *Policies and incentives* to promote the adoption of new production technologies (DDP Principle 1).

Table 1. Summary of results of DDP-based analysis (19).

DDP principle **Time frame**	**Pre-QSMAS** **(1970–1990)**	**QSMAS adoption** **(1990–2006)**	**Issues QSMAS must address in the future** **(2007–2020)**
P1. Degradation always involves human and environmental drivers	*Human drivers:* • Increasing population growth • High poverty • Limited access to services	*Human drivers*: • Collective action • Policies and financial incentives	*Human drivers*: • Increasing integration to local and regional markets • Improved financial support for crop diversification • Increasing land value • Decreasing labor
	Environmental drivers: • Soil and water losses and loss of soil fertility	*Environmental drivers*: • Technological change	*Environmental drivers*: • Market-oriented sustainable production • Expanded area for livestock
P2. The critical dynamics of dryland systems are determined by 'slow' variables, both biophysical and socio-economic	*Human factors:* • Unsatisfactory levels of food production to meet household requirements	*Human factors*: • Increased food security at household level	*Human factors*: • Long-term profitability of crop/livestock production • Increasing value of land
	Biophysical factors: • Increasing deforestation rates • Loss of soil cover • Reduced water holding capacity	*Biophysical factors* • Increased water holding capacity • Increased soil cover and tree density	*Biophysical factors* • Livestock density • Demand for water and nutrients
P3. Slow variables possess multiple thresholds that, if crossed, cause the system to move into a new state or condition	*Socio-economic thresholds* • Seasonal food and water scarcity	*Socio-economic thresholds* • Food and water security • Enough fuel wood supply to meet household demands	*Socio-economic thresholds* • Increased value of the land • Payment for environmental services
	Biophysical thresholds: • Incapacity of eroded soils to recover its productivity • Collapse of the S&B technology.	*Biophysical thresholds* • New equilibrium between food production and forest conservation • Reduced soil and water losses	*Biophysical thresholds* • Adequate balance between crops, trees and cattle in the landscape • Maintain high biodiversity
P4. The objectives, connections between, and perspectives and attitudes of different stakeholders demand consideration of the multi-level, nested and networked nature of H-E systems	*Socio-economic*: • Isolation from markets and support services • Weak organization at the community and watershed scales *Biophysical:* • Soil and vegetation losses affecting water availability for 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) and infrastructure development and provision of environmental services (basin)	*Country policies supporting*: • Greater freedom to trade with neighboring countries • Improved connectedness with markets through better infrastructure • True democracy to stimulate local initiative
P5. The key to maintaining functional co-adaptation of coupled human and ecological systems is an up-to-date body of 'hybrid' environmental knowledge that integrates local management and policy experience with science-based knowledge, all of which is mediated through an effective institutional organization	• Top-down approach to solve complex problems	• Bottom-up policies supporting no burning, improved water use and landscape conservation • Indigenous + technical knowledge to improve crop yields and resilience	• New knowledge needed to support intensification and diversification • Improved institutional and policy capacity to support changes

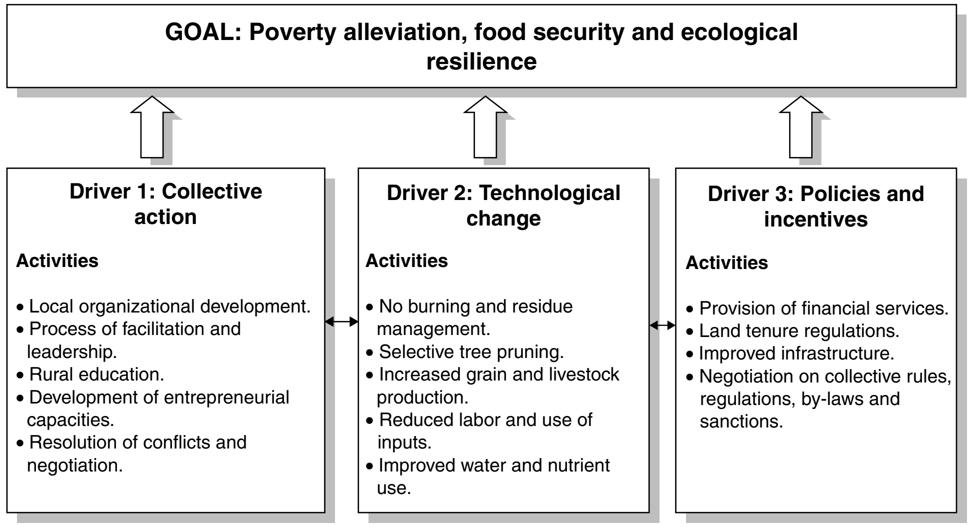

Figure 2. Drivers and activities associated with scaling up of QSMAS in the Lempira region.

Figure 2 shows the main activities associated with each driver. Adoption was also facilitated by farmer application of the 'Human Farm' principles developed by Elias Sanchez[30]. These principles emphasize that improved management of natural resources needs to be accompanied by the strengthening of human capital at the individual and community levels (DDP Principle 2).

With the support of FAO and several NGOs, local communities strengthened their capacity to negotiate incentives and benefits for the region (DDP Principle 4). Household heads organized water committees at the micro-watershed level to improve access to safe water. Local governments negotiated with the central government to implement long-distance learning radio programs (DDP Principle 4) and to improve the curricula of local schools and achieve better access to health services (DDP Principle 2). FAO and other development projects supported the formation of small co-operatives and financial services to strengthen the entrepreneurial capacity of men and women to transform and add value to their agricultural outputs and sell them through local and regional markets (DDP Principles 3 and 4). 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 of their production systems[31].

Communal banks were another important financial mechanism supporting the implementation of the QSMAS. Their role was not limited to credit provision; they also served as a focus for collective action and enforcement of local policies. For example, credit was given only to farmers who did not burn their land. This new 'moral order' was supported by national and local laws forbidding the use of fire and protecting common forestlands and water reservoirs (DDP Principle 2).

This process caused a profound change in the organizational culture and structure of development in the region (DDP Principle 4). A new threshold of guaranteed food security, improved soil and water productivity and enhanced managerial capacity was reached as a result of a new balance between production and conservation (DDP Principle 3). The system resulted in a 27% reduction in labor requirements and an 18% reduction in land preparation and weed control[13]. At the landscape level, QSMAS contributed to the conservation of more than 40 native species of trees and shrubs[26] and the fields serve as sinks for methane with low emission levels of nitrous oxide[22]. Table 2 summarizes the main impacts of QSMAS in terms of land and water productivity (DDP Principle 2), forest conservation and local strengthening at household and community levels (DDP Principle 5).

Future-QSMAS

During the past 16 years, the widespread adoption of the QSMAS in the Lempira region has improved food security, water availability (DDP Principle 2) and has ensured an adequate supply of fuelwood for small farmers. More recently, however, the intensification and diversification of agriculture have been accelerated in response to increasing opportunities to sell to local and regional markets (DDP Principles 1 and 4). Although new markets bring new opportunities for farmers, they also pose some challenges. These changes can simultaneously lead to both increases and decreases in sustainability (DDP Principle 3), as the QSMAS is further modified. For example, some innovative farmers are planting introduced grasses under the QSMAS to intensify livestock production and others are simply increasing livestock consumption of crop residues. While the former can increase animal output and maintain or improve soil structure and fertility (DDP Principle 2), the latter could eliminate the hydrologic benefits of the QSMAS if protective soil cover were removed and soil compaction resulted (DDP Principle 3). Vegetable crop production with irrigation, stimulated by increasing trade

Table 2. Impacts and beneficiaries of the adoption of the QSMAS in the Lempira region (30).

Management component	Impacts	Beneficiaries
Increased soil fertility and agricultural productivity:		
1. Permanent soil cover	• Increased water holding capacity (from 8 to 29%) • Soil loss reduced from 300 to 16 $t\,ha^{-1}$	6000 small farmers practicing the QSMAS
2. Improved crop varieties	• Maize and bean yields increased by 30–40%	Farmers practicing the QSMAS
3. Five new grass species validated and disseminated	• Improved livestock production	Livestock producers
4. Two new feeding options for the dry season	• Increased milk production during the dry season	
Improved water quality and availability:		
1. Participatory watershed management	• More than 100 water committees and small irrigation projects established	1150 producers benefited by small irrigation projects
Sustainable management of forest resources:		
1. No burning	• 6000 ha managed without burning	6000 small farmers
2. Improved utilization of forest resources	• Local communities trained in the use of timber products	40 wood artisans
Improved entrepreneurial capacity:		
1. Improved financial availability	• 105 communal banks • Three cooperatives established • Three small milk-processing enterprises established	• 962 members benefited (55% men and 45% women) • Ten women's groups producing cheese
2. Entrepreneurial capacity enhanced	• Several financial systems developed	• 185 direct and 254 indirect jobs
3. Improved capacity to develop projects	• 648 development projects	• 20 municipalities
Education oriented to test and introduce innovations in Natural Resource Management (NRM):		
1. Rural education including innovations to improve land and water use	• Four communal technical institutes incorporate NRM principles in their curricula	• 867 students learn and apply new knowledge in 2001
2. New education materials available at local schools	• Four manuals	• 200 students of the Instituto Técnico Comunitario

with neighboring El Salvador, has the potential to increase cash flow, but these new production systems may require different soil and water management strategies (DDP Principle 4).

Other anticipated concerns, such as increasing pest and disease incidence (DDP Principle 3), will demand new knowledge and inputs (DDP Principle 5). In fact, anecdotal observations from researchers and farmer comments indicate that herbicide and insecticide use are already high in the areas that have adopted QSMAS. Another major concern is the increasing risk of more severe weather events (DDP Principle 3) that have been observed in the past because of climate change.

Although some intensification and diversification are clearly possible while maintaining the benefits of the current QSMAS, continuing co-adaptation of this human–environmental system will be required (DDP Principle 1) to maintain its resilience and benefits (DDP Principle 2), including improved water storage, recycling of nutrients and environmental services for downstream users. The discussion below focuses on key issues that QSMAS practitioners should consider if the benefits of the system are to be maintained.

Integration with markets

The construction of a bridge between the Lempira region and El Salvador during the 1990s was a key event (DDP Principle 3) that accelerated the integration of small farmers to markets and cross-border trade (DDP Principle 4). Small farmers practicing the QSMAS have benefited by selling their maize and bean surpluses at elevated prices. If international demand for maize continues to increase in the future, due to interest in the production of bio-fuels (DDP Principle 4), the pressure to increase production will rise, and farmers will need to learn how to further improve crop water and nutrient use efficiency (DDP Principle 5). Conversely, access to grain imports (whole and/or as industrialized products), coupled with labor shortage and off-farm income could reduce farmers, interest in local grain production, thus increasing livestock and open grassland expansion in QSMAS-dominated areas (DDP Principles 1 and 3).

Improved rural financing

Access to formal and informal credit markets in the region should stimulate crop and livestock intensification of QSMAS. Farmers may reduce the area devoted to traditional crops and allow the introduction of new crop options with market potential using irrigation, improved storage facilities and improved varieties. Because of improvements in soil fertility and water availability under the QSMAS, crop and livestock production can be increased allowing further intensification of the system. However, indiscriminate increase of livestock can affect soil conditions, ground cover and tree density (DDP Principle 3). To be sustainable, intensification will have to be based on the strategic allocation of available soil and water resources under QSMAS to maintain an adequate tree density and soil cover and avoid soil compaction and erosion. A new cycle of technological change based on the combination of local and technical knowledge will likely be required to sustain an increase in crop and livestock production (DDP Principle 5).

Land value

Land ownership and value have been positively associated with the use of soil conservation practices[32], and in some cases the value of the land has increased because of the use of these practices (DDP Principle 2). This has been the case for land managed under QSMAS. Although there is no formal system to price the land in the region, farmers generally recognize that under QSMAS, land value is at least 30% higher than in areas without QSMAS (DDP Principle 3). This is a positive factor that may limit drastic changes of the system under intensification processes. Many farmers growing new crops on rented lands are now obliged to maintain permanent tree cover without burning.

Reduced labor

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 (DDP Principle 4). This will become another factor influencing the intensification and diversification processes.

Toward a New Balance to Support Intensification and Diversification

If QSMAS is to continue to support the sustainable growth of the rural population in Lempira, a new balance between production and conservation will be needed (DDP Principle 3). This balance will require an optimum allocation in space and time of financial and land resources to support diverse crop and livestock production systems. Improved agricultural practices associated with the QSMAS will result, on the one hand, in enhanced productivity and resource quality and, on the other, in increased land value and reduced risks that will contribute to improved economic viability and social acceptance of the system in the long term (DDP Principle 2). This will require that local communities in the Lempira region learn to negotiate policies to ensure the benefits of improved land and water use for both upstream and downstream users. Economic benefits of improved water availability for downstream users should be shared with small farmers in upper catchments under a new arrangement (DDP Principle 4). Given the increased scarcity of both water and energy, this hydrologic benefit alone could support the adoption of the QSMAS. The alternative threshold will be of degradation and loss of resilience of the system if indiscriminate intensification of crop and livestock occurs without maintaining an adequate tree density and soil cover and avoiding soil compaction and erosion (DDP Principle 3).

The primary elements of the QSMAS—replacement of forest clearing, burning and tillage with thinning, pruning and direct planting—could be adopted and adapted in many parts of the world (Fig. 2). The key elements of the development process—honest participatory research and development—can also be usefully extended to other regions. However, adapting the system must be done carefully if long-term benefits are to be realized. As fresh water becomes scarcer, and demands for food and biofuel increase, it is also crucial to conserve biodiversity. To accomplish these goals simultaneously requires innovative approaches to crop production, such as described for the QSMAS to help restore degraded landscapes in Honduras. While the DDP is a useful framework for systematically identifying the critical variables and processes that determine the sustainability of any particular production system, it is ultimately no more clairvoyant than the collective wisdom of those who choose to apply it. The DDP can, however, help ensure that knowledge is integrated and applied.

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References

1 Heerink, N., van Keulen, H., and Kuipers, M. (eds). 2001. Economic Policy and Sustainable Land Use: Recent Advances in Quantitative Analysis for Developing Countries. Springer Physica-Verlag, New York, NY.

2 Sivakumar, M.V.K. and Valentin, C. 1997. Agroecological zones and the assessment of crop production potential.

Philosophical Transactions of the Royal Society of London Series B—Biological Sciences 352:907–916.

3 Sayer, J. and Campbell, B. 2004. Learning by doing on tropical American hillsides. In J. Sayer and B. Campbell (eds). The Science of Sustainable Development: Local Livelihoods and the Global Environment. Cambridge University Press, Cambridge, UK. p. 170–187.

4 Shriar, A.J. 2007. In search of sustainable land use and food security in the arid hillside regions of Central America: putting the horse before the cart. Human Ecology 35:275–287.

5 Young, P.D. (ed.). 1991. Fragile lands management. In Latin America and the Caribbean: A Synthesis. DESFIL Technical Report. Development Alternatives, Inc., Bethesda, MD.

6 CIAT. 2005. An innovative approach to prevent, reduce and reverse land degradation in the tropics. Conceptual Framework. Internal Document, International Center for Tropical Agriculture, CIAT, Cali, Colombia. p. 10.

7 Hellin, J., Williams, L.A., and Cherrett, I. 1999. The Quezungual system: an indigenous agroforestry system from western Honduras. Agroforestry Systems 46:229–237.

8 Janzen, D. 1988. Guanacaste National Park: tropical ecology and biocultural restoration. In J. Claims Jr (ed.). Rehabilitating Damaged Ecosystems. Volume 11. CRC Press, Boca Raton, FL. p. 143–192.

9 Nicholaides, J.J., Bandy, D.E., Sanchez, P.A., Benites, J.R., Villachica, J.H., Coutu, A.J., and Valverde, C.S. 1985. Agricultural alternatives for the Amazon Basin. Bioscience 35:279–285.

10 Melendez, G., Vernooy, R., and Briceño, J. (eds). 1999. Frijol tapado en Costa Rica: fortalezas, opciones y desafíos. In Agronomia Costarricence. ACCS, San José, CR. p. 60.

11 Alvarez Welchez, L. and Cherret, I. 2002. The Quesungual systems in Honduras: alternative to slash-and-burn. Magazine on Low Input and Sustainable Agriculture (LEISA) 18(3): 10–11. Available at Web site: http://www.leisa.info (accessed 28 March 2010).

12 Clercx, L. and Deugd, M. 2002. Pobreza, agricultura sostenible y servicios financieros rurales en América Latina: Reflexiones sobre un estudio de caso en el departamento de Lempira, Honduras. 1 a ed. Centro de estudios para el desarrollo rural Universidad Libre de Ámsterdam (CDR-ULA), Managua. p. 55. Available at Web site: http://www.cdr.or.cr/publicaciones.htm (accessed 28 March 2010).

13 FAO. 2005. El Sistema Agroforestal Quesungual. In R. Argueta (ed.) Una Opción para el Manejo de Suelos en Zonas Secas de Ladera. FAO, Tegucigalpa, Honduras. p. 49.

14 Barrios, E. and Trejo, M.T. 2003. Implications of local soil knowledge for integrated soil management in Latin America. Geoderma 111:217–231.

15 Armitage, D. 2004. Nature-society dynamics, policy narratives, and ecosystem management: integrating perspectives on upland change and complexity in Central Sulawesi, Indonesia. Ecosystems 7:717–728.

16 Brady, N.C. 1996. Alternatives to slash-and-burn: a global imperative. Agriculture Ecosystems and Environment 58:3–11.

17 Vosti, S.A. and Witcover, J. 1996. Slash-and-burn agriculture—household perspectives. Agriculture Ecosystems and Environment 58:23–38.

18 Reynolds, J.F., Smith, D.M.S., Lambin, E.F., Turner, B.L., Mortimore, M., Batterbury, S.P.J., Downing, T.E., Dowlatabadi, H., Fernandez, R.J., Herrick, J.E., Huber-Sannwald, E., Jiang, H., Leemans, R., Lynam, T., Maestre, F., Walker, B., and Ayarza, M. 2007. Global desertification: building a science for dryland development. Science 316:847–851.

19 Anderson, P.J. and Putz, F.E. 2002. Harvesting and conservation: are both possible for the palm, *Iriartea deltoidea*? Forest Ecology and Management 170:271–283.

20 Huber-Sannwald, E., Maestre, F.T., Herrick, J., and Reynolds, J.F. 2006. Ecohydrological feedbacks and linkages associated with land degradation: a case study from Mexico. Hydrological Processes 20(15):3395–3411.

21 Ordoñez, J. 2004. Main factors influencing maize production in the Quesungual agroforestry system in Southern Honduras: an explorative study. Masters thesis, University of Wagenningen.

22 CPWF. 2009. Quesungual slash and mulch agroforestry system (QSMAS): Improving crop water productivity, food security and resource quality in the sub-humid tropics. Project Completion Report: 1 September 2007 to 15 March 2009. p. 61. Available at Web site: http://www.waterandfood.org (accessed 28 March 2010).

23 Poesen, J. and Lavee, H. 1994. Rock fragments in top soils: significance and processes. Catena 23:1–28.

24 Rivera, M. and Amézquita, E. 2006. Efectos de diferente contenido de piedra y frecuencias de aplicación de riego en el almacenamiento de agua en el suelo y en la producción de biomasa de Maíz (*Zea mays* L.) bajo invernadero. In Memorias del XIII Congreso Colombiano de la Ciencia del Suelo (SCCS), Conénfasis en sostenibilidad del suelo y competitividad agrícola, Bogotá, Colombia, Octubre 2006.

25 Amuedo-Dorantes, C. and Pozo, S. 2004. Workers' remittances and the real exchange rate: a paradox of gifts. World Development 32:1407–1417.

26 FAO. 2004. Historia de un proceso de desarrollo: Metodología del programa Lempira Sur. Proyecto Gobernabilidad local en Lempira. GCP/HON/028/NET Documento de Campo 01. p. 122.

27 Stafford Smith, D.M. and Reynolds, J.F. 2001. Desertification: a new paradigm for an old problem. In D.M. Stafford Smith and J.M. Reynolds (eds). Global Desertification: Do Humans Cause Deserts? Dalhem Workshop Report 88. Dahlem University Press, Berlin, Germany.

28 Ruben, R. and Clercx, L. 2003. Rural Finance, Poverty Alleviation and Sustainable Land Use: The Role of Credit for the Adoption of Agroforestry Systems in Occidental Honduras. p. 24. Available at Web site: http://library.wur.nl/file/wurpubs/LUWPUBRD

29 Ayarza, M.A. and Welchez, L.A. 2004. Drivers affecting 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. p. 187–201.

30 Smith, S. 1994. The Human Farm: A Tale of Changing Lives and Changing Lands. Kumarian Press Inc., West Hartford, CT.

31 Suazo, T.E., Gómez, L.V., Mejía, C.R., Villatoro, D., Castro, G., del Cid, W., Zelaya, C., Cherret, I., Lindemann, T., and Gaviria, L. 2004. Historia de un proceso de desarrollo: Metodología del programa Lempira Sur. Programa Lempira Sur. Proyecto de gobernabilidad Local en Lempira. GCP/HON/028/NET. FAO, Tegucigalpa, Honduras. p. 148.

32 Jansen, H., Siegel, P.B., and Pichón, F. 2005. Identifying the drivers of sustainable rural growth and poverty reduction in Honduras. International Food Policy Research Institute (IFPRI). DSGD Discussion Paper No. 19.