AGRICULTURE PRACTICES

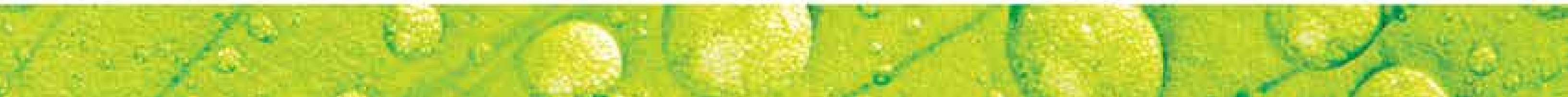
IMPROVING WATER PRODUCTIVITY
IN RAINFED PRODUCTION SYSTEMS IN CENTRAL AMERICA

TEMAS DE DEBATE

Global Water Initiative
Howard G. Buffett Foundation

THE HOWARD G. BUFFETT FOUNDATION

CRS
CATHOLIC RELIEF SERVICES



Authorship, editing and technical coordination:
The GWI team with support from Daniel Moss

AGRICULTURE PRACTICES

IMPROVING WATER PRODUCTIVITY

IN RAINFED PRODUCTION SYSTEMS IN CENTRAL AMERICA

GWI would like to thank all of the agencies, institutions, and organizations that have collaborated with us in each one of the three countries that concern us: Nicaragua, El Salvador and Honduras, without whose participation this work would not have been possible.

Created by:
GWI Team (Global Water Initative)
Central America
San Salvador, 2015

Content

Acronyms and Abbreviations

Cajón Project	Proyecto de Manejo de los Recursos Naturales Renovables de la Cuenca del Embalse el Cajón
CEC	Cation-exchange capacity
CIAL	Comité de Investigación Agrícola Local (Local Agricultural Research Committee)
CIAT	Centro Internacional de Agricultura Tropical
CONABISH	Comité Nacional de Bienes y Servicios Ambientales, Honduras
CRS	Catholic Relief Services
CENTA	Centro Nacional de Tecnología Agropecuaria y Forestal, El Salvador
DICTA	Dirección de Ciencia y Tecnología Agropecuaria, Honduras
FOCUENCAS	El Programa de Innovación, aprendizaje y comunicación para la cogestión adaptativa de cuencas
INTA	Instituto Nicaragüense de Tecnología Agropecuaria, Nicaragua
LUPE	Land Use and Productivity Enhancement Project
MARENA	Ministerio del Ambiente y los Recursos Naturales, Nicaragua
MiCuenca	(My Watershed, the title used locally for Phase I of the Global Water Initiative Central America, funded by the Howard G. Buffett Foundation and implemented by CRS)
MST	Proyecto Manejo Sostenible de la Tierra – MARENA, Nicaragua
PAES	Programa ambiental de El Salvador
PASOLAC	Programa para la Agricultura Sostenible en Laderas de América Central
PESA	Programa Especial para la Seguridad Alimentaria – FAO
PIMCHAS	Proyecto Integral de Manejo de Cuencas Hidrográficas, Agua y Saneamiento, Nicaragua
POSAF	Programa Socioambiental y de Desarrollo Forestal, Nicaragua
QSMAS	Quesungual Slash and Mulch Agroforestry System
PRODERNOR	Proyecto de Desarrollo Rural del Nororiente de El Salvador
SDC	Swiss Agency for Development and Cooperation
SSA	Sub-Saharan Africa
UNA	Universidad Nacional Agraria, Managua, Nicaragua
USAID	United States Agency for International Development

1. Introduction to the Topics for Debate Series

Agriculture represents the main source of livelihood for much of the rural population living at a poverty threshold. For many developing countries, agriculture is also a driving force for general economic growth, and therefore a means to poverty reduction. The demand for food and forage continues to increase throughout the world [1]; this required demand will be met only if productivity is improved. In Central America, this means producing more food in the same extension of land and in a context when climate change and price volatility are the norm.

The situation in Central America is a mirror of what is happening in other regions of the world. This leads development experts to conclude that "rain-fed agriculture continues to be the main source of food, feed and fiber worldwide, particularly in areas where rural subsistence systems prevail" [2].

1.1. Food insecurity in Central America

After almost half a century characterized by a constant decrease in the prices of basic foods, it is predicted that prices will remain unstable throughout the next decades [3]. The rise in food prices during 2008 and 2011 demonstrated how market volatility affected worldwide food security [4].

Food prices have a direct effect on the poverty of the region given the fact that food represents the largest percentage of family budgets in Central America, both for urban and rural families in Central America [5]. It is estimated that 1.1 million people fell into poverty, while another two million already living on the threshold of poverty level descended into extreme poverty [6].

The price crisis shook Central American economies to the core, given the fact that the countries in the region import approximately 40% of their food supplies [7]. That condition makes them particularly vulnerable. Production of basic grains only improved 2.5% per year between 2000 and 2009, barely keeping up with the growth rate of the local population [8]. With a growing demand for food and a national production dependent on imports, in the short term the region will find itself more and more vulnerable to global market instability.

---

1. During the course of the next 40 years, agriculture will need to double its food, fiber and fuel production to cover the increasing demand created by a growing world population, better economic conditions, as well as changing consumption patterns and lifestyles. Some projections (FAO 2009) suggest that production will need to be increased by approximately 70% by the year 2050 just to keep up with expected food demand.
2. Translation from GWI. Molden, D. (ed.) (2007): Water for Food, Water for Life: Comprehensive Assessment of Water Management for Food. Earthscan, London.
3. Note: Global grain prices are strongly correlated with the cost of oil. Visit: http://www.paulchefurka.ca/Oil_Food.html.
4. FAO (2011) Addressing high food prices: A synthesis report of FAO policy consultations at regional and sub regional level. Rome, FAO October, 2011
5. Food and nutrition insecurity in Latin America and the Caribbean.CEPAL, 2009.
6. CEPAL (2008) Central American Isthmus: Global Crisis, Challenges, Opportunities and New Strategies
7. IICA (2011) The Food Security Situation in the Americas. Page 15. http://www.iica.int/Esp/Programas/SeguridadAlimentaria/IICAPublicaciones/B2914i.pdf.
8. Based on data provided by the FAO, grain production increased by 2.56% and general food production increased by 4.3% during the decade preceding 2009. Reported by IICA (2011) The Food Security Situation in the Americas.

1.2. Environmental degradation in Central America

Two of the most critical environmental issues being faced by Central America are soil degradation and water pollution; both problems exacerbated by climate change.

Central America is naturally susceptible to soil erosion due to its topography: 70% of its territory is comprised of hills. And the situation is further compounded by the expansion of the agricultural frontier into natural ecosystems, as well as the continuing custom of burning the land to prepare it for planting [9].

The changes in land use practices for agricultural expansion were the principle reason for environmental degradation in the past 50 years [10]. In fact, Central America is the only region of the world where poor agricultural practices are the principal cause of soil degradation.

The productive capacity of agriculture in the region has been affected by the widespread degradation of agricultural lands and river basins. It is estimated that approximately 80% of the land destined for agriculture has been affected by man-induced soil degradation, this being the highest percentage of all the regions throughout the world. Central America is the only region worldwide where improper farming practices have been the main cause of soil degradation, even more so that deforestation itself (Oldeman et al., 1991; Zurek, 2002). The severely degraded Central American soils also cause massive water resource loss. Instead of infiltrating and being used in plant transpiration to produce biomass, the water is lost as run-off.

At the same time, climate change is predicted to reduce agricultural production by 15% in Central America [11]. In the last two decades, climate patterns in the region have changed considerably. These changes are clearly evident in: (a) the increase of average temperatures; and, (b) the frequency and intensity of storms and droughts. The net impact of the increase in temperatures is hard to measure, however, some studies in the last few years have demonstrated that two rain-fed crops which are fundamental to the region, coffee[12] and corn[13], will be negatively impacted by this situation.

The impact of more frequent and intense storms on agricultural production is more difficult to predict, given the unforeseeable nature of the climate. But impacts are already evident in the region. Extreme climatic events have become more frequent since the 60's. These storms have immediate and long-term effects on agriculture; in the short term, wind and rain damage crops, while over the medium and long ter, the extreme rain accelerates soil erosion and results in decreased soil fertility for future planting seasons.

9.Review: Bossio, D. y Geheb, K. (2008) Conserving Land, Protecting Water. Comprehensive Assessment of Water Management in Agriculture, Series 6. CAB International.

10. Millennium Ecosystem Assessment (MEA). Ecosystems and Human Wellbeing: Synthesis. Washington, D.C.: Island Press. 2005.

11. CEPAL (2014) Potential Impact of climate change over basic grains in Central America.

12. CGIAR and CRS (2010). Coffee Under Pressure: http://www.slideshare.net/ciatdapa/2009-03-18-coffee-under-pressure-cup-ciat-sfl-meeting.

13. TOR Report (2012) Tortillas on the Roaster, Summary Report: CIAT, CIMMYT, and CRS. http://newswire.crs.org/wp-content/uploads/2012/10/CRS_Tortillas_on_the_roaster_summary_report.

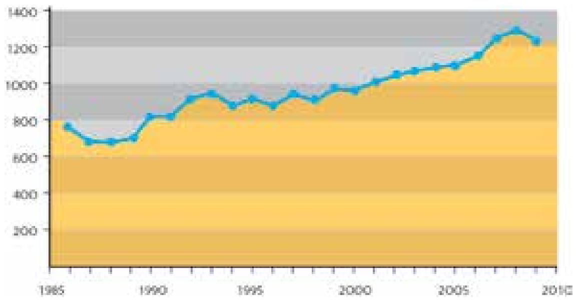
1.3. Rain-fed Agriculture: Challenges and opportunities

In Central America, small-scale rain-fed agriculture produces 2/3 of the food while occupying over 80% of the agricultural lands in the region [14]. With this type of agriculture, the countries face three persistent and closely intertwined challenges: food insecurity, poverty and environmental degradation. Rain-fed agriculture, or that which depends solely on rain, is practiced mainly by small farming families. That characteristic is a fundamental part of the problem as well as a key to its solution. A clear strategy to improve food production and food security within the region is to increase the productivity of family farms. The current state of degradation of farming land in Central America due to poor management of soil and water, represents not only risks and added vulnerability, but also the opportunity to produce more food with less freshwater resources (Rockström, 2007). Improving water productivity then becomes a critical answer to the increasing scarcity of this resource, as well as being able to provide sufficient water for ecosystems and satisfy the growing demand of cities and industries (Molden y Oweis, 2007).

There is great potential to improve crop yield and therefore the productivity of water in rain-fed agricultural systems by way of the adoption of agronomic practices and proven water management techniques. There are considerable variations within rain-fed agriculture yields in Central America, which highlights existing challenges and opportunities to increase rain-fed production. Average corn yield is currently below 1,500 kg/ha (see figure 1)[15]. A conservative yield goal should be of 3,000 kg/ha for corn grown on hillside farms[16].

Evidence shows that in semiarid, sub-humid regions, as well as in dry sub-humid areas, the biggest challenge to water for rain-fed agriculture is the extreme variability of rainfall, marked by rainfall events, high intensity storms and an increasing frequency in droughts and dry periods. In Central America there is a short dry period in the midst of the rainy season, locally referred to as "canícula" (summer heatwave). This is perhaps the single most serious climate risk factor for farmers, and given it's severity, represents an important factor in crop decisions. When the canícula is longer and drier than usual, it threatens the crops in both planting cycles, the first and second.

Figure 1: Estimate of average corn yields in CA4 countries (1985-2010).



Sources: FAOSTAT (2012), RedSICTA 2011 and analysis conducted by Hileman, J. (2012)

---

[14] Siebert y Doll (2010) Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation. Journal of Hydrology. Vol. 384.
Also see: FAO (2014). Family agriculture in Latin America and the Caribbean: Policy recommendations. These numbers belong to global scale numbers: 80% of farm lands in the world are irrigated with rainwater and produce 62% of basic food in the world (FAOSTAT 2005) as reported by Rockström, J. (2007): Unlocking the potential of rain-fed agriculture. Chapter 8: Managing water in rain-fed agriculture. IWMI.

[15] Data provided by FAOStat (2012), RedSICTA (2011). However, official statistics combine data from irrigated and rain-fed farm lands, hence the figure shows the productivity of corn irrigated with rainwater on the basis of a statistical analysis of corn in the region conducted by J. Hileman 2012 (unpublished material).

[16] Turrent, A., et al. (2012) Achieving Mexico's Maize Potential. Global Development and Environment Institute. Work document No. 12-03.

1.4. Good practices in rain-fed agriculture

During the last decades there has been a significant amount of analysis and learning about sustainable agriculture, There have been advances in training and education that are effective to incentivize small-farming families to improve their agricultural practices. There are many success stories, both at a smaller and greater scale.

The better practices for sustainable agriculture are described as “Green Water practices” (Water-Smart Agriculture)[17]. The GWI initiative is promoting “Green Water” as a focus for rain-fed systems in Central America[18].

1.5. Reinvesting in rain-fed agriculture

During the past twenty years, the political environment of the Central American countries has not been conducive to promoting investment in smaller scale rain-fed agriculture. Since the 90’s there has been a dramatic decrease in the small-scale farm sector[19]. The lack of public investment in agriculture has limited agricultural research, as well as training and extension services[20].

However, after two decades of neglecting the agricultural sector and family-based agriculture in Central America, the food price crisis of 2008 and 2011 forced policy makers as well as the international community to reconsider the dominant agricultural and economic model in place since the early 90’s, which emphasized production for exports over production for food security[21].

To revitalize rain-fed agriculture in Central America, particularly in the hands of small producers, it is necessary to shift towards an agroforestry focus, silvopastoral and conservation agriculture practices. For both farmers and governments, these seem to be the correct decisions to manage water, soil and climate variability. From the government perspective, policies, programs and investments in human capital, as well as access to financial and extension services for small farmers and recuperating local knowledge, are all pertinent to initiating efforts in this direction.

---

17. Turrent, A., et al. (2012) Achieving Mexico’s Maize Potential.Global Development and Environment Institute.Work document No. 12-03.

18. TOR Report (2012). The TOR report concludes that“improving soil fertility and its management at a large scale can represent the most important adaptation technique towards climate change available to small farmers in Central America”.

19. IFAD 2011: since the beginning of the 2000s, agricultural budgets barely averaged 2% of the GDP in the region, even though 15%-30% of the economies in these countries depended on agriculture. http://www.ifad.org/hfs/index.htm.

20. IIASTD LAC Report (2009) and Trejos, R., C. Pomareda and J. Villasuso (2004) Policies and Institutions for Agriculture in the XXI century. IICA, Costa Rica.

21 .IIASTD LAC Report (2009).

1. 6. Debate topics to revive rain-fed agriculture in Central America

The objectives of this Debate Series are: (a) contribute to the revitalization of investments in rain-fed agriculture; and, (b) promote the best and most efficient investments based on available knowledge and past experience.

To initiate the discussion, the work was based on three questions:

1. Which practices and technologies have the biggest impacts in improving rain-fed agriculture?
2. Which extension services have been explored and applied in Central America? And, what is their potential to revitalize rain-fed agriculture?
3. What financing mechanisms work best for farming families practicing rain-fed agriculture?

Since mid-2013, the Central American GWI Initiative has conducted a series of interviews, reviewed literature and organized a series of events and round tables in El Salvador, Honduras and Nicaragua to answer the previous questions.

This work was carried out in a participatory manner with the network of actors involved in each country: local and central government, NGOs, and both the academic and private sectors. The objective was, in the first place, to evaluate the situation of extension, financing and agricultural practices in each country, uniting the voice and experiences of all actors. This task was meant to promote interaction, reflection and joint analysis. With this intention, a learning alliance was organized in each country, which included all stakeholders involved in each one of the topics. The role of the learning alliance consisted of collecting information, generating reflections based on the information and validating the final product of the consultations.

In the first place, an opportunity was opened so that the institutions in charge of implementing extension services, financing and agricultural practices would become involved and take on ownership of the reflection process. These institutions took responsibility for collecting information within the territories. At the same time, dialogue, discussion and reflection spaces were opened amongst diverse actors. For the reflection and strategic dialogue, forums and meetings were utilized. These reflection spaces were complemented by field visits to observe the concrete territorial situation.

2. Water productivity – the key to future food security and economic development

A challenging future

Over the next 40 years, agriculture must double its production of food, feed, fiber and fuel to meet the demand created by a growing world population, improved economic conditions in middle income countries and subsequent changes in consumption patterns and lifestyles. Some projections (FAO, 2009) suggest that production will have to increase nearly 70% by 2050 simply to keep pace with the demand for food. Such an increase will only be achieved if productivity is improved, which in the case of the Americas means producing more on the same amount of land. Extending the agricultural frontier is now practically impossible (FAO, 2011; IICA et al., 2011). Agriculture is an engine of economic growth and is the sector in which a large majority of the rural poor make their living. Gains in rainfed agricultural have the potential to reduce poverty.

To feed a growing and wealthier population with more diverse diets will require an increase in overall biomass production. However, an increase in biomass production requires more water, since there is a well-established linear relationship between plant biomass production (leaves, stems, roots, grain) and evapotranspiration (Tanner & Sinclair, 1983; Steduto & Albrizio, 2005). Evapotranspiration needed for biomass production could increase 60%–90% by 2050. Covering this need through withdrawals from natural water systems appears unsustainable since agricultural water withdrawals from natural systems already constitute about 70% of all the water withdrawn for human purposes. Extracting additional water for agriculture will strain terrestrial and aquatic ecosystems and intensify competition for water resources. Improved water productivity is thus a critical response to increasing water scarcity, to the need to leave enough water to sustain ecosystems and to meet the growing demands of cities and industries. Improved water productivity will reduce the need for additional water and land (Molden et al., 2007).

Increasing Water Productivity - Growing More Food with Less Water

Water productivity is defined as the ratio of the net benefits from crop, forestry, fishery, livestock, and mixed agricultural systems to the amount of water required to produce those benefits. In its broadest sense, it reflects the objectives of producing more food, income, livelihoods, and ecological benefits at less social and environmental cost per unit of water used, where water use means either water delivered to a use or depleted by a use (Steduto et al., 2007).

There is considerable scope for improving water productivity in many rainfed, irrigated, livestock, and fisheries systems in many regions of the world. Many farmers in developing countries could raise water productivity by adopting proven agronomic and water management practices because raising land productivity generally leads to increases in water productivity. Many promising pathways for raising water productivity are available, from fully rainfed to fully irrigated farming systems. These include supplemental irrigation (some irrigation to supplement rainfall or bridge dry spells); soil fertility maintenance; deficit irrigation; small-scale affordable water harvesting/storage, delivery, and application; modern irrigation technologies (such as pressured systems and drip irrigation); and soil-water conservation through e.g. zero or minimum tillage. Breeding can help indirectly by reducing biomass losses through increased resistance to pests and diseases, vigorous early growth for rapid ground cover, early maturing varieties, and reduced susceptibility to drought. But water productivity gains are context dependent and are assessed through an integrated basin analysis (Steduto et al., 2007).

A Special Opportunity in Rainfed Agriculture for Water Productivity Gains

Rainfed farming covers most of the world's cropland (80%) and produces most of the world's cereal grains (more than 60%), generating livelihoods in rural areas and producing food for cities (FAOSTAT, 2005). In the future, rainfed agriculture will continue to produce the bulk of the world's food. However, crop yields in rainfed agriculture systems, especially in the areas dominated by smallholders in the tropics are low, and thus is water productivity. This provides significant opportunities for producing more food with less freshwater (Rockström et al., 2007).

The high potential to improve yields and water productivity in rainfed agriculture systems through proven agronomic and water management practices is supported by evidence showing that the total amount of water is not the key limiting factor for improved yields, even in so-called dry lands (Hatibu et al., 2003). Instead, the major water-related challenge for rainfed agriculture in semiarid and dry sub-humid regions is the extreme variability in rainfall, characterized by few rainfall events, high-intensity storms, and high frequency of dry spells and droughts. These regions cover some 40% of the world's land area and host roughly 40% of the world's population. It is therefore critical to understand how hydro-climatic conditions and water management affect yields in rainfed agriculture. The key challenge is to reduce water-related risks posed by high rainfall variability rather than only focus on an absolute lack of water. In semiarid and dy sub-humid regions, there is generally enough rainfall to double and often even quadruple yields in rainfed farming systems, even in water-constrained regions. But it is available at the wrong time, resulting in dry spells that reduce or impede production. Much of the water is lost. The water challenge in these rainfed areas is to enhance yields by improving water availability and the water uptake capacity of crops. Investments in soil, crop, and farm management are required (Wani et al, 2009).

The Case of Central America

Rainfed agriculture currently represents 70% of Central America's production and covers 2/3 of the land used for agriculture. With respect to water use, Central America follows the global trend: approximately 70% of its water is currently used for agriculture. This usage in and of itself should not generate water scarcity given that the annual per capita water availability in Central America is approximately 23,000 m3 (Beekmann, 2014). The water availability for agriculture, however, is compromised by the irregular spatial and temporal distribution of rainfall. While annual precipitation rates range from 1150 mm to 5000 mm, marked seasonality is evident on the Pacific slope, with well-defined dry periods (December-April) and rainy periods (May- November). On the Caribbean slope there is a continuous rainy period, with only small decreases in rainfall during April and October. The Caribbean slope has approximately 70% of the region's water resources while the Pacific has roughly 30%. This is the opposite of the situation vis-à-vis the concentration of population and productive activities. As a consequence a dry and therefore highly vulnerable corridor spans the entire region, mainly on the Pacific slope.

The historic climate pattern in the region (Central America and southern Mexico) also includes a dry period within the wet season, called the canicula. The timing and severity of the canicula is perhaps the most serious climate risk factor to farmers, and is a major factor for farmers' cropping decisions. When the canicula is very dry or longer than usual, it threatens crops in both the primera (May to August) and postrera (September to November) seasons.

Photo: Axel Schmidt

The region's productive capacity in agriculture is further influenced by the widespread degradation of agriculture lands and watersheds. About 80% of Central America's agricultural land is estimated to be affected by human-induced soil degradation, the highest percentage of any region in the world. Central America is the only region in the world where agricultural mismanagement is the leading cause of soil degradation, over and above deforestation (Oldeman et al., 1991, Zurek, 2002). The severe soil degradation in Central America causes massive water run-off. Most water is "lost", rather than infiltrated and used by plants for biomass production through transpiration. Future modeling predicts temperature rises (causing higher rates of evaporation and transpiration) while rainfall is predicted to fall (reduced precipitation). Without interventions, soil water availability will deteriorate and increase the risk of so-called agricultural droughts (water scarcity in the plant root zone caused by land degradation and poor soil-plant management) (Rockström et al., 2007; Schmidt et al., 2012). Finally, it should be noted that water productivity in Central America is also reduced through insufficient water infrastructure and water management, resulting in poor water quality as well (Beekmann, 2014).

Given these concerning projections, improving water productivity is fundamental for strengthening productive, economically sustainable, environmentally sound, and culturally appropriate agriculture systems that guarantee food security and economic development into the future.

Photo: Axel Schmidt

3. Water & Soil Management Practices – Learning from the past?

Hundreds of millions of dollars have been spent on rural development and agriculture projects in Central America over the past several decades. Projects on water and soil conservation in hillside agriculture were common in the 1990s. For example, the Land Use and Productivity Enhancement Project (LUPE) funded by USAID, and the Programa para la Agricultura Sostenible en Laderas de America Central (PASOLAC) funded by SDC, were implemented in several countries in the region and. In addition, there have been, and continue to be, countless efforts to improve water & soil management as part of development projects.

Did these programs and projects achieve the impacts they intended? One could imagine a long list of evaluation questions: Which projects were successful at changing behavior, which were not, and why? Did initial adoption lead to more sustainable production over the long-term? Were water & soil management practices maintained after the projects ended? Which practices could be identified as the most strategic and successful at improving water productivity? What are the factors that lead to successful adoption and which fail?

Desperately needed are evaluations, discussions and debates that provide a solid knowledge base for future project design, targeted extension and training programs, investment decisions, and policy initiatives. These evaluations would also form an “evidence base” that provides the substance, quality and the credibility to any advocacy effort for rain-fed agriculture with governments, international donors, the development cooperation community, as well as with the private sector.

While there has been a tremendous amount of data and information generated by many different programs and institutions (government and non-government) over the past several decades on rainfed agriculture systems and water management in Central America, it has not been systematically collected and analyzed. It is often impossible to access, making it difficult to evaluate and use. By and large these data are recorded during the project life span or shortly after project termination; critical review and learning from errors in past design and implementation is rarely found. This remarkable lack of in-depth analysis may be due to low capacity in the region for documentation (writing and archiving). Short time frames and quickly shifting directions of funding sources may also prevent institutions from retrospective analysis, review and learning. There may exist fear of sharing results when not everything is a success story. The result is diminished understanding and institutional memory. What data exists collects dust in desk drawers.

The Global Water Initiative (GWI) in Central America seeks continuous learning and knowledge generation. The present document provides inputs for a wider and urgently needed discussion among farmers, the development community, donors and governments about water productivity and management in rainfed agriculture systems in Central America. By collecting, reviewing and synthesizing past experiences with water & soil management practices, deriving lessons learned and identifying gaps, the document offers a foundation for evaluation and information exchange that build a comprehensive knowledge platform.

4. Collecting and Analyzing Information

The primary source for this document is a thorough literature review on practices for water and soil management in the hillsides of Central America. Literature in this context is mostly “grey literature”, or unpublished documents, unregistered and unsearchable in literature or bibliographic catalogues, databases, or the internet. Authors of these documents are predominantly staff of non-governmental organizations, local universities, national research institutions, ministries, or consultants contracted by donors. Documents consist mainly of reports, student theses, or manuals, technical guides and other extension material. The review included the collection of information on the current policy framework for rainfed agriculture systems and management practices. Impact studies conducted in Nicaragua, Honduras and El Salvador were reviewed as well as the literature on water productivity. These studies were core to the literature review and introduced collaborators and partners to the study.

The literature review identified key actors and past projects for in-depth interviews and field visits where individual farmers or farmer groups were asked about their experiences with projects that promoted improved water and soil management. Since field visits took place at least five years after the projects had ended, real adoption rates and the reasons for adoption or non-adoption could be discussed and compared to the final project reports.

In El Salvador, a total number of 11 projects and programs implemented between 1981and 2013 were reviewed based on available documentation. The projects had lasted from 2 to 20 years (multiple program phases) and were predominately financed by international development cooperation (total investment of US$ 123 million). The government program PRODENOR, and the projects PAES and Mi Cuenca were selected for field visits and an in-depth interview process, which was complemented by a formal questionnaire survey among 108 farmers. The field review was conducted in the Departments of San Salvador (San Martin), Cuscatlán (San José Guayabal), Morazán (Torola, Arambala, and Perquín) and La Unión (Nueva Esparta). In Nicaragua, the survey identified 20 programs and projects carried out between 1994 and 2013 with an estimated investment of US$ 250 million. The programs of the Ministry of Natural Resources and Environment (MARENA), POSAF, PIMCHAS, and MST, as well as programs of international cooperation such as PASOLAC, PESA or FOCUENCAS, the research results from CIAT, INTA and UNA, and lessons learned from CRS projects were all reviewed and key technical staff interviewed. In the dry corridor regions of Honduras prioritized by its government, the collection of primary information included participatory consultation events in close collaboration with DICTA. Information was also collected during a study tour with Honduras’ Comité Nacional de Bienes y Servicios Ambientales (CONABISH).

The review process described above took place in national discussion round tables with key actors in each of the three countries. Facilitated by CRS, key informants from government entities, universities, non-governmental and farmer organizations, and finance sector discussed and substantiated the information obtained. These knowledgeable respondents also served as a valuable source of information.

This data and information were consolidated, analyzed and summarized into a draft document on the status of soil and water management practices to improve water productivity in the rainfed agriculture systems in the three countries. The draft was submitted to a broad evaluation and validation process by stakeholders in public fora that included presentations for civil society, government, academia, non-governmental organizations, farmer organizations, experts and international research institutions. The iterative validation process resulted in country specific documents, which will be published elsewhere. The present discussion paper draws on these documents to provide a regional analytical perspective.

5. Agricultural Practices to improve Water Productivity in Central America

Water productivity is intimately linked to soil management, soil fertility management, and thus to agronomy (Breman, Groot, and van Keulen 2001). Agriculture practices can contribute substantially to the improvement of water productivity through two major tasks. The first is to maximize the infiltration of rainfall for increased water retention, thereby avoiding runoff and the loss of both water and topsoil. Equally important is the second task: to minimize evaporation from the soil surface and reduce transpiration by weeds (Keller & Seckler, 2005, Hillel, 2008). Both tasks increase plant water availability and water uptake capacities. By maintaining plant nutrient supply at optimum levels, biomass production per unit water transpired will be maximized. Yield increases are generally linked to improved water productivity demanding optimal crop management (Molden et al. 2007).

The following section describes agricultural practices and systems identified throughout the literature review and field survey as having potential to improve water productivity in the rainfed agriculture systems of Nicaragua, Honduras and El Salvador. They are grouped into agronomic, vegetative and structural practices. Several practices overlap between groups. Detailed technical descriptions of these well-known practices are widely available (e.g. PASOLAC, 2000). The focus of this chapter is the relationship of these practices with water productivity and thus with soil management, soil fertility management, and agronomy.

5.1 Agronomic practices for soil conservation and water management

These practices refer to the application of physical interventions in crop cultivation to maintain or improve long-term production increases and soil health. They focus on protecting the soil surface (reducing runoff and water erosion) and increasing soil organic matter content. These measures improve water infiltration, water retention and nutrient availability for plants, resulting in higher yield and thus higher water productivity.

These agronomic practices are only to a small degree location and crop-specific interventions. They are short-term or point interventions during a cropping period and have to be repeated over several cropping cycles to be effective. Generally, they can be applied in different locations (different soil types and slopes) without major adjustments. The practices contribute to soil rehabilitation and the enhancement of biological, physical and chemical properties (soil health). They provide improved conditions for seed germination, root system development, overall crop development, stress resistance, and eventually, crop yield. The agronomic practices identified during the review and survey that tend to be used most often by small and medium producers in these countries, are: no burn practices, crop residue management, minimum tillage, application of organic fertilizers, sowing density and plant spatial arrangements, and contour farming.

No burn & crop residue management

Since pre-Colombian times, burning of crop residues and natural vegetation has been a common practice in Central America. Residues are usually burned to control insects or disease or to make next seasons' fieldwork easier. Burning destroys the litter layer and thus diminishes the amount of organic matter returned to the soil (Amado et al, 1998). The heat generated by fire accelerates the loss of soil moisture. The organisms that inhabit the soil surface, a portion of the topsoil and

AGRICULTURE PRACTICES can contribute substantially to the improvement of water productivity through two major tasks. The first is to maximize the infiltration of rainfall for increased water retention, thereby avoiding runoff and the loss of both water and topsoil. Equally important is the second task: to minimize evaporation from the soil surface and reduce transpiration by weeds (Keller & Seckler, 2005, Hillel, 2008)

litter layer are destroyed. For future decomposition to take place, energy has to be put first into rebuilding the microbial community before plant available nutrients can be released from the soil to roots.

Burning is also often practiced to improve the quality of grazing land. The philosophy behind the practice is that destroying the dry and non-palatable grass will induce the sprouting of fresh grass. Some of the detrimental effects of long term burning besides soil moisture loss include decreases in organic matter, total nitrogen, total sulfur, carbon/nitrogen ratios, extractable carbon, polysaccharide, ammonium, and available phosphorus (Pimentel et al., 1995; Mills & Frey, 2004). Given these devastating effects on water availability and soil fertility, no-burn practices are a prerequisite, or the first pillar, required for sustainable agriculture and water management in Central America. Although some success in eliminating agricultural burning has been achieved during the last decade (e.g. in Lempira Sur, Honduras), Central America is still choked with fire and smoke each year at the end of the dry season.

The second pillar of sustainable agriculture in Central America is soil cover / crop residue management. Soil cover reduces soil water losses through evaporation by acting as an insulating layer. This diminishes the temperature of topsoil and eliminates the drying effect of wind. Heat from the sun is only slowly transmitted down to the soil surface from surface residue through the air trapped within the residue layer. Consequently the soil surface remains cooler and the rate of soil water evaporation is slowed. The thicker the layer of trapped air, the greater will be the insulating effect.

Soil temperature not only influences the absorption of water and nutrients by plants, seed germination and root development, but also microbial activity and crusting and hardening of the soil. Roots absorb more water when soil temperature increases, up to a maximum of 35˚C. Thereafter higher temperatures restrict water absorption. The reduction of topsoil temperatures enhances germination of most seeds.

Crop residues left on the soil surface lead to higher soil aggregation, increased porosity and a higher number of macropores, facilitating rainwater infiltration. Their decomposition depends on the activity of microorganisms and soil meso and macro fauna. The macro fauna of earthworms, beetles, termites and ants promote the integration of residues into topsoil. Residue cover reduces or eliminates splash erosion. Therefore surface crusting, sealing and rainfall-induced compaction are reduced. The soil cover forms small diversion dams that slow runoff and allow more time for infiltration. Sediment is deposed behind these diversions and remains in the field. Residue cover is one of the most effective and least expensive methods for soil protection (Mitchell et al., 2012). In Choluteca, Honduras, Thurow et al. (2004) reported production increases up to 30% through the use of crop residue in maize systems compared to plots where residues were burned. In some areas it is economically much more effective to use the natural vegetation as soil cover in cropping areas. It is not a new practice, as this is usually done in shifting cultivation systems, when the use of fire is abandoned. An example is the Quesungual Slash and Mulch Agroforestry System in southern Honduras.

The main disadvantage of using residue covers for reducing direct evaporation is the large quantity of residues required, which is considerably greater than the quantity needed to ensure that rainfall infiltrates into the soil. Often, regions with high evaporation losses also suffer from a shortage of rainfall, which restricts production of vegetative matter. Frequently there are also other demands on residues, which take priority, such as fodder, thatching and construction (Klocke et al. 2009; van Donk et al. 2010).

Since crop residues have multiple uses as dry season forage, fuel and building material, and since available residue amounts differ widely among cropping systems, there is no easy answer to the optimal weight (thickness of residue layer) and percentage of soil cover necessary to achieve the described benefits in Central America. Field research is required.

In Choluteca, Thurow et al. (2004) reported production increases up to 30% through the use of crop residue in maize systems compared to plots where residues were burned.

Minimum tillage

This umbrella term can include reduced tillage, minimum tillage, zero or no-till, direct drill, mulch tillage, stubble-mulch farming, strip tillage, and plough-plant (Mannering & Fenster, 1983). No-till farming is a way of growing crops or pasture from year to year without disturbing the soil through tillage. No-till is an agricultural technique, which improves soil quality (soil function), carbon and organic matter retention, nutrient cycling and soil aggregation (Blanco-Canqui et al., 2009). It protects soil from erosion, evaporation of water, and structural breakdown (Derpsch et al., 2010). More water is available for crop production through improved water infiltration (old root channels from the previous crop facilitate deeper rooting and enhance the infiltration and percolation of rainwater), less runoff and reduced evaporative losses. Better infiltration and less crusting allows more water to be stored in the soil profile rather than lost to runoff. Minimizing exposure of the soil surface to wind and sunlight reduces evaporation and keeps the soil surface cooler, often resulting in better rooting, especially near the soil surface. Better rooting makes the plant more efficient in using light rainfall events that don't soak far into the soil profile. One concern is that depending on the soil moisture holding capacity of the soil, this improved infiltration may lead to leaching nutrients below the active crop rooting zone (http://cropwatch.unl.edu/tillage).

The main disadvantage of using residue covers for reducing direct evaporation is the large quantity of residues required, which is considerably greater than the quantity needed to ensure that rainfall infiltrates into the soil. There are also other demands such as fodder, thatching and construction.

There are several factors that can hinder the application of conservation tillage:

(i) Producers are used to using low density planting to suit low moisture availability,

(ii) hand jab planters may be an effective alternative (ACT, 2010).

No-till is so far mainly found in mechanized high production farming with good rainfall, or for wind erosion control where there is large-scale mechanized cereal production. It has been less frequently implemented in low input level crop production or subsistence agriculture in hillsides. But the principles are equally effective in any conditions - maximize cover by returning crop residues, don't invert the topsoil layer, and use a high crop density of vigorously vegetative crops. Conservation tillage also has the advantage of reducing the need for terraces or other permanent structures.

There are, however, several disadvantages, which can hinder the application of conservation tillage. Dense plant covers may be incompatible with the well-tested strategy of using low plant populations to suit low moisture availability. Crop residues may have competing value as feed for livestock (Reyes et al., 2013), and planting through surface mulches is not easy for ox-drawn planter. Hand jab planters may be an effective alternative (ACT, 2010).

Organic fertilizers

Organic fertilizers are fertilizers derived from animal or vegetable matter (e.g., compost, leaves, manure, slurry, worm castings, peat). Processed organic fertilizers include compost, blood meal, bone meal, fish meal, and feather meal. Decomposing crop residue or nitrogen rich green manure from prior years is another source of fertility.
Although the density of nutrients in organic material is comparatively modest, they have many advantages. The majority of nitrogen-supplying organic fertilizers contains insoluble nitrogen and acts as a slow-release fertilizer (Prasad et al., 2004). By their nature, organic fertilizers increase physical and biological nutrient storage mechanisms in soils, mitigating risks of over-fertilization. Organic fertilizer nutrient content, solubility, and nutrient release rates are typically much lower than mineral (inorganic) fertilizers. Cong et al (2006) showed that potential mineralizable nitrogen in the soil was 182–285% higher in organic mulched systems than in the synthetic control.

Organic fertilizers also re-emphasize the role of humus and other organic components of soil, which are believed to play several important roles. These include mobilizing existing soil nutrients so that good growth is achieved with lower nutrient densities, while wasting less. In addition, organic fertilizers release nutrients at a slower, more consistent rate, helping to avoid the boom-and-bust pattern of inorganic fertilizer applications. Organics increase soil moisture retention, reduce temporary plant moisture stress, improve soil structure and thus prevent topsoil erosion (Bot & Benitez, 2005). Where animals provide organic fertilizer for cropped parcels, the development and management of integrated crop livestock systems is an important opportunity to improve soil and water management, given that most of the water for agriculture runs through mixed production systems (Simon Cook, pers. communication).

The production and application of organic fertilizer has been promoted for many years in Central America despite the higher labor and transport costs relative to inorganic fertilizers. The composition of organic fertilizers tends to be more complex and variable than a standardized inorganic product, making fertility management more difficult.

The production and application of organic fertilizer has been promoted for many years in Central America, however it requires higher labor and transport costs relative than inorganic fertilizers; likewise, its management is more difficult.

Planting density / spatial arrangements

During the field surveys, farmers identified adjustments to the spatial distribution of seed for basic grain production as a simple and effective practice to improve water productivity. It has been well established that low maize production in Central America is linked to inadequate row spacing and in-row planting distances, resulting in low plant populations and yield (Bolaños, 1995). Lamm et al. (2009) found that increasing plant density from 66,300 to 82,300 plants/ha generally increased grain yield and water productivity of maize in Kansas (USA). However, there is some indication that the positive relationship between plant density and water productivity only applies if water and nutrient supply are not limited.

Al-Kaisi and Yin (2003) found that on more sandy soils in northeast Colorado, the optimal plant density for corn is less than 60,000 plants/ha. This signals the need for lower planting density for soils with lower water holding capacity. Dalianis et al. (1996) report that decreasing plant density increased water productivity in sorghum in a Mediterranean climate. Farahani et al. (2007) showed decreasing water productivity with increased density in maize plots in Iran. These different results indicate that plant density is an important factor in maximizing water productivity and that plant density shifts for specific soils and locations.

A second factor to consider is the effect of increasing plant density per unit area on water consumption. Sinclair & Gardner (1998) describe this as perhaps the most important source of growth in food production over the past few decades. Since increased plant density increases total biomass per unit area, total transpiration per unit area would increase proportionally. However, as noted before, increased plant densities also decrease evaporation losses from the soil. Thus total evapotranspiration would not increase proportionally and some of the reduced evaporation losses would be transferred to transpiration (Keller & Seckler, 2005).

Passioura & Angus (2010) discussed the well-known principle that the yield of a crop growing on stored water is determined not just by the total amount of water available within the root zone but also by the rate at which it becomes accessible to roots. For cereals to achieve maximum yield, this rate should be such that when roots stop growing after the onset of flowering, water continues to reach them by mass flow down a potential gradient. The availability of water during the period when grains are filling helps to delay leaf senescence so that the duration of this phase is longer than when metabolites are drawn from resources in the stem. A more uniform planting geometry, avoiding wider row spacing and multiple seed planting per hole, would improve soil water availability in the root zone.

More research is needed to determine optimum plant density in Central America.

Changes in plant density can provide significant increases in water productivity if they are adjusted to location-specific rainfall and soil conditions. However, more research is needed in the case of Central America to determine optimum plant density. The traditional planting arrangements and thinning out of crop canopies is also s a flexible way to adapt to uncertain environmental conditions. Adjustments in planting density must be combined with other practices to ensure soil water availability during the decisive crop development stages.

Contour farming

Contour farming is the practice of tilling sloped land along lines of consistent elevation perpendicular to the slope line in order to conserve rainwater and reduce soil losses from surface erosion. These objectives are achieved by means of furrows, crop rows, and wheel tracks across slopes, all of which act as reservoirs to catch and retain rainwater, thereby permitting increased infiltration and more uniform distribution of water. When combined with crop residue management and cover crop practices, contour farming contributes to soil water retention through decreased evaporation. In water-logged soils, contours should have an offset of 0.5% to ensure adequate drainage without erosion. Contour farming has been practiced for centuries in parts of the world where irrigation is important. In Central America contour farming is found predominately in maize-bean systems and has yet to be consistently combined with other agronomic practices such as zero tillage, reduced seeding rate and row spacing. Contour farming is found throughout the three countries and costs do not differ from conventional soil preparation and planting. It is easy to implement but requires behavior change (FAO, 1993).

Adjustments in planting density must be combined with other practices to ensure soil water availability during the decisive crop development stages.

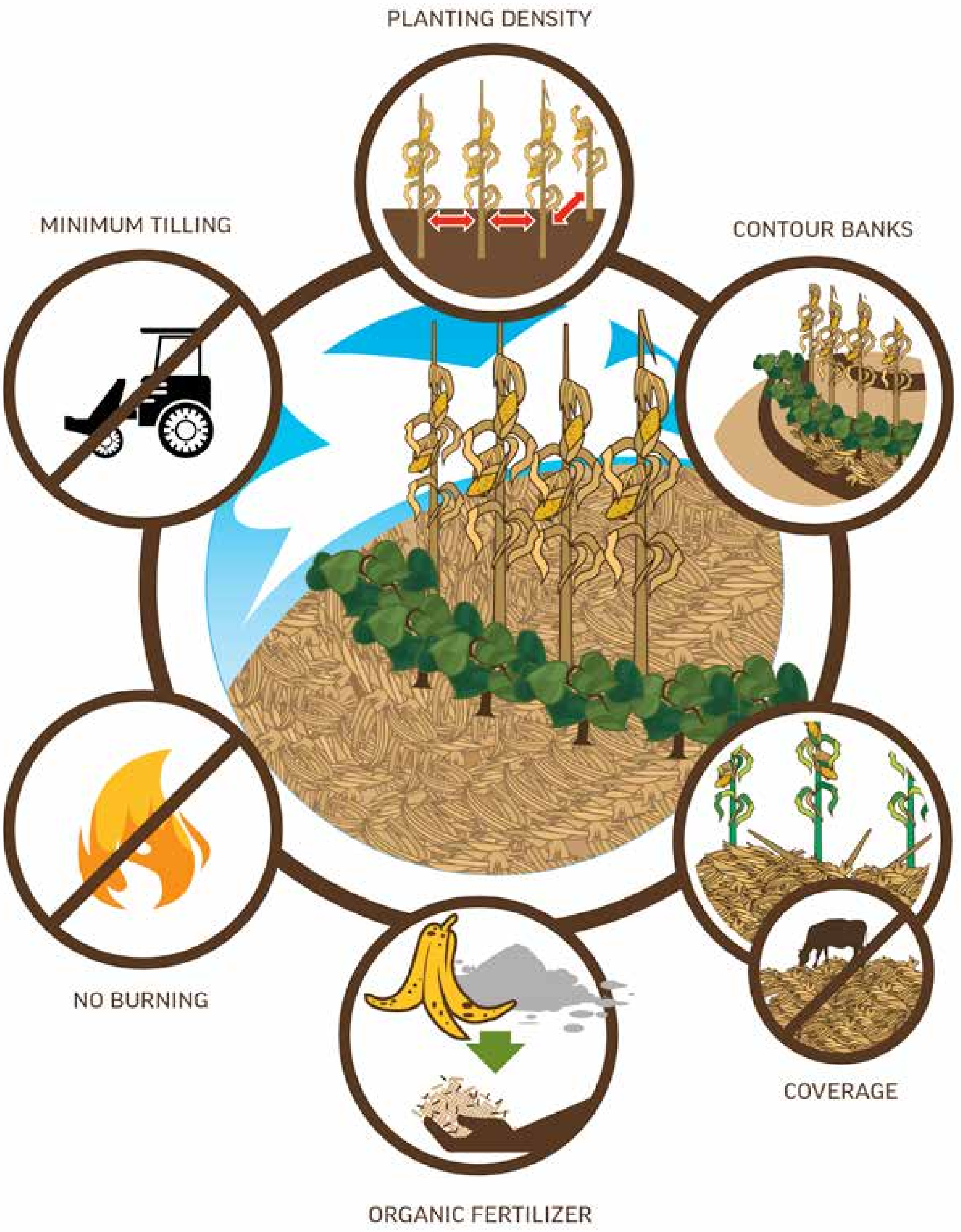
All of the identified agronomic practices require an integrated farming system approach. They reach their full potential to improve water productivity only when combined over repeated production periods. While each of them is fairly easy to implement, their timely application within location-specific conditions requires knowledge, planning and adaptation.

Contour farming, Nicaragua Photos: Jose Angel Cruz

Contour farming is found throughout the three countries and costs do not differ from conventional soil preparation and planting. It is easy to implement but requires behavior change (FAO, 1993).

All of the identified agronomic practices reach their full potential to improve water productivity only when combined over repeated production periods.

AGRICULTURAL PRACTICES



5.2 Vegetative practices for soil conservation and water management

These measures involve the deliberate planting of trees, shrubs, grasses, or the retention of areas of natural vegetation (e.g. reforestation, contour hedgerows, and natural vegetative strips), which are of long duration and can lead to a change in slope profile. They tend to be zoned on the contour or at right angles to wind direction and spaced according to steepness of slope.

Live Barriers

Live barriers are strips of vegetation planted along the contour, which serve to anchor the soil in place with plant roots and slow down the movement of water downslope. They are planted above hillside ditches to prevent the ditches from filling with soil and to prevent hillside erosion. The most common types of live barriers are plants from the grass family because of the dense foliage and root system networks produced. In addition the grasses are valuable as forage for animals, or, in the case of sugar cane and lemon grass, for human consumption. Many plant species have great potential as live barriers, especially when considering agroforestry systems where contour strips of nitrogen-fixing and/or wood or fruit producing trees may be used.

In areas where soil texture is high in sand, infiltration is generally not a problem and infiltration ditches are not appropriate as they collapse with rainfall. Under these conditions, permanent live barriers, especially in combination with cover crops, can stem the loss of water downslope, stabilize soil structure and increase organic matter in the root zone, which with time, increases soil water holding capacity. In Nicaragua, Honduras and El Salvador live barriers are reported to increase soil retention, reduce run-off and nutrient loss, and increase biomass production, contributing to improved water productivity (Thurow & Smith, 1998; Welchez, 1999; Mendoza & Cassel, 2002; Pérez, 2003; Gámez, 2006; López, 2008).

Intercropping

Intercropping is the practice of growing two or more crops on the same unit of land that differ in growth habits, phenological characteristics and productivity (IITA, 1980). The most common goal of intercropping is to produce a greater combined yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop (Ouma & Jeruto, 2010). Careful planning is required, taking into account the soil, climate, crops, and varieties. It is particularly important that crops not compete with each other for physical space, nutrients, water, or sunlight. Examples of intercropping strategies are planting a deep-rooted crop with a shallow-rooted crop, or planting a tall crop with a shorter crop that requires partial shade.

When crops are carefully selected, other agronomic benefits are also achieved. Lodging-prone plants, those that are likely to bend over in wind or heavy rain, may be given structural support by their companion crop. Creepers can also benefit from structural support. Some plants are used to suppress weeds or provide nutrients. Delicate or light-sensitive plants may be given shade or protection, or otherwise wasted space can be utilized. An example is the tropical multi-tier system where coconut occupies the upper tier, banana the middle tier, and pineapple, ginger, or leguminous fodder, medicinal or aromatic plants occupy the lowest tier (Trenbath, 1976; Mt. Pleasant, 2006)

The degree of spatial and temporal overlap in the companion crops can vary somewhat, but both requirements must be met for a cropping system to be an intercrop. Numerous types of intercropping, all of which vary the temporal and spatial mixture to some degree, have been identified (Lithourgidis, 2011). Mixed intercropping, as the name implies, is the most basic form in which the component crops are totally mixed in the available space. Variations include alley cropping, where crops are grown in between rows of trees, and strip cropping, where multiple rows, or a strip, of one crop are alternated with multiple rows of another crop. Row cropping arranges the component crops in alternate rows.

Intercropping also uses the practice of sowing a fast growing crop with a slow growing crop, so that the fast growing crop is harvested before the slow growing crop starts to mature. This obviously involves some temporal separation of the two crops. Further temporal separation is found in relay cropping, where the second crop is sown during the growth of the first, often near the onset of reproductive development or fruiting, so that the first crop is harvested in time to make room for full development of the second.

In Nicaragua, Honduras and El Salvador live barriers are reported to increase soil retention in combination with cover crops and other complementary practices, reduce run-off and nutrient loss, and increase biomass production, contributing to improved water productivity (Thurow & Smith, 1998; Welchez, 1999; Mendoza & Cassel, 2002; Pérez, 2003; Gámez, 2006; López, 2008).

Although intercropping is practiced in Central America, its potential is far from fully developed. The most common forms are maize-bean systems where typically, the C4 cereal crop, maize, is the dominant plant species, whereas the C3 legume crop, such as Phaseolus bean, is the associated or secondary species. Canopy structures and rooting systems of cereal crops are generally different from those of legume crops, e.g. maize can form higher canopy structures than beans (Allen et al., 1998). This suggests that the component crops have differing spatial and temporal use of environmental resources. Intercrops may make use of radiation, water and nutrients more efficiently than monocrops (Willey, 1990).

The legume/cereal intercropping pattern is generally more productive than a reference sole crop (Tsubo et al., 2005). The biological basis for intercropping involves complementarity of resource use by the two crops (Gaballah & Ouda. 2008).

Increased productivity of intercropped soybean and maize over the sole crop has been attributed to better use of solar radiation (Keating & Carberry, 1993), nutrients (Willey, 1990) and water (Morris & Garrity, 1993). Intercrops have been known to conserve water, largely due to early high leaf area index and higher leaf area (Ogindo & Walker, 2005). Morris & Garrity (1993) found that water capture by intercrops is about 7% higher compared to a sole crop. Water use efficiency was higher under soybean/maize intercropping as compared to sole maize and sole soybean (Borhom, 2001, cited in Gaballah & Ouda. 2008). Similarly, Morris & Garrity (1993) reported that water use efficiency of intercrops was higher by about 18% compared to sole crop. Considering the reduced risk of crop failure, intercropping is a good option for climate change adaptation in agriculture systems.

Although intercropping is practiced in Central America, its potential is far from fully developed, but we know they can make better use of solar radiation, nutrients and water in a more efficient way compared to sole crop (Willey, 1990).

Mucuna-Maize System in northern Honduras: Cover crop use in Central America has been widely documented in these systems. It decreased the labor required for maize farming even as it increased yields, increased water infiltration. Higher infiltration rates and porosity affect profile recharge and water holding capacity which in turn makes more water available to the maize crop, supporting such important biological activities as decomposition and mineralization (Buckles et al., 1998; Neill & Lee, 1999; Anderson et al., 2001).

Cover Crops

A cover crop is a crop planted to manage soil fertility, soil quality, water, weeds, pests, disease, biodiversity and wildlife within an agroecosystem (Lu et al. 2000). By reducing soil erosion, cover crops often reduce the rate and quantity of water that drains off the field, which would normally pose environmental risks to waterways and ecosystems downstream (Dabney et al. 2001). Cover crop biomass acts as a physical barrier between rainfall and the soil surface, allowing raindrops to steadily trickle down through the soil profile. Cover crop root growth results in the formation of soil pores, which in addition to enhancing the habitat of soil macro fauna, provides pathways for water to filter through the soil profile rather than draining off the field as surface flow. With increased water infiltration, the potential for soil water storage and the recharging of aquifers is improved (Joyce et al. 2002).

Just before cover crops are cut, they contain a large amount of moisture. For that reason, they are sometimes called 'catch crops'. When the cover crop is incorporated into the soil, or left on the soil surface, it often increases soil moisture. In agroecosystems where water for crop production is in short supply, cover crops can be used as a mulch to conserve water by shading and cooling the soil surface and reducing evaporation of soil moisture.

While cover crops can help to conserve water, they can also draw down soil water supply in low rainfall areas. In these cases, farmers often face a tradeoff between the benefits of increased cover crop growth and the drawbacks of reduced soil moisture.

Cover crop use in Central America has been widely documented, particularly the maize-mucuna system in Northern Honduras. In the early 1970s, farmers in this region began rotating maize with the velvetbean (Mucuna ssp.), a system learned from Guatemalan immigrants.
The mucuna-maize system decreased the labor required for maize farming even as it increased yields, prevented erosion, and conferred a variety of other agronomic benefits such as increased water infiltration. Higher infiltration rates and porosity affect profile recharge and water holding capacity which in turn makes more water available to the maize crop, supporting such important biological activities as decomposition and mineralization (Buckles et al., 1998; Neill & Lee, 1999; Anderson et al., 2001).

Buffer Zones / Reforestation

Buffer zones are defined as a strip of vegetated land between the agricultural land and a body of water. Buffer zones are the last line of defense to buffer a water body from the effects of land use activities. The wider the vegetated buffer zone, the more effective it is at filtering sediment and pollutants and storing runoff. The width of a buffer zone depends on its function.

The principal benefits of buffer zones are trapping and storing sediments by creating a separation between a body of water and cultivated land. The buffer reduces sedimentation of the water body, which translates to reduced maintenance of the water body. Runoff water quality improves, with beneficial impacts on the landscape and the watershed. In addition, buffer zones stabilize river banks.

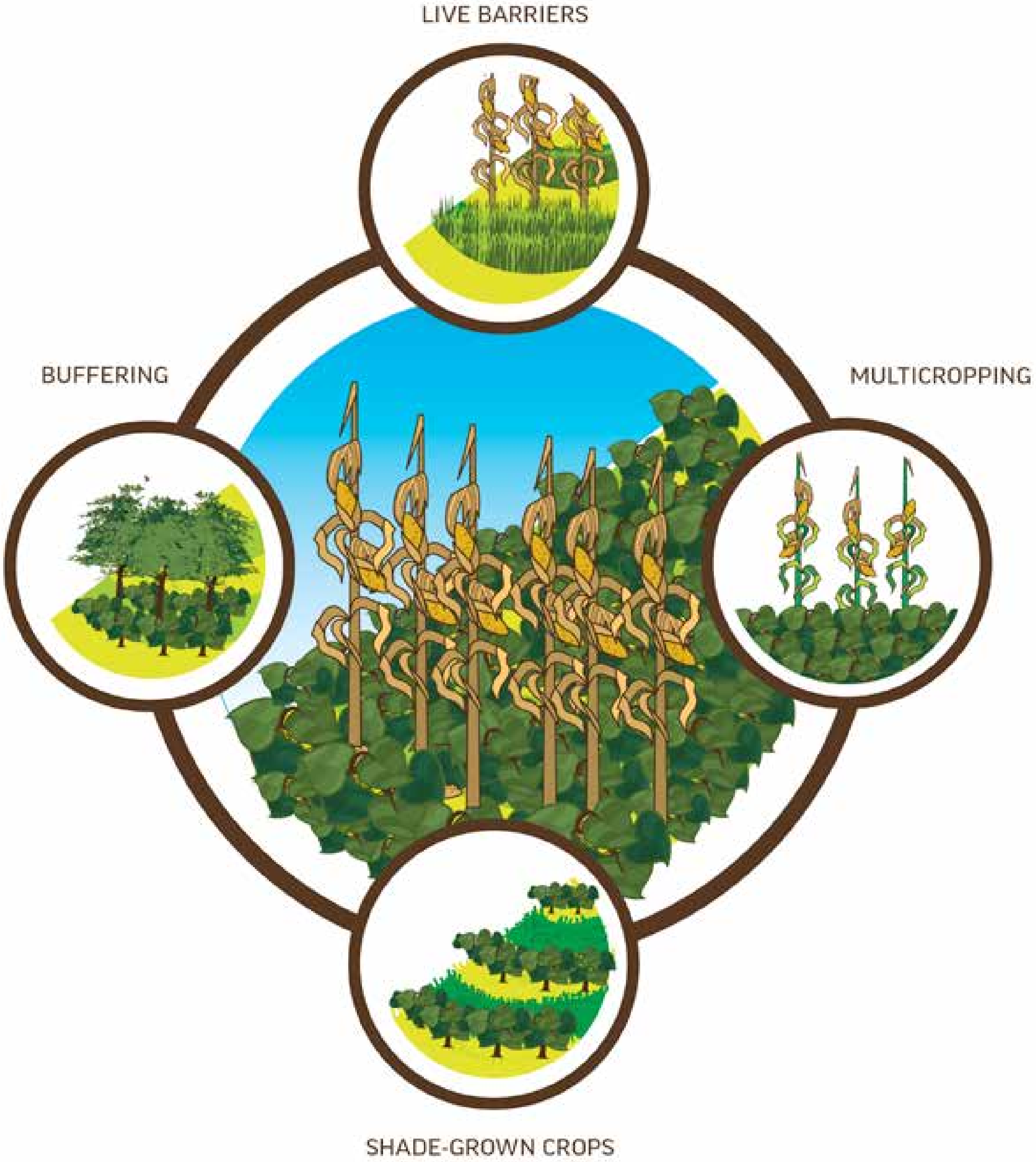
The root system of the buffer zone vegetation and trapped sediments binds the soil on the bank and increases its stability. The vegetation on the bank increases the surface roughness and slows surface runoff. This minimizes the impact of heavy rain, decreases bank erosion and minimizes channel movement.

Buffer zones also contribute to improved water storage, reduced flooding and increased aquifer recharge. The extensive root systems of vegetation in buffer zones increase the water holding capacity of the soil and aquifer recharge by improving soil porosity. During high rainfall events, runoff to rivers and creeks is slowed down by storage of water. The risk of flooding is lowered. Finally, strategically planned buffer zones with trees can act as a wind barrier to conserve valuable top soil (Haycock et al., 1997) and reduce evapotranspiration. In Honduras such buffer zones are contemplated in the Ley Forestal, Art. 123, (Legislation on Forests), although implementation is limited (see Chapter 7).

> Buffer zones contribute to improved water storage, reduced flooding and increased aquifer recharge. Buffer zones with trees can also act as a wind barrier to conserve valuable top soil (Haycock et al., 1997) and they reduce evapotranspiration.

> In Honduras such buffer zones are contemplated in the Ley Forestal, Art. 123 of the Legislation on Forests, although implementation is limited.

VEGETATIVE PRACTICES



5.3 Structural practices for soil conservation and water management

Structural practices involve the construction of physical structures (e.g. graded banks or bunds, contour stone lines, level bench terraces, artificial waterways and drop structures) to increase the time and concentration of runoff, thereby allowing more of it to infiltrate into the soil nearer where precipitation falls. These practices lead to a change in slope profile, dividing a long slope into several short ones and thereby reducing amount and velocity of surface runoff and resulting damage. These physical structures are of long duration or are semi-permanent and require substantial inputs of labor or investment when first installed and over time for maintenance. They are zoned on the contour and spaced according to slope (Hudson, 1995). They are an important part of water and soil conservation practices, particularly under the climatic conditions dominating Central America, with torrential rain events and prolonged dry spells (canicula).

Contour trenches

Contour trenches are the practice of plowing fields at a right angle to the slope. Contour trenches are infiltration ditches dug along a hillside in such a way that they follow a contour and run perpendicular to the flow of water. The soil excavated from the ditch is used to form a berm (a narrow shelf) on the downhill edge of the ditch, although observations of some systems in Central America indicate that the berm, often referred to as a 'bund' in Asia, is uphill from the ditch. The berm can be planted with permanent vegetation (native grasses, legumes) to stabilize the soil, while the roots and foliage trap any sediment that would overflow from the trench in heavy rainfall events. Contour trenches are used to slow down and attract runoff water, which then infiltrates into the soil. Data from CENTA (2000) showed infiltration through contour trenches of 7400 m3/ha/y in Guaymango and San Juan Opico, El Salvador, while reducing soil erosion by 40 t/ha/y (Argueta, 2000).

Small-scale contour trenches can also be used within a level field. Depending on local sub-surface conditions (geological layers blocking infiltration), contour trenches facilitate recharge into surrounding groundwater systems which in turn improves soil moisture and regulates water flow. Recharge capacity depends on permeability and rainfall. Information in Central America on both topics is difficult to acquire, given poor field data recording and availability. Contour trench construction requires either high labor inputs or mechanical excavation machinery resulting in high implementation costs. In addition, trenches will silt up with time and need regular maintenance.

It must be kept in mind that contour trench construction requires either high labor inputs or mechanical excavation machinery resulting in high implementation costs. In addition, trenches will silt up with time and need regular maintenance.

Stone wall barriers not only help reduce water and soil losses, but also help minimize the slope gradient to facilitate cultivation. A disadvantage of dead barriers is that when they are impermeable, they can result in unintentional gullies leading downslope on either side of the dead barrier when rainfall is intense.

Dead barriers

Dead barriers function similarly to live barriers, the difference being that they are composed of rocks, plant residues, or other non-living materials. If rocks are present in a field, they are a useful construction material and their removal from the soil makes it easier to work. Another advantage is that the work can be completed during the dry season, meaning that they are in place and functioning at the start of the rainy season. If enough rocks are present, the barriers can be constructed as rock walls of sufficient height so that bench terraces are formed as the soil fills in behind each wall. If sufficient rocks are not present, the barriers lose their effectiveness as the soil fills in behind them, and they should be supplemented with the planting of live barriers. Stone wall barriers not only help reduce water and soil losses, but also help minimize the slope gradient to facilitate cultivation. A disadvantage of dead barriers is that when they are impermeable, they can result in unintentional gullies leading downslope on either side of the dead barrier when rainfall is intense.

Terraces

Terraces can be defined as mechanical structures comprising a channel and a bank made of earth or stone. They are constructed perpendicular to the slope. Terraces intercept runoff and encourage infiltration, evaporation or diversion towards a predetermined and protected safe outlet at a controlled velocity, which prevents channel erosion. They increase soil moisture content through improved infiltration, smooth the topography and improve the conditions for mechanization (FAO, 2000).

Terraces can considerably reduce soil loss due to erosion if they are well planned, correctly constructed and properly maintained. Results obtained in Paraná, Brazil, showed that terracing makes it possible to reduce soil losses by half, quite independently of the system of cultivation employed. The efficiency of a terrace system will also depend on the adoption of other conservation practices such as contour planting, strip cropping and soil cover. Other factors to be taken into account are the dimensions and type of construction, as well as their stability and how well they function (Rufino, 1989).

Terraces are generally recommended for slopes of 4 to 50 percent (Rufino, 1989). At all sites studied, the production of above-ground biomass and increase in yield was greater on terraced plots, even under dry conditions. However, many walls are not protected with vegetation, as recommended, and failure to maintain these structures reduces their effectiveness.

Because terracing requires a substantial investment, it should only be introduced when soil erosion cannot be controlled by the application of simpler soil conservation practices. Terracing is useful in situations where runoff is common but cannot be adequately controlled by other conservation practices, and where the intensity and volume of runoff surpass the water storage capacity of the soil. Terraces are generally recommended for slopes of 4 to 50 percent (Rufino, 1989).

A path-breaking example of successful implementation of terraces in Honduras was studied by Thompson (1992), as part of the USAID LUPE project. Thompson concluded in his evaluation of the project in the department of Choluteca, that terraces built with stone retention walls are effective in retaining topsoil, thus reducing soil loss. Plots utilizing a combination of stone walls and mulch cover showed the least soil movement. The shallow but fertile soils of the study sites were derived

from basaltic parent material. Thompson detected no significant decline in soil chemical properties and found that soil organic matter content accumulated directly above terrace walls at all sites.
Terracing increased water storage capacity by maintaining greater topsoil depth, by creating improved soil through deposition above the stone walls, and by producing soils with reduced amounts of coarse fragments. Terracing positively affected grain yield, attributed to more available water. At all sites studied, the production of above-ground biomass was greater on terraced plots, demonstrating that terraces provide improved growing conditions if soil water is not depleted below critical levels.
Thompson points out problems concerning terrace wall stability which can arise as soil is redistributed within terraces. Many walls were not protected with vegetation, as recommended. Failure to maintain these structures reduces their effectiveness. He also notes that production area is reduced due to the space occupied by retention walls. However, this area loss can be offset by yield increases even under dry conditions.

Drainage waterways

Safe waterways are natural drainage lines or are specially constructed drainage lines that lead the runoff from storm water diversion drains and channel terraces downslope to lower-lying areas. They should be protected with native vegetation, and designed with a shape and cross section capable of conducting the maximum expected runoff without risking erosion of the sides or channel of the waterway. Normally, safe waterways can be established by taking advantage of natural drainage lines, depressions, fields under pasture, or the edges of thickets, woods and bush areas (Sheng, 1989; FAO, 2000).

Drainage waterways are the principle component of floodwater farming, practiced for centuries by the Hopi and Navajo Indians of northern Arizona, and the Papago Indians of southern Arizona. These techniques make simple barriers of wooden posts and woven brush to slow and spread natural floodwaters more evenly into valleys. Such farming of valley bottoms is an ancient practice and has been well documented in Tunisia and the Negev desert in Israel. The diversion of runoff water onto prepared level terraces is another old and widely used method (Hudson, 1987).

Through the drainage waterways, run-off is diverted and harvested to improve water availability in flatter areas, while avoiding erosion and severe gullies on higher slopes. This measure can be linked to water harvesting practices, described below.

Water harvesting

Water harvesting is the collection of runoff, which may be collected from roofs and ground surfaces as well as from intermittent or ephemeral watercourses. Uses include human and livestock consumption, agriculture (crop, fodder, pasture, trees, kitchen gardens, agro-processing) and for environmental management (forests, protected areas, wildlife) (Critchley & Siegert, 1991; FAO, 1994; Falkenmark et al., 2001; Anderson & Burton, 2009; Scheierling et al., 2013).

Water harvesting offers under-exploited opportunities for the predominantly rainfed farming systems in Central America. It follows a simple principle of capturing potentially damaging runoff and using it for plant growth or water supply. This is particularly important in areas where rainfall is limited, uneven or unreliable with pronounced dry spells such as Central America (McCartney et al., 2013).

Water harvesting stores the water and makes it available where and when there is shortage. Water harvesting buffers and bridges drought spells and dry seasons and can reallocate water within a landscape, and over time. Water harvesting captures water for domestic use, replenishes green water supplies or increases the availability of blue water locally (Mekdaschi & Liniger, 2013).

Water harvesting has been practiced successfully for millennia and some recent interventions in Central America have had significant local impact (e.g. Cajina Canelo & Faustino, 2007; Pulver et al., 2012). Yet water harvesting's potential remains largely unknown and unappreciated in the region.

The applicability and impact of water harvesting technologies depend on local conditions, with varying "pros" and "cons". On the "pro" side, improving the efficiency with which rainfall is used reduces pressure on traditional water resources and hence on water itself. It provides alternatives to full-fledged irrigation schemes fed by blue water resources (surface and ground water), which are not always economically and technically feasible in smallholder operations. With water harvesting techniques, production risks are reduced, resulting in reduced vulnerability and increased farm resilience.

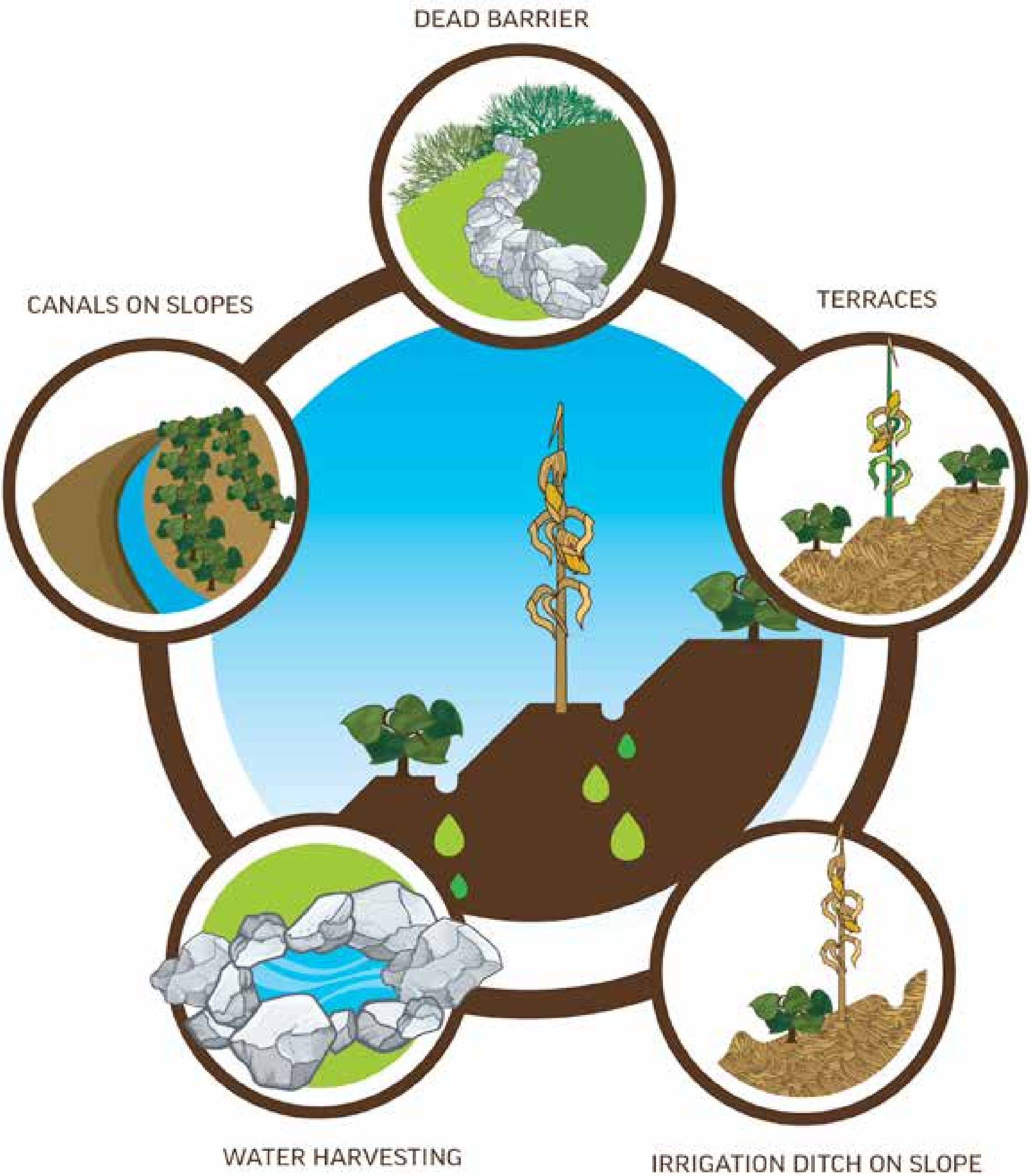
Water harvesting technologies also comes with uncertainties and risks; the first is dependence on variable rainfall. In Central America, the prevailing climatic conditions include strong seasonality and erratic rainfall, which may present challenges in ensuring sufficient quantity of water when needed. Supply of harvested water is limited by storage capacity, design and costs of water harvesting structures, particularly the high initial investments and/or labor requirements for maintenance. In addition, structures and catchment areas may take up productive land, a limited resource in most areas of Central America. Further challenges include jointly used structures which can lead to maintenance disagreements, upstream-downstream rights disagreements, and problems in acceptance of new systems and associated rules and regulations. There is also the possibility that uncoordinated implementation of water harvesting structures may deprive downstream ecosystems of water, especially where floodwater is diverted (Prinz, 1996; Falkenmark et al., 2001; Liniger & Critchley, 2007; Rockström et al., 2007; Anderson & Burton, 2009; Liniger et al., 2011; Critchley & Gowing, 2012; Oweis et al., 2012; Scheierling et al., 2013). Given agro-ecological conditions in Central America and predicted impacts of climate change on agriculture systems in the region (Schmidt et al., 2012), water harvesting is an important strategic practice to improve water productivity. There appears to be real potential for water harvesting in the drought-prone areas of Nicaragua, Honduras, El Salvador. What is missing, however, is the identification of areas where soil parameters, rainfall and temperature regimes, evaporation pressure and slope formation offer conditions for successful implementation. A clear estimate of how much water is really "harvestable" in each area is necessary to define location-specific irrigation strategies and plans, taking into account crops with the highest water use efficiency potential, time of the year and phenological crop stages, market opportunities and prices. In addition, an assessment of the impacts of widespread water harvesting on the green and blue water resources of specific landscapes and the lower parts of watersheds is not available.

In summary, the regulation of runoff during heavy rain events is a strategic approach to improve water productivity in Central America through increasing water infiltration, storage of water to cover dry spells and expanding production into the dry season. The structural practices identified during field surveys and discussion tables with farmers provide measures that will reduce water-related risks posed by high rainfall variability. These infrastructure activities require not only the investments to build them but demand constant maintenance. They are likely to change the hydrological cycle of a landscape and affect upstream and downstream relationships. Careful planning, monitoring and measurements are necessary for the implementation of such structures. Only in combination with agronomic and vegetative practices within a production systems approach will the real potential of these structures be realized and justify the investment.

The structural practices identified during field surveys and discussion tables with farmers provide measures that will reduce water-related risks posed by high rainfall variability. However, they are likely to change the hydrological cycle of a landscape and affect upstream and downstream relationships.

Photo: Jim Patrico, Progressive Farmer Magazine

STRUCTURAL PRACTICES



5.4 Agriculture Systems and their Water Productivity

Practices to improve water productivity are not stand-alone interventions. Only the combinations of agronomic, vegetative and structural practices unleash their full potential for soil and water management. The practices are linked by interaction and interdependence to achieve a specified production objective within an agriculture system. In order to manage and achieve sustainable outputs from these systems, the interactions and interdependencies have to be understood. They depend heavily on location-specific soil and climatic conditions and the specific plant species, factors not always well understood by the agronomists providing technical assistance to farmers (see complementary report on extension services in Central America). It is therefore appropriate to evaluate agriculture systems or systems approaches for their impact on water productivity. Given the diversity of agriculture systems, this section will solely focus on agroforestry, conservation agriculture and crop-livestock systems. These three system approaches are commonly considered as having the most potential to improve water productivity in rainfed agriculture and have been heavily promoted over the last decade in Central America.

Practices to improve water productivity are not stand-alone interventions, rather they are a combintacion of agronomic, vegetative and structural practices.

Agroforestry

Agroforestry describes a complex land use system where trees are grown in association with agricultural crops, pastures or livestock. There are both ecological and economic interactions between system components. Agroforestry systems are diverse in their spatial and temporal arrangement and design and provide environmental functions required for ecosystem sustainability (Wallace et al., 2004). Potential benefits from agroforestry can be numerous, ranging from diversification of production to improved natural-resources utilization. The key benefits in terms of natural-resources use are soil conservation for erosion protection as well as improved soil fertility. Under what conditions the mix of trees and crops improves the overall rainfall-use efficiency is a complex issue. It depends on whether water productivity gains are calculated directly, as quantity or rain used for transpiration in support of plant growth, or indirectly, by increasing water productivity, in terms improving the ratio of biomass or yield over volume of water utilized.

Wallace et al. (2004) describe the challenge of ascertaining the water balance of an agroforestry system. The balance includes processes of interception and radiation intensities that influence evaporation rates from the soil surface and tree canopies. Factors such as plant species, canopy development, rainfall intensity, soil type and their interactions add complexity to understanding the water cycle in these systems.

In humid tropical climates, compared to a mono-crop, the water-balance components of an agroforestry system with 50% tree cover vary up to 50% in increased interception losses. Variation depends on whether the location is continental, montane or coastal. In a semi-arid climate, interception losses are completely compensated for by a decrease in soil evaporation, but only partially in a humid tropical climate. Runoff, soil moisture and drainage are all likely to decrease in an agroforestry system, with the amount varying according to soil type, slope and species. The extra canopy and the ability of tree roots to exploit water deep in the soil will lead to a general increase in transpiration (Schellekens et al. 1999; Wallace et al., 1999; Ong & Swallow, 2003).

There are a number of agroforestry practices that are designed to conserve water and reduce runoff by their direct effect on soil slope. Planting trees or hedgerows on the contour of sloped land can result in formation of natural terraces, as water and soil collect up-slope of the hedgerow. The barrier effect of the hedgerow not only reduces soil loss but also runoff, commonly to about one-third of its value without hedges (Kiepe, 1995 a,b). This increased infiltration rate also reduces runoff in these contour-hedgerow systems (see chapters 5.2 and 5.3).

Similarly, the field survey for this paper revealed data from El Salvador showing 87% erosion reduction, increased biomass production and soil moisture retention up to 20 days in agroforestry plots compared with conventional plots (Segura, 1999). In Carazo, Nicaragua, MARENA-POSAF II (2005 a, b) reported an annual increase of 440 m3/ha of soil water retention in a dispersed tree–cropping system. For multi-story coffee systems in Jinotega, the same source indicates 575 m3/ha/y, and for plots with managed natural tree regeneration in Dipilto, a total of 985 m3/ ha/y. Despite possible methodological challenges in establishing these numbers, they show the positive effects of agroforestry systems on soil erosion, soil water retention and thus on water productivity in Central America.

The most successful and impressive example of the potential of agroforestry systems is the Quesungual Slash and Mulch Agroforestry System (QSMAS) developed in southwest Honduras by local farmers and experts from FAO. QSMAS is a smallholder production system, which applies a group of technologies in the 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, beans, sorghum). The system has also been adopted in other sub-humid regions of southwest and southeast Honduras, northwest Nicaragua, and Guatemala.

Under experimental conditions, QSMAS is at least as effective as slash & burn systems for the production of maize, and more efficient than slash & burn to produce common beans. Undoubtedly, QSMAS increases system resilience, efficient nutrient cycling, improved crop water productivity, and increased and sustained carbon synthesis and accumulation. An important effect is the increased availability of soil water (40 - 74 m3/ha and 15 cm soil depth) in the latter part of the bimodal rainy season, when rainfall is usually irregular (dry spells during key stages of crop development) or inadequate (shorter rainy season) (Baltodano & Mendoza, 2007). The success in increased adoption by smallholders is partially driven by QSMAS' substantial contribution to food security through improved crop water productivity and yields at lower cost; improved water cycling through reduced runoff, erosion, water turbidity and surface evaporation, as well as increased infiltration, soil water storage capacity and use of 'green' water (Castro et al., 2009). There are other situations in which agroforestry systems can increase water productivity, for example, if the understory crop is a C3 species, which is usually light-saturated in the open. The partial shade may have little effect on its assimilation while reducing transpiration (Ong et al., 1996). There can be microclimate modification in agroforestry systems, due to the presence of an elevated tree canopy. This may alter radiation, humidity and temperature around an understory crop. Tree shade increases air humidity around understory vegetation particularly in semi-arid climates, e.g. in systems with shelter belts or wind-breaks (Brenner, 1996).

Agroforestry systems can improve water productivity where water depth is beyond the reach of crop rooting systems. This depends on the specific tree species and their root systems, and the presence or absence of impenetrable soil layers. Since trees are the permanent components of agroforestry systems, trees can use the water from rain that falls outside the cropping season and increase soil water content underneath their canopies if the water 'saved' by reduced soil evaporation, combined with funneling of intercepted rainfall as stem flow exceeds that removed by the root systems beneath tree canopies (Ong & Leakey, 1999). At high tree densities (depending on canopy architecture), the proportion of rainfall 'lost' as interception by tree canopies and used for tree transpiration would exceed that 'saved' by shading and stem flow, resulting in drier soil below the tree canopy. Van Noordwijk & Ong (1999) expressed this as the amount of water used per unit of shade. This may be one of the most important factors for the observed difference between savannah and alley-cropping systems and between cloud-forest vegetation and fast-growing tree plantations.

Although there is clearly great potential for agroforestry systems to conserve and improve the use of water resources, agroforestry does not automatically brings about all of the above benefits. To maximize benefits, an agroforestry system must be designed for the given environment (climate, soil), it must be feasible within local and on-farm constraints, and it must be economically viable and acceptable to the farmer. If not well managed, an agroforestry system, as with any agricultural or forestry system, leads to multiple competitive interactions and may undermine efficient water use. It is important to bear in mind that tree-crop interactions may change from competitive to complementary or neutral, depending on the age, size and population of the dominant species, as well as the supply and accessibility of resources needed for plant growth.

A major challenge is how to look beyond the plot and farm level in order to understand interactions between plots and the landscape, watershed and regional scales (catchment hydrology). The conventional approach is to sum across areas of similar hydro-ecological conditions, assuming that the factors involved in scaling up are proportional to the area occupied by each zone. However, this approach might overstate the beneficial effects of water saved at the plot level, since water used in one plot is not available to down-slope plots. This approach also misses the effect of land use on the quality of water available to down-slope users (Ong & Swallow, 2003).

Given the potential benefits that agroforestry systems have for water productivity, it is crucial to understand how these systems work and design location-specific systems and management guidelines. Central America has much to benefit from agroforestry's contribution to improving water productivity in the region.

Agroforestry systems can improve water productivity where water depth is beyond the reach of crop rooting systems.

A major challenge is how to look beyond the plot and farm level in order to understand interactions between plots and the landscape, watershed and regional scales (catchment hydrology).

Similarly, the field survey for this paper revealed data from El Salvador showing 87% erosion reduction, increased biomass production and soil moisture retention up to 20 days in agroforestry plots compared with conventional plots (Segura, 1999).

Conservation Agriculture

The conservation agriculture approach consists of varied farming systems that include the three basic practices that define conservation agriculture – minimal soil disturbance (minimum or no tillage), permanent soil cover via crop residues, mulch, or cover crops; and crop rotation (Giller et al., 2009). Several of these practices are described in Chapters 5.1 and 5.2 of this document. Conservation agriculture favors improvements in soils as rooting environments. It is not a single technology, but one or more technologies based on one or more of the three main conservation agriculture principles described. Conservation agriculture functions best when all three features are combined (Hobbs, 2007; Corbeels et al., 2014).

Derpsch at al. (2010) summarize the improved interactions between the four factors of conservation agriculture: (a) physical: better porosity for root growth, movement of water and root-respiration gases; (b) chemical: raised cation exchange capacity (CEC) gives better capture, release of inherent and applied nutrients: greater control/release of nutrients; (c) biological: more organisms, organic matter and transformation products; and, (d) hydrological: more water available.

The combination of these features raises productivity and makes the soil a better environment for the plant roots. Improvements in soil porosity have two major positive effects with regard to water productivity: improved water infiltration and soil water retention, which prolong the availability of plant-available soil moisture in times of drought. With improved water infiltration, conservation agriculture maximizes groundwater recharge and reduces flood risks. In soils with impeded drainage, however, conservation agriculture might increase the severity and frequency of waterlogging (Thierfelder & Wall, 2011). The permanent soil cover in conservation agriculture maintains infiltration rates by protecting the soil surface from high-energy raindrops and surface-sealing. This is corroborated by Derpsch et al. (1986) and Alvarez & Steinbach (2009) who found higher crop yields under no-till systems due to higher water retention, improved water infiltration and aggregate stability in soils under limited tillage.

Increased soil organic matter results in improved nutrient release into soil water – nutrients from organic matter and applied through fertilizer. Thus the availability of both water and plant nutrients is extended together, increasing their efficient use. Under these conditions, plants better express their genetic potential. In conservation agriculture systems and tillage systems in Latin America, Africa and Asia yield improvements have ranged from 20% to 120% (FAO, 2001).

Conservation Agriculture under contrasting Rainfall Regimes

Evidence suggests that conservation agriculture offers the greatest benefits in low rainfall areas. Scopel (1996) and Scopel et al., (2001) report on trials in Mexico, where maize yield increases under conservation agriculture were significantly higher in zones with marginal rainfall (400–600 mm/year) as compared to yield increases under more favorable conditions (600–800 mm/year). Analysis of soil properties under the different systems suggested that this difference is related to water uptake. Similarly, Monneveux et al. (2006) found that no-till led to superior root development and water uptake during the dry season in Mexico. A long-term study of rainfed maize production in the highlands of Mexico (Verhulst et al., 2011 a,b) found that yields under no-till exceeded those under conventional tillage by 31 percent on average from 1997–2009, but that the benefit of no-till was especially pronounced in very dry years. Franchini et al. (2012) in southern Brazil also found that over the long term, no-till and crop rotation promoted more stable yields, particularly in years with little rainfall. However, in contrast to these findings, Corbeels' et al. (2014) meta-analysis of crop responses to conservation agriculture in sub-Saharan Africa do not show a better performance of conservation agriculture under drier rainfall regimes as compared to wetter regimes. They found less variation in weighted mean difference in no-tillage systems with rotations compared to systems without rotation, which suggests more crop yield stability (less risk) with the use of crop rotations.

In Carazo, Nicaragua, MARENA-POSAF II (2005 a, b) reported an annual increase of 440 m3/ha of soil water retention in a dispersed tree–cropping system. For multi-story coffee systems in Jinotega, the same source indicates 575 m3/ha/y, and for plots with managed natural tree regeneration in Dipilto, a total of 985 m3/ha/y.

In Honduras, under experimental conditions, QSMAS is at least as effective as slash & burn systems for the production of maize, and more efficient than slash & burn to produce common beans.

Given the potential benefits that agroforestry systems have for water productivity, it is crucial to understand how these systems work and design location-specific systems and management guidelines.

Photo: Axel Schmidt

In Mexico,
maize yield increases under conservation agriculture were significantly higher in zones with marginal rainfall (400–600 mm/year) as compared to yield increases under more favorable conditions (600–800 mm/year). Scopel (1996) and Scopel et al., (2001)

Conservation Agriculture Adoption in Central American Hillsides

Although the adoption levels of conservation agriculture in LAC are fairly high, they tend to be concentrated among wealthier farmers on large-scale, fuel-dependent mechanized farms (Kassam et al., 2009, McCarthy, 2014). Most of the evidence provided originates from Mexico and South America, particularly Brazil, Argentina and Paraguay. The literature review and field survey did not uncover a sufficient body of evidence on the implementation of the full range of conservation agriculture practices in Honduras, El Salvador and Nicaragua. Although some practices are already applied, the introduction of conservation agriculture to smallholder systems in Central America has been challenging. However, Pachico et al. (2010) estimated a high potential for the introduction of conservation agriculture, recognizing that both traditional and conventional maize production practices on steep slopes are already using zero tillage for pre-plant land preparation. Thus, the first element of conservation agriculture is already present in farmer practices on steep slopes in Central American hillsides.

Traditional and conventional maize production practices on steep slopes are already using zero tillage for pre-plant land preparation.

Competition from Grazing

Pachico et al. (2010) found that the second element of conservation agriculture - leaving crop residue on the field to cover the soil during the dry season - has not been the general practice either in traditional or conventional agriculture in Central America. Burning crop residues is still common as is removing the maize stubble /crop residue for use as animal feed, principally for cattle. The pressure for livestock feed is a constraint to the widespread adoption of leaving crop residues in the field as soil cover. Given their pressing need for animal feed in the dry season, it will not be easy to convince farmers that the soil improvement consequences of maintaining crop residue is a better use than as livestock feed. Even farmers who do not own livestock themselves may sell maize stubble to a neighbor who needs it for his cattle (Reyes et al., 2013, Valbuena, 2014).

Consequently, to achieve full adoption of conservation agriculture practices in El Salvador, Pachico et al. (2010) conclude that identification of an alternative source of cattle feed may be necessary. An approach that could be tested with farmers would be to devote some part (perhaps 20-25%) of the area currently in maize to plots of grass/legume forages. These forages could be grazed; cut and carried to stall-fed animals; or made into hay for the dry season.
Conversion of part of their maize land to forage would benefit farmers first by improving income from livestock and secondarily by improving soil and thus maize yield. The soil improvement would come first from having soil cover as part of conservation agriculture and secondarily through enhanced nutrient cycling through increased manure due to improved feeding of cattle with forages. The introduction of forages into the system would also constitute an effective crop rotation, the third essential element of conservation agriculture.
More research on forage options and matching them with specific production systems in Central America is needed to overcome the crop residue barrier for widespread adoption of conversation agriculture. The impacts on water productivity are unknown and have to be addressed. Which feeding system would work best, and how much land needs to be put into pastures to be able to leave maize residue in the field, should be tested with farmers and adapted to their individual circumstances.

Conservation Agriculture and Fertilizer

Since minimal tillage without mulch commonly results in depressed yields, the use of fertilizer to enhance crop productivity and the availability of organic residue is essential for smallholder farmers that seek to adopt conservation agriculture (Vanhulst et al., 2011b, Baudron et al., 2012). A case study from Kenya demonstrates how fertilizer increases maize stubble productivity above thresholds for minimal initial soil cover required for initiating conservation agriculture (about 3 t/ha) (Guto et al, 2011). Vanlauwe et al. (2014) conclude that strategies for using conservation agriculture in Sub-Sarahan Africa (SSA) must integrate the appropriate use of fertilizer to increase the likelihood of benefits for smallholder farmers, including improvements in water productivity.

Nutrient and Soil Management for Water Productivity - Manage Soil to Manage Water

It is estimated that water use efficiency can be increased by 15-25% through adequate nutrient management. (Hartfield et al. ; 2001)

Scientific research in Central America on conservation agriculture systems lags behind other parts of the world.

Hatfield et al. (2001) estimate that water use efficiency can be increased by 15-25% through adequate nutrient management. The plant's nutrient status has an indirect effect on water use efficiency through the physiological efficiency of the plant. An optimal nutrient status ensures the highest biomass output per unit water used. The authors found that through soil management, water use efficiency can be further increased by 25-40%. These findings underline the critical role of soil management and plant nutrient management to improve water use efficiency and thus water productivity in Central America.

Barron (2012) indicated that water availability for a crop can be enhanced almost instantly through improved soil management (tillage, infiltration structures, see former sections of this chapter), and nutrient availability by adding inorganic and /or organic nutrients. However, learning to manage soils for maximum water productivity and to create a bridge between dry spells can take a long time. Soil stabilization may not occur in tropical semi-arid and sub-humid areas for 10 to 20 years due to the challenge of building the chemical and biological soil properties, including soil organic matter balance.

Additional Research Needed on Synergies

Although there is an increasing amount of scientific evidence indicating improved water productivity through the implementation of conservation agriculture, all the potential and actual benefits are not fully understood, There are many synergistic interactions between the various components of conservation agriculture practices that are not fully explained. Scientific research in Central America on conservation agriculture systems lags behind other parts of the world. This is partly because conservation agriculture is a complex, knowledge intensive system which requires adequate staffing within enabling institutional networks.

Adopción de la agricultura de conservación en las laderas de Centroamérica

INTEGRATED PEST MANAGEMENT (IPM) AND CONSERVATION AGRICULTURE

Conservation agriculture, as a productive system, pursues economic efficiency, as well as conserving, improving and managing soil, water, pests and available biological resources, through an agricultural practice that is more committed to the environment.

Conservation agriculture incorporates integrated crop management, and shares the same objective: the convergence of production and environmental conservation. In this context, IPM is a valuable tool for the objectives of conservation agriculture to be achieved.

Escobar Betancourt, Jose Cristobal. "Manejo Integrado de Plagas de Cultivos Horticolas." MINISTRY OF AGRICULTURE AND LIVESTOCK, NATIONAL CENTER OF AGRICULTURAL AND FOREST TECHNOLOGY. PHASE II OF THE PROJECT ON SUSTAINABLE AGRICULTURE ON SLOPE AREAS.

Mixed Crop Livestock Systems

Mixed crop livestock systems, which were common in the past (Mazoyer & Roudart, 2006) are again attracting worldwide interest. These systems represent the highest level of integration among agricultural systems and offer many benefits. Crops tend to yield more energy and protein per unit land area than animals but nutritive value and income from animal production tends to be higher than from crops. Livestock can also support cropping, for example by permitting wider crop rotations, managing risk, adding value to crop residues and grains, supplying draft power (Schiere et al, 2006), and recycling excess nutrients for soil fertility management (Hendrickson et al., 2008; Tarawali et al., 2011). Mixed crop-livestock systems generate higher economic efficiency in saving production costs through complementarities between crops and livestock (Wilkins, 2008). Diversifying production can reduce farmers' exposure to risks of market fluctuations (Russelle et al., 2007) and challenging climate conditions.

Mixed farming is the largest category of livestock systems in the world in terms of animal numbers, productivity and the number of people it services (Thornton et al., 2002). Most of the world's animal production comes from rainfed mixed crop–livestock systems in developing countries and from intensive industrialized production in developed countries (Herrero et al., 2010). Livestock products provide one third of the human protein intake, just as they consume almost one third of the water used for agriculture globally (Herrero et al., 2009). With demand increasing for animal products and competition for water growing more contentious, improving livestock water productivity is essential (Descheemaeker et al., 2010).

The literature review and field survey in Central America on water productivity did not turn up existing data or reports on livestock water productivity. This is not surprising since livestock water productivity is a relatively new concept (Peden et al., 2007, 2009). Knowledge gaps exist and reference points are lacking. As a starting point for further research and discussion, research findings and concepts from other regions are summarized here.

Livestock water productivity is defined as the ratio of net beneficial livestock-related products and services to the water depleted in producing them. Three basic strategies help to increase livestock water productivity: 1) improved feed management (improving feed quality, improving feed water productivity, feed type selection, grazing management); 2) water management, and animal management (increasing animal productivity, improving animal health); and, 3) sufficient drinking water for animals of adequate quality, particularly in the dry season (Fujisaka et al., 2005). A single strategy may not be effective. Rather, a balanced, site-specific approach making use of all three strategies will be more effective.

Livestock water productivity does not seek to maximize the number of livestock or the production of animal products and services. Rather, it seeks to produce the same benefits with fewer animals and less demand for agricultural water. It requires increasing the productivity of each animal (Peden et al., 2007; Descheemaeker et al., 2010). Animal production depends on access to sufficient supplies of quality feed—grains, crop residues and by-products, pasture, tree fodder, and forage crops. Peden et al. (2007) suggest that since feed production is one of the world's largest uses of agricultural water, the strategic sourcing of animal feed is the entry point for improving global livestock water productivity.

Livestock research and particularly forage research in the past 50 years has not adequately addressed the linkage between livestock feed and water management. Science-based knowledge of water use for feed remains limited. Judicious selection of feed sources is potentially one of the most effective ways of improving global agricultural water productivity. Peden et al. (2007) estimate that water transpired for feed production is about 50 times or more the amount of an animal's drinking water intake. Therefore, increasing livestock water productivity will depend strongly on increasing the amount of feed animals use for production relative to the amounts used for their maintenance.

The literature review and field survey in Central America on water productivity did not turn up existing data or reports on livestock water productivity.

Water use in feed production varies substantially (Blümmel et al., 2009) and depends on the type of feed used (e.g., grains, forages, concentrates, crop residues, pastures), climatic conditions, field management and irrigation. As such, a strategic choice of feed types has the potential to increase livestock water productivity (Descheemaeker et al., 2010). In mixed crop–livestock systems, crop residues are an important feed source for ruminants (Devendra & Thomas, 2002; Reyes et al., 2013). Because crop residues do not consume any additional water, they present a good opportunity to increase feed water productivity. However, there are trade-offs when using crop residue for animal with regard to soil fertility maintenance and improved soil structure. Furthermore, crop residues have little nutritional value, at best meeting only an animal's maintenance requirements (Coleman & Moore, 2003).

Feed production is the largest water consumer for livestock production in mixed systems (Singh et al., 2004). Hence interventions that increase feed water productivity directly increase livestock water productivity. Substantial research has been directed at increasing crop water productivity, which is reflected in the large number of scientific publications on the topic (for comprehensive review, see e.g. Kijne et al., 2003). Most of the recommendations for improving crop water productivity apply also to improving feed water productivity. In general, agronomic measures directed at healthy, vigorously growing crops favor productive transpiration over unproductive water losses. Alleviating water stress improves water productivity, only if other stresses (nutrient deficiencies, weeds, and diseases) also are alleviated or removed (Bouman, 2007).

Increasing Grazing Productivity of Marginal Land

Pastures or forages in Central America are often located on marginal land, unsuitable for crop production (Peters et al., 2001, Steinfeld et al., 2006). Therefore, making use of the available feed resources in these areas increases overall system productivity. However, pastures in Central America are generally in an advanced state of degradation due to inappropriate grazing management (Holmann et al., 2004a). In these cases, water is lost from the system as runoff, with lower water productivity as a result. Consequently, careful grazing management employing adaptive stocking densities is essential (Lascano, 1991). Fodder trees provide several benefits that enhance livestock water productivity. In addition to providing nutritious fodder, the trees stabilize land, decrease erosion, improve soil structure and fertility, and increase ecosystem stability (Romero et al., 1994). Little information is available on the water productivity of different forages, concentrates and supplements (Peden et al., 2007), but adding highly nutritive fodder sources to the animal diet improves animal productivity (Lenné et al., 2003; Holmann et al, 2004b). Peters et al. (2011) provide information on available forage options for Central America including grasses, multipurpose legumes and shrubs for improved animal performance and soil enhancement.

Animals' Drinking Water Supply

During the six months of dry season in Central America, animals often walk long distances to watering points, thus expending substantial energy (Fujisaka et al., 2005). Although the amount of water needed for drinking is small in comparison with the amount needed to produce feed, providing this small volume is a strategic choice (Peden et al., 2007). The water enables animals to access feed and convert it into animal products. Its availability makes a large difference in overall livestock water productivity (Peden et al., 2009). Furthermore, sufficient watering points are instrumental for optimal distribution of animals to make best use of available feed (grazing management) and to avoid soil and pasture degradation (Wilson, 2007). Water harvesting (see chapter 5.3) offers a huge potential for the continuous access to quality drinking water during the dry season.

Animal Care

Low animal productivity in Central America is manifested in low daily live weight gains and milk production, low growth and calving rates, and high mortality rates (Szott et al., 2000). One of the reasons is insufficient animal management, including inappropriate animal selection for breeding and the provision of veterinary services, which undermines all other efforts to increase livestock (water) productivity. Diseased or stressed animals lead to lower productivity as they consume feed and water but do not deliver outputs or services as they should. Decreasing the ratio of feed energy needed for animal maintenance relative to that used for productive purposes improves animal productivity (Peden et al., 2009), and thus water productivity in mixed crop-livestock systems. Key to increases in water productivity is appropriate animal husbandry including veterinary services and disease control to improve animal health.

Further Research Needs

To obtain improved water productivity in highly complex mixed crop-livestock systems, enhanced management skills are needed. However, research, education, and extension systems in Central America and indeed throughout the world fail to provide the required information, knowledge and practical guidelines (Peden et al., 2006). There are only a few examples of research and assessments that attempt to understand the total water needs of livestock and how animal production affects water resources. The consequence has been lost opportunities to increase feed/livestock water productivity and maximize investment returns in water and livestock development. A lack of knowledge and understanding impedes sound decision-making and implementation of targeted interventions (Peden et al., 2009).

In Central America, most development planners have been biased toward the crop sector, and policy makers have usually treated the livestock sector as subsidiary. Moreover, the livestock agenda is usually not integrated into irrigation development, biofuel investments or reforestation investments. This may be due to a focus on commodities and an agricultural system's parts, rather than on mixed farming as interconnected wholes, also called complex adaptive systems, which through their diversity are likely to offer better solutions for future challenges. Developing mixed farming requires understanding interactions and combinations of functions rather than maximizing yields or benefits of any one individual part, e.g. grain, milk, soil, biophysics, or even social aspects (Schiere et al., 2006). The literature reveals diverse practices and systems to improve water productivity in Central America but field data on water use efficiency and water productivity in the region is slim. The relatively better data base on erosion control, which indirectly links to water productivity, demonstrates what is possible to understand with more systematic research. Changes in mindsets, attitudes and policies, due to additional research and support for experimentation, will facilitate the integration of crop, livestock, land and water management at farm, landscape, and institutional levels (Peden et al., 2009)

6. Adoption of Agricultural Practices to improve Water Productivity in Central America

The literature review, field surveys and round table discussions identified a limited number of practices that improve water productivity and have been adopted by smallholders in each of the three countries. In Nicaragua, for example, live barriers, strip cropping, no burn & crop residue management including minimum tillage and cover crops, as well as water harvesting, were the most important practices implemented by farmers. In El Salvador this identical set of practices was supplemented by contour and infiltration ditches, dead barriers and terraces in coffee production. The review in Honduras revealed a similar set of practices, supplemented by adjustments to planting density. In all three countries these practices are implemented predominately on small demonstration plots. Despite numerous programs and projects in the region during the last 30 years, implementation on larger scale farm plots is uncommon and the practices described in chapter 5 were scattered across projects and geographic areas, with low adoption rates. This chapter looks at the obstacles and opportunities affecting adoption.

Impact of Location

The field survey in the three countries corroborated the finding of Hellin & Schrader (2003); when the project interventions that offer direct incentives end, farmers tend to abandon most promoted practices.

Experience showed that physical/ structural measures were abandoned when maintenance was required.

Respondents identified practices that improve soil moisture as having higher adoption potential across the three countries and noted that physical / structural measures were abandoned when maintenance was required. No geographical patterns on adoption could be established. Overall, there was very little hard evidence (data) on the effectiveness or adoption of the practices that improve water productivity.

These findings confirm PASOLAC (2000) statements that practices are “farmer-specific”. Adoption will happen as a function of the specific location and production system, production goals, farmers’ priorities and management skills. On the one hand, the hillsides of Central America are a heterogeneous environment, often with a diversity of agro-ecological, micro-climate and socio-economic conditions present among neighboring farms (e.g., infrastructure, livestock, markets), or even between plots of the same farm (e.g. soil, slope). On the other hand, each practice has a fairly well-defined set of characteristics with regard to ecological adaptation, effectiveness at improving water productivity, costs of implementation and maintenance, and perceived benefits for the farmer. The challenge is to match the practices with location-specific conditions. This requires a significant amount of information, knowledge and advisory skills, which has rarely been available in the past. One-size-fits-all approaches are associated with low rates of long-term adoption and behavior change.

It is often observed that, when project intervention offers direct incentives, farmers tend to abandon best practices after time has passed.

Economic Returns of Practices

The farmer survey clearly revealed that farmers adopted practices when they perceived a net economic return on the investment, a finding well documented in the literature (e.g. Lutz et al., 1994; Saín & Barreto, 1996; Scherr, 2000; Bravo-Ureta et al., 2003; Prins, 2004). Adoption is particularly limited among subsistence farmers who depend on an immediate return on investments in soil and water conservation. These economic benefits are not necessarily evident until the medium and long-term. The short-term needs of farmers, including the need to reduce risks, were found to play a significant role in perceived profitability of conservation structures and thus the level of adoption (Hansen et al., 1987; Ellis-Jones & Mason 1999; Antle et al., 2007).

Despite this widespread understanding, Pomareda (2008) states that the effect of adopting water and soil practices on cost-benefit ratios in the socio-economic context of smallholders are still not fully understood. Furthermore, several authors (Lutz et al., 1994; Reardon & Vosti, 1995; Lapar & Pandey, 1999) point out that economic returns from conservation practices, though a necessary condition for adoption, do not sufficiently explain adoption patterns among smallholders.

It is often observed that, when project intervention offers direct incentives, farmers tend to abandon best practices after time has passed.

Human, Social and Financial Capital

Since the pioneering work by Ryan & Gross (1943), a wealth of studies has analyzed variables affecting the adoption of new agricultural technologies. Detailed reviews of this literature can be found in Feder et al. (1985), Lindner (1987), Feder & Umali (1993), Rogers (1995) and Lichtenberg (2001). Viewed through a broad cross-disciplinary lens, there is agreement that the adoption of agricultural technology depends on a range of personal, social, cultural and economic factors that interact with the innovation itself (Pannell et al., 2006). Prokopy et al. (2008) show that higher levels of education, capital, income, farm size, access to information, positive environmental attitudes, environmental awareness and utilization of social networks are generally positively associated with adoption of best management practices. Given the current situation in education, extension and human capital in Central America, serious barriers to adoption continue to exist.

Rogers (1995) classified the variables for adopting a new technology into three groups: 1) human capital; 2) structural factors; and 3) social capital. Regarding human capital, authors mention the effect of age, gender, education, literacy, agricultural experience and training. Among structural factors, farm size, land tenure and credit have been widely analyzed.

Recent studies evaluate the effect of access to social networks and institutions on farmer perception of new technology and the subsequent effect on adoption (e.g., Shultz et al., 1997, Winters et al., 2004).

With regard to adopting soil conservation technologies, research and economic theory suggest that farmers' perception of local soil erosion problems, household attributes and assets, plot slope, land use patterns and the overall location-specific conditions are relevant in design of an appropriate model for adoption (Solis et al., 2006).

This finding is consistent with the results of roundtable discussions in all three countries – strengthening human capital through education, agricultural training and technical assistance is essential to help farmers better understand the attributes of new technologies. However, in El Salvador farmers argued that despite being aware of the environmental benefits and having technical knowledge about the practices, due to high transaction costs, they cannot afford the transition from conventional management to more sustainable practices.

Some experiences show (Solis et al., 2006) that farmers' perception of local soil erosion problems, plot slope, land use patterns and the overall location-specific conditions are relevant in design of an appropriate model for adoption. (Solis et al., 2006)

Selection of Practices and Technologies

Technology itself influences adoption and usage decisions (Adesina & Zinnah, 1993). In particular, the relative complexity, risk and investment characteristics of technologies affect both adoption and diffusion (Batz et al., 1999). The risk preferences of farmers influence technology adoption decisions, especially if capital-intensive technology costs are irreversible (Howley et al., 2012). In an analysis of differences between capital-intensive and management-intensive technologies, El-Osta & Morehart (2002) found that farmer age, farm size and specialization in production (e.g. dairy) increased the likelihood of adopting a capital-intensive technology, whereas education level and size of operation positively affected the decision to adopt a management-intensive technology. These findings emphasize the importance of education and training for the adoption of improved water productivity practices in Central America. This is especially true because many of the practices and systems described in this document are knowledge- and management-intensive.

Extension Services

Many studies concur that extension services are a key factor not only for the adoption of agroforestry systems, but for agriculture technologies in general (Feder & Slade, 1986; Hansen et al. (1987); Saín & Barreto, 1996; Ramírez & Shultz, 2000; Marsh & Pannell, 2000; Garforth et al., 2003; Pattanayak et al., 2003). Shultz et al. (1997) stress the importance of farm visit frequency by extension agents for successful adoption. In Honduras, participatory extension methods such as the CIAL methodology (Braun, 2003; Humphries et al., 2005) have had a positive impact on innovation and adoption of new agricultural technologies.

Given the complex farmer location- and technology-specific conditions for adoption, it seems impossible for research and extension systems to develop appropriate "packages" that fit the circumstances of all farmers and farmer groups. Making adaptions for local conditions requires not only a wealth of information and knowledge about agronomic and agro-ecological principles, advanced communication skills and time, but also a good understanding of the local conditions which only farmers at each location can provide. Considerable farmer participation is therefore required. Indeed, in the case of conservation agriculture in more developed countries, extension and research have been substantially farmer-driven (Wall, 2007).

A deeper analysis of the extension services and innovation systems in Central America is required, especially models of participatory development and diffusion of innovations (Gündel, 1998; Cramb 2000).

Neill & Lee (1999) attributed the widespread dissemination of the maize-mucuna system in Northern Honduras to farmer-to-farmer extension.

Farmer Participation

In light of the farmer-, location- and technology-specific conditions for adoption, the roundtable discussions in all three countries emphasized the need for greater farmer participation in project planning and implementation. Project design in Central America does not generally contemplate the heterogeneity of hillside conditions. Projects tend to pre-define water and soil conservation practices to promote during short project life spans. Ashby et al. (1996) stress the vital role of farmers in promoting soil and water conservation practices (via farmer to farmer extension). Neill & Lee (1999) attributed the widespread dissemination of the maize-mucuna system in Northern Honduras to farmer-to-farmer extension. They estimated a diffusion rate of more than 60% of farmers by 1992, finding that diffusion was largely spontaneous (unassisted by extensionists or NGOs). The maize-mucuna system has become a widely acknowledged “success story” of diffusion of a conservation agriculture system.

Market Access as a Factor

The eventual decline in the application of mucuna in maize production was associated with changing market access for maize, among other factors (Neill & Lee, 1999). Jansen et al. (2006) reported similar findings of decreasing adoption with higher market access for other crops in Honduras. Other authors’ reports differed. Posthumus (2005) concluded in a study about adoption of bench terraces, slow-forming terraces, infiltration ditches, and conservation practices in Peru that market access increased the adoption of slow-forming terraces. The ambiguity in literature with regard to market access reflects the location and farmer specific context of adoption.

Importance of Social Networks

Several authors stress the importance of social network connections and group membership for successful adoption (Hansen et al. 1987; Ashby et al. 1996; Witter et al. 1996; Cramb 2000; Swinton, 2000, Posthumus 2005). In a recent review, McCarthy (2014) concluded that the adoption of conservation practices increased with the number of community-based organizations in an area and the number of external organizations focusing on integrated development stressing the importance of building social capital. There is a body of literature focusing on farmers’ motivations, values, objectives and behavioral influences as a factor in technology adoption (e.g. Rehman et al., 2007; Aragão-Pereira, 2011). The literature explains how social norms, beliefs about a technology's performance and importance and farmers' intentions to change practices impact on the adoption of technologies. Sauer & Zilberman (2010) showed the positive impact of peer-group behavior on farmers' technology adoption decisions. Further insights into behavioral change are key for further work on farmer adoption in Central America.

Influence of Land Tenure on Adoption

Solis et al. (2006) indicate that land ownership also has a positive and significant impact on adoption. By contrast, land size shows a negative and significant effect on adoption, indicating that smaller farms have a higher probability of engaging in soil conservation activities than larger ones. In their study based on the PAES project in Salvador and the CAJON project in Honduras, Solis et al. (2006) found that producers with higher levels of investment in soil conservation also exhibit higher average technical efficiency. These producers also have the smallest farms and present the highest partial elasticity of production with respect to total cultivated land. These results suggest that in less-productive areas, access to land is denied to many efficient rural producers (Deininger et al., 2003). Given the complex issue of land tenure in Latin America and the rental land market that deals with the issue of contract duration (long-term vs. annual), these two factors should be emphasized in program design and implementation with linkages to financial support. Smallholders, however, frequently face credit constraints. New, creative financial products are required for rainfed agriculture systems dominated by smallholders to help farmers undertake the initial investments for soil and water conservation and productivity improvements.

Given the complex issue of land tenure in Latin America and the rental land market that deals with the issue of contract duration (long-term vs. annual), these two factors should be emphasized in program design and implementation with linkages to financial support. Smallholders, however, frequently face credit constraints.

The Special Case of Agroforesty Adoption

Given the diverse opportunities for the integration of trees into production systems and the importance of coffee and cocoa production in Central America, areas with silvo-pastoral systems appear to have increased (>2 M ha) in the last decade (Ibrahim, 2013). However, most of them are low input silvo-pastoral systems of some kind of linear arrangement such as living fences (adoption rate > 90% of farms with livestock) with more complex, intensive systems such as protein banks, alley or plantation grazing trailing far behind (very low adoption rates). Ibrahim et al. (2010) attribute this lack of adoption to the demanding requirements for capital and labor associated with the establishment of complex agroforestry systems, missing knowledge and technical assistance, as well as inappropriate policies and incentives for adoption.

Current et al. (1995), in their review of 21 agroforestry projects in Central America, suggest a number of factors affecting agroforestry adoption in Central America. Farmers are attracted to new technologies based on economic returns, the profitability of a given system compared to alternative land uses. Farmers evaluate the resource requirements of the given system, local costs of labor and materials, and local prices for tree products. Adoption is also a function of risk management, including the extent to which a given agroforestry system stabilizes yields and provides multiple sources of income. Current et al. (1995) suggest that lack of formal land tenure decreased adoption but was not a binding constraint; rather tree harvesting laws and regulations created to protect forests (causing insecurity regarding permission to harvest trees in the future) were found to be limiting in the agroforestry projects that were reviewed.

The main barriers to adoption of agroforestry systems such as technical assistance, training, provision of planting materials, credit and other financial and material incentives, identified by Ibrahim et al. (2010), are the same ones which had been identified 15 years earlier by Current et al. (1995), indicating limited progress towards a more enabling policy environment for agroforestry adoption in Central America in the last two decades. To make matters worse, agroforestry programs do not tend to contemplate the necessary 5-10 year periods needed for successful adoption of agroforestry systems. The specific growth rates of each tree species are considerable longer than short government administration periods and policy horizons.

Information and conclusions from other regions in the world might not apply to Central America. The effects of agroforestry vary widely by location (Muschler & Bonneman, 1997), perhaps more than any of the other technologies discussed here. The tree species most appropriate for agroforestry will vary geographically, making comparing effects across agroforestry studies from different locations difficult. A great deal of value-added can be gained by even basic research on different agroforestry varieties in different agro-ecological regions (McCarthy, 2014).

Farmers are attracted to new technologies based on economic returns, the profitability of a given system compared to alternative land uses.

The specific growth rates of each tree species are considerable longer than development projects and policy horizons

Assembling a Research Agenda on Adoption

Good data on adoption in Central America of the combined three conservation agriculture practices is relatively scarce. Few studies have been carried out in Latin America (for review see Knowler & Bradshaw, 2007), and only three in Central America (Sain & Barreto, 1996; De Herrera & Sain, 1999; Pachico et al., 2010).

Conservation agriculture adoption cannot necessarily be generalized to other countries and regions because conservation agriculture has different effects depending on the climate and soil type in a given area (Zinn et al., 2005; Giller et al., 2009). Evidence from South America comes from farmers who rely on fuel-based farming systems, which have a completely different cost-benefit structure than smallholder systems in Central America that use no fuel at all (McCarthy, 2014). Thus, it is critical to generate data specifically on smallholder systems in Central America. The studies that do exist give a mixed, unclear picture. McCarthy et al. (2011) and Wall (2007) reviewed the empirical evidence on major constraints to the adoption of conservation agriculture by smallholders (not specific to Central America). The authors mention the following constraints: (1) the competing need in many areas to use crop residues for animal feed; (2) increased expenditures on herbicides and/or labor for weeding, at least during the initial years; (3) weak links to extension services to acquire information on conservation agriculture (a relatively knowledge-intensive technology); (4) limited access to direct seeding equipment; (5) limited availability of appropriate cover crop seeds in the market; and (6) tight networks among farmers, which may work to reinforce traditional tillage practices. McCarthy (2014) concluded that larger-scale farmers, especially those reliant on fuel-based mechanization, are more likely to adopt conservation agriculture. This also holds true for farmers with secure tenure and/or who own the land farmed, who have access to information on conservation agriculture (e.g. through extension), and who are located in areas prone to soil erosion and lower rainfall.

It is worth noting that longer-term studies have found positive results from adoption of conservation agriculture

Clearly, factoring time into impact and adoption studies is essential. Valid adoption or non-adoption rates can only be established years after project interventions end, or in widespread policysupported programs, which, to date, do not exist in Central America, In the case of soil enhancement or conservation agriculture, it is crucial to conduct long-term studies of the effects on crop yields and thus on water productivity. Many of the studies that found no significant effects of conservation agriculture on soil or yields were carried out over a period of five years or less (Roldán et al., 2003; Astier et al., 2006), and yet longer-term studies have found positive results from adoption of conservation agriculture (Erenstein et al., 2012; Franchini et al., 2012).

7. Policy Framework – An Enabling Environment for Water & Soil Management?

Whether water & soil conservation practices are adopted and how those practices are managed is influenced by a diversity of factors, summarized in the previous section. Most of these factors, such as access to markets and extension services, land tenure, education and social networks, farmer participation and research and innovation, are linked to national policy and regulatory frameworks. The question we explore here is: Are these frameworks conducive to the adoption of water and soil conservation practices and thus to the improvement of water productivity in Central America?

This section seeks to summarize the analyses that emerged from round table discussions in each of the three countries. Those roundtables undertook a detailed analysis of the complex sets of principles, goals, rules and guidelines (policy framework) orienting agricultural planning, investment, and development. To a lesser degree, the roundtables discussed the strategic opportunities and constraints – the legal, organizational, fiscal, informational, political, and cultural considerations – that impact the capacity of different stakeholders to engage in development processes in a sustained and effective manner (enabling environment).

Broad Landscape of Policies and Legislation – but No Linkages

The three country reviews revealed a large body of scattered legislation and policies on water and soil conservation. These range from directives for the implementation of international treaties (e.g. UN Climate Change Convention) to direct national laws and policies (e.g. National Law on Environment and Natural Resources, National Water Law, Policy on the Management of Water Resources), to indirect national legislation such as the Act on Organization, Competition, and Procedures of the Executive and the Municipality Act in Nicaragua, and finally, to local municipal ordinances. Stakeholder participation is featured to some degree within these laws, regulations and policies but the laws and policies are not well linked, making the prospect of participation something of a labyrinth. In some cases they conflict with other laws and policies, that undermine their relevance.

More than a dozen pieces of water and soil legislation are currently active in the three countries. In the case of El Salvador, they are implemented by 27 institutions. Legislation and policies offer contradictory directives on natural resource conservation and agriculture and tend to disperse responsibilities and duplicate efforts. This can generate inter-institutional coordination problems and exaggerate the alleged contradictions between the agriculture and environmental sectors.

Legal Frameworks are Not Implemented, Nor Enforced

Responsibilities for water and soil conservation have been entrusted to different institutions in the three countries. Each institution varies in their ability to manage related tasks. For example, conservation work may be isolated from agriculture development because of inadequate coordination mechanisms, the shortage of funds, vehicles and other essential equipment, as well as the lack of experienced, well-trained human resources (Centro Humboldt, 2011). The lack of highly competent staff may be due to the shortfalls of investment in education and extension services and may explain, partially, the low adoption rates of water and soil conservation practices in Central America. The lack of incentives designed to attract and retain trained personnel in the rural areas may further contribute negatively to this situation (see GWI publication on Extension). All institutions are hampered by contradicting legal regulations. For example, forest protection laws may be impeding the harvest of tree products by farmers, undermining adoption of agroforestry practices.

Short-term Perspectives of Investment and the Valley Focus

Naturally, since there are a variety of laws, there are also conflicts of interest, often to the detriment of soil and water conservation. Priority investments of limited public funds tend to be to facilitate export crops to earn foreign exchange. Within this short term, revenue-enhancing perspective, investing in sustainable water and soil conservation practices, which have longer-term returns, is seen as a waste of resources. With priority given to agriculture export crops such as bananas/plantain, pineapple, sugar cane, oil palm, and water melons, agricultural development has occurred principally in the larger valleys where more favorable water and soil conditions are found. During the last 50 years, agriculture policies and economic research in Central America have focused on valleys. Investments in hillside rainfed agriculture have been neglected (Pelupessy & Ruben, 2000).

Overall public investment in agriculture has fallen in all countries since the 1980's. In El Salvador, for example, the national budget dedicated to agriculture has decreased from 6.4% in 1984 to less than 1.9% in 1999. In recent years, public investment levels have remained low, despite the fact that agriculture contributes 12% to gross domestic product of El Salvador. In Nicaragua, most investments are comprised largely of foreign aid (Arauz, 2012).

Frequent Change – Political Instability

Frequent change in government and subsequent programmatic and personnel reorganization is highly disruptive. Soil and water conservation programs, due to their essentially longer-term nature, are particularly sensitive to the disruptions. The fluctuations make longer-term planning impossible and result in migration of experienced staff to other sectors. At the municipal level, implementation and enforcement of legislation remains a challenge due to the lack of qualified staff.

Caution for Direct Incentives and the Importance of Indirect Incentives

Policy incentives are widely used to induce behavior change in groups or individuals. To motivate farmers to adopt new water and soil management techniques and practices, many governments and development organizations introduce direct incentives such as cash payments for labor, grants, subsidies, loans, as well as in kind payments such as plant material, food aid (food-for-work) and agricultural tools. Direct incentives may also be used at the beginning of soil and water projects to mitigate the sometimes-high investment requirements of soil conservation practices and to overcome the delayed economic benefits, which may take several years to be realized. Direct incentives are sometimes used as compensation for the off-site benefits of conservation enjoyed by society (Stocking & Tengberg, 1999). The entire concept of payment for ecosystem services is based on compensating farmers to implement practices of social interest such as reducing downstream siltation for healthier reservoirs, aquatic ecosystems and drinking water

(Huszar, 1999; Rosa et al., 2004).

Hellin & Schrader (2003) describe direct incentives to win over farmers' participation in water and soil conservation projects as a powerful and tempting tool, but qualified it as a dubious instrument for achieving the mid- and longer-term goals of sustainable land use and efficient natural resource management. Direct incentives create dependency in rural communities (Bunch, 1982) and undermine key components of human development, namely participatory decision-making, group empowerment, and farmer experimentation (Hinchcliffe et al., 1995; Steiner, 1996; Schrader, 2002). Hellin & Schrader (2003) showed in their analyses of soil conservation projects in Honduras that farmers tend to abandon most promoted practices when the direct incentives end. The authors recommend that soil and water conservation programs should, wherever possible, avoid the use of direct incentives.

Almekinders (2002) points out that one of the greatest incentives for improved land management is an enabling environment that features secure access to land, seeds, markets, professional extension services and education. Favorable prices for agricultural inputs and products are also essential. These constitute indirect incentives and may include fiscal and legislative measures like tax concessions (Sanders & Cahill, 1999). Development organizations tend to ignore indirect incentives and favor direct incentives because the former are outside of their sphere of action – except where they might support small farmer advocacy to win a package of indirect incentives. Such incentive programs are clearly essential to influence; they play a key role in orienting land management decisions (Hellin & Schrader, 2003).

Almekinders (2002) points out that one of the greatest incentives for improved land management is an enabling environment that features secure access to land, seeds, markets, professional extension services and education. Such incentive programs are clearly essential to influence; they play a key role in orienting land management decisions (Hellin & Schrader, 2003).

Lack of farmer participation in the design of soil and conservation intiatives (SCI) is evident in project documents. Hellin and Haigh (2002) note that, in Honduras, farmers show greater concern for pests and drought than loss of soil. In this context, farmers may very well feel SCI recommendations are irrelevant, and they may reject official recommendations or abandon them once direct incentives run out (Shaxson, 1997).

According to some studies (Bunch, 1982), direct incentives create (external) dependency in rural communities.

Different experiences in the region have shown that Improvements in water productivity in agriculture systems is influenced both by biophysical and socio-political-economic conditions.

The Need for Integrated Policies – the System or Value Chain Approach

Improved water productivity in agriculture systems is influenced both by biophysical and socio-political-economic conditions. As discussed, technical interventions are much more likely to be adopted when the institutional, cultural, and economic contexts of the target communities are taken into account, and supported by enabling policies (Peden et al., 2009). Biophysical and socio-political-economic interventions are not mutually exclusive, but rather interact. One domain affects the other. An integrated approach has a better potential to improve water productivity in Central America.

An example of such an approach is found in the Honduran coffee sector. Research revealed government policies supporting an entire value chain. The approach paid attention to resolving legal aspects such security and land access, promoting local organization among producers, investing in research and technology transfer through strong extension services, and providing financing for all parts of the value chain, from production to processing to marketing.

Specifically, the social organization of coffee producers (e.g. Asociación Nacional de Café - ANACAFE) was identified as a success factor, demonstrating the need and value of collective action. The national coffee institute in Honduras (Instituto Hondureño Del Café – IHCAFE) was recognized for its research in genetic resources (new varieties), crop management, processing and quality control, as well as for providing technical assistance and extension services. The legal distribution of land titles was understood to lay the groundwork for investments and credit availability. The Banco Hondureño de Café (BANHCAFE) was critical to supporting transactions and investments. All of these components working together constitute an enabling policy and institutional framework. By supporting these components, one of the most important agriculture sectors in Honduras has been strengthened.

Is This Enough – What is Needed in the Future?

In the future, integrated policies, sustained investments and institutions, and innovation - not business as usual – will be essential to ensure that agriculture can meet rising global food demand and respond to the changes, challenges and opportunities facing rainfed agriculture in Central America. Higher investments in public research and development, extension, education, and their links with one another, are critical to create the necessary enabling environment for creativity and scale.

Innovation is related to a strong research and development capacity, coordinated collective action, exchange of knowledge among diverse actors, and incentives and resources to form partnerships and businesses. Innovation systems are what is needed in Central America. No blueprint exists for making such agricultural innovation happen. What is clear, however, is that it if rainfed agriculture is to flourish in Central America, an integrated approach towards innovation is essential.

8. Concluding remarks

Increasing water productivity will be the single most important strategic objective for Central American agriculture in the future. Rainfed agricultural systems will have to cope with increased output demands at the same time as changing climate conditions will aggravate water availability and distribution throughout the cropping cycles. The present review revealed a considerable potential to increase water productivity in Central America through management practices that increase infiltration of rainfall for improved water retention, avoid unproductive water loss through evaporation, and maximize transpiration in crop canopies for improved biomass production and yields. Given the region's current low agricultural productivity, small gains in yield will have significant impact on food security and poverty alleviation.

Unleashing the Potential of Improved Water Productivity Practices

During the field surveys for this report, a series of inter-related agronomic, vegetative, and structural soil and water management practices were identified as essential steps to improve water productivity. To reach their full potential, they are best combined and repeated over multiple production periods and require an integrated farm management approach. This combination of practices unleashes their full potential. The interactions and interdependencies of the practices and the ecosystems within which they are applied have to be well understood.

While each of the practices is fairly easy to implement, their timely application within location-specific conditions requires knowledge, planning and adaptation. They depend heavily on location-specific soil and climatic conditions and plant species, factors not always well understood by the agronomists providing technical assistance to farmers.

In the case of vegetative practices, although the benefits are widely known, their potential is far from fully developed. The erratic implementation of more complex practices such as intercropping reveal serious knowledge gaps on plant and variety characteristics, soil and climate conditions, and management capacities. Careful planning is required to make sure that crops do not compete with each other for physical space, nutrients, water, or sunlight.

Structural practices regulate runoff during heavy rain events and are considered as a strategic approach to improving water productivity in Central America. The techniques increase water infiltration, harvest and store water for use during dry spells, and expand production into the dry season. This and other structural practices help farmers reduce water-related risks posed by high rainfall variability. However, they require not only investments to build or implement, but demand constant maintenance. They are also likely to change the hydrological cycle of a landscape and affect upstream and downstream relationships. Again, careful planning, monitoring and measuring (data, information and knowledge) is essential.

Understanding and Managing Agricultural Systems

Soil and water management practices are best understood within a systems perspective. The present document reviewed the three system approaches (agroforestry, conservation agriculture, and integrated mixed crop-livestock systems) that are commonly considered as having the most potential to improve water productivity in rainfed agriculture, and have been heavily promoted over the last decade in Central America.

Corroborating insights from the application of these practices, agroforestry systems must be designed for the given environment (climate, soil, socio-economic farm situation, management capacities) in order to improve the use of water resources. If not well managed, an agroforestry system, as with any agricultural or forestry system, leads to multiple competitive interactions and may undermine efficient water use. Tree-crop systems are dynamic in their interactions over time, demanding management adjustments. Given the potential benefits that agroforestry systems have for water productivity, it is crucial to understand how these systems work in order to design location-specific systems and management guidelines.

Similar complexity is found in conservation agriculture. It is not a single technology, but one or more technologies based on one or more of the three main conservation agriculture principles. Conservation agriculture functions best in improving water productivity when all three features are combined. Although scientific research from around the world finds improved water productivity through conservation agriculture, all the potential and actual benefits are not entirely understood, nor are synergistic interactions between conservation agriculture's various components fully explained. Most of the existing scientific evidence on conservation agriculture comes from large-scale, fuel-dependent mechanized farms. Further research in the hillside environments of Central America for location-specific implementation of principles is required.

Mixed crop-livestock systems add another layer of complexity to farm management by integrating animals into the farming system. These systems represent the highest level of integration among agricultural systems and offer benefits such as higher economic efficiency and reduced exposure to market and climate risks. While they are common in the region, knowledge gaps exist and reference points are lacking with regard to livestock water productivity and the overall water productivity of these complex systems in Central America. It is evident that to obtain improved water productivity in mixed crop-livestock systems, enhanced management skills are needed. However, research, education, and extension systems in Central America - and indeed throughout the world - fail to provide the required information, knowledge and practical guideline, impeding sound decision-making about targeted interventions.

Following the style of agricultural production systems in temperate regions twhich emphasize industrialized and highly specialized operations, development planners and policy-makers tend to separate crops from livestock production. Investments in agriculture tend to focus on commodities and on agricultural system's parts, rather than on mixed farming as interconnected wholes. However, complex, inter-connected systems, through their diversity, are likely to offer better solutions for future challenges. Mixed farming requires understanding interactions and combined functions rather than benefits of any one individual part, e.g. grain, milk, soil, biophysics, or even social aspects.

After Years of Promotion, Adoption Rates Remain Low

In the present paper, adoption of new practices has been described as a function of the location- and production system-specific conditions, farmers' production goals and priorities, and the required knowledge and management skills to handle complex practices and systems. Given the current situation in education, research, innovation, extension and human capital in Central America, it is not surprising that adoption of "knowledge- and management-intensive" practices has lagged. In all three countries these practices were found predominately on small demonstration plots and scattered across projects and geographic areas.

The heterogeneous and diverse environment of Central American hillsides holds a challenge for research and extension systems to match practices with location-specific conditions. Adaptations for local conditions requires not only a wealth of information and knowledge about agronomic and agro-ecological principles, advanced communication skills and time, but also a good understanding of the local conditions which only farmers at each location can provide. Considerable farmer participation is therefore required. Recurrent efforts to promote and implement one-size-fits-all approaches are associated with low rates of long-term adoption and behavior change.

The Need for a New Strategic Approach – Building on Diversity

The central importance of soil management to improve water productivity demands new thinking. Soil conservation approaches have to be revised. The exclusively prescriptive "engineering" regime of technical interventions, usually as structures, earthworks and methods to control runoff and erosion, has persistently failed (Critchley, 1991). The sustainable development approach of the 1990's, brought a new strategic direction, not just for soil conservation but also for rural development (Hurni et al., 1996), promoting a longer-term vision that included notions such as self-reliance (Pretty, 1995), local knowledge (Reij et al, 1996), and land husbandry (Roose, 1996). These were attempts to develop a more holistic and integrative approach to dealing with soil management and land problems. Although there is a wealth of experience with these approaches to soil conservation, from the strictly technology transfer point of view, none have fully met their initial promise. None have been embraced properly by soil conservation's ultimate clients, the land users (Stocking, 2002)

Therefore, Stocking (2002) suggests capitalizing on the huge diversity found in rainfed smallholder systems such as in Central America. Small farmers use small local variations in soil, microclimate and water conditions to produce a great variety of crops. Commonly described as traditional, this farming landscape is very dynamic; results of learning and experimentation are found everywhere. Centrally important is the internal dynamism of so many small-farming systems, yielding a constantly changing patchwork of complex and dynamic relationships between people, plants and the environment.

Stocking argues that diversity directs us away from universalist and blue-print solutions that are often rejected not because they are wrong but because of the vast heterogeneity of land use conditions and circumstances. A good example of diversity is the 220 agroforestry associations documented by Guo & Padoch (1995) amongst ethnic minority communities in eight prefectures of Yunnan, Southwest China. No one practice works for all these associations and indeed they are all stronger from learning from one another's particular adaptations.

The diversity of practices incorporates the vast knowledge and experience of farmers coping with environmental degradation. Local applications are a product of many influences that have been tried, tested and adapted. There are many types of interventions, at different scales, both spatially and temporally, that are appropriate for different circumstances and problems. This variety of interventions must be understood and appreciated by the farmer, the household, local communities, district councils, and national and international policy makers.

A diversity of practices has great potential for making land use systems more resilient, and hence increasing sustainability. Diversity provides a broad body of land use solutions to cope with external forces such as climate change, population increase, and economic recession. Since these threats are likewise diverse, land users need many available solutions, obtained by diversifying, not by specializing.

Brookfield (2001) uses the term “agro-diversity” to describe all forms and aspects of diversity found in small-scale agriculture systems in the tropics. Agro-diversity has been defined as the many ways in which farmers use the natural diversity of the environment for production, including their choice of crops and land, water and biota management systems.

Agrodiversity runs opposite to the idea that there are technologies that, if promoted properly, will solve the major global environmental and developmental problems: food security, climate change, loss of biodiversity, and land degradation. Agrodiversity is not easily dissected, explained and understood. The interconnections and relationships are complicated and its ever-changing nature is not amenable to tidy textbook examples to be promoted and implemented. Agrodiversity asks us to believe that there are many solutions and varieties of options. It means that the most appropriate approach to soil conservation may vary not only from place to place, but household to fhoushold and individual to individual (Stocking, 2002).

Furthering the Discussion

The findings of this report support Stocking’s thesis. However, is there sufficient knowledge about agro-diversity in Central America? The research for this document revealed a lack of data and information on soil, water, production and economic parameters, as well as on adoption, effectiveness, and efficiencies of water productivity enhancing practices. As a consequence, not all proposed questions in this document could be answered sufficiently. It is challenging to understand the diverse interactions between plots and the landscape, watershed and regional scales. The complexity of agro-diversity demands sophisticated and nuanced management skills. Underinvestment in basic and secondary education and technical formation has hampered learning.

Being able to answer all the questions posed in this report will be decisive to realize the great potential in Central America to improve water productivity and enable rainfed agriculture to thrive. A thorough discussion is needed among farmers, governments, the research and development community, donor agencies and the private sector about how to achieve this goal in a holistic, knowledge-intensive fashion that addresses the diverse conditions in the hillsides of Central America. Extensive documentation, applied research and support for experimentation and learning are initial steps; many others are still to be defined.

In the case of vegetative practices, although the benefits are widely known, their potential is far from fully developed. Careful planning is required to make sure that crops do not compete with each other for physical space, nutrients, water, or sunlight.

The implementation of diverse practices has greater potential to increase resilience and sustainability.

Ensuring there is extensive documentation, applied research and support for experimentation and learning are initial steps; many others are still to be defined.

Bibliography

ACT – African Conservation Tillage Network 2010. Jab Planter user manual. Available at: http://teca.fao.org/sites/default/files/technology_files/jab%20planter.pdf. (Accessed on 19/09/2014)

Adesina, A. & Zinnah, M. 1993. Technology characteristics, farmers' perceptions and ad option decisions: A tobit model application in Sierra Leone. Agricultural Economics 9: 297-311

Allen, R., Pereira, L., Raes, D. & Smith, M. 1998. Crop evapotranspiration: Guideline for computing crop water requirements. FAO Irrigation and Drainage Paper 56. Natural Resources Management and Environment Department. United Nations Food and Agriculture Organization, Rome, Italy. 174 p.

Almekinders, C. 2002. Incentive measures for sustainable land use and conservation of agrobiodiversity. Proceedings of the workshop on experiences and lessons from Southern Africa, Lusaka, Zambia, 11–14 September 2001. Southern African Development Community Plant Genetic Resources Centre (SPGRC).Lusaka, Zambia. 172 p.

Al-Kaisi, M. & Yin, X. 2003. Effects of nitrogen rate, irrigation rate, and plant population on corn yield and water use efficiency. Agronomy Journal 95:1475-1482.

Alvarez, R. & Steinbach, H. 2009. A review of the effects of tillage systems on some soil physical properties, water content, nitrate availability and crop yield in the Argentine pampas. Soil and Tillage Research 104(1): 1-15.

Amado, T., Fernández, S.B. & Mielniczuk, J. 1998. Nitrogen availability as affected by ten years of cover crop and tillage systems in southern Brazil. Journal of Soil and Water Conservation 53(3): 268-271.

Anderson, I.M. & Burton, M. 2009. Best practices and guidelines for water harvesting and community based (small scale) irrigation in the Nile basin. Water Harvesting Report. Nile Basin Initiative - Efficient Water Use for Agricultural Production Project (EWUAP), Kent, UK. 35 p.

Anderson, S., Gündel, S., Pound, B. & Triomphe, B. 2001. Cover crops in smallholder agriculture: lessons from Latin America. ITDG Publishing, London, UK. 136 p.

Antle, J.M., Stoorvogel, J. & Valdivia, R. 2007. Assessing the economic impacts of agricultural carbon sequestration: Terraces and agroforestry in the Peruvian Andes. Agriculture, Ecosystems & Environment 122(4): 435-45.

Aragão Pereira, M. 2011. Understanding adoption and non-adoption of technology: a case study of innovative beef farmers from Mato Grosso do Sul State, Brazil. Ph.D. thesis. Lincoln University Digital Thesis. New Zealand. 334 p.

Arauz, A. 2012. Análisis de la cooperación oficial externa al sector agropecuario y forestal, con énfasis a los fondos fuera del presupuesto del gobierno de Nicaragua. Informe del proyecto: Nicaragua-estudio de gasto público del sector agropecuario y forestal. World Bank, Managua, Nicaragua. 67 p.

Argueta, O., 2000. Valoración de la acequia de ladera como alternativa para el uso sostenible de los suelos en El Salvador. Thesis. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica. 144 p.

Ashby, J.A., Beltrán, J., Guerrero, M. & Ramos, H. 1996. Improving the acceptability to farmers of soil conservation practices. Journal of Soil and Water Conservation 51(4): 309-312.

Astier, M., Maass, J., Etchevers-Barra, J., Pena, J. & González, F. 2006. Short-term green manure and tillage management effects on maize yield and soil quality in an Andisol. Soil and Tillage Research 88(1): 153-159.

Baltodano M.E. & Mendoza, R.B. 2007. Evaluación y cuantificación de los efectos productivos y ambientales del sistema agroforestal Quesungual. Centro Internacional de Agricultura Tropical (CIAT), Managua, Nicaragua, 26 p.

Barron, J. 2012. Soil as a water resource: Some thoughts on managing soils for productive landscapes meeting development challenges. Wageningen UR Open Journal thematic issue. Available at: http://library.wur.nl/ojs/index.php/AE2012 (Accessed on 19/09/2014).

Batz, F. J., Peters, K. J., & Janssen, W. 1999. The influence of technology characteristics on the rate and speed of adoption. Agricultural Economics 21: 121-130.

Baudron, F., Tittonell, P., Corbeels, M., Letourmy, P., & Giller, K. 2012. Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. Field Crops Research 132: 117-128.

Beekman, G., Cruz Majluf, S., Espinoza, N., García Benevente, E., Herrera Toledo, C., Medina Hidalgo, D., Williams, D. & García-Winder, M. 2014. Water to feed the land. Inter-American Institute for Cooperation on Agriculture (IICA), San Jose, Costa Rica. 100 p.

Blanco-Canqui, H., Mikha, M., Benjamin, J., Stone, L., Schlegel, A., Lyon, D., Vigil, M. & Stahlman, P. 2009. Regional study of no-till impacts on near-surface aggregate properties that influence soil erodibility. Soil Science Society of America Journal 73(4): 1361. doi:10.2136/sssaj2008.0401.

Blümmel, M., Samad, M., Singh, O.P. & Amede, T. 2009. Opportunities and limitations of food-feed crops for livestock feeding and implications for livestock water productivity. The Rangeland Journal 31: 207-212.

Bolaños, J. 1995. Productividad con conservación: Estrategias para la producción sostenible de maíz de laderas. In: Sain. G., Miranda B., Rivera, J. Choto de Cerna, C. (eds.). Taller de productividad y conservación de los recursos en la agricultura de laderas. San Jose, Costa Rica. Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT), Instituto Interamericano de Cooperación para la Agricultura (IICA). 98 p.

Borhom, T. 2001. Studies on water requirements for some crops under different cropping systems. M. Sc. Thesis. Agriculture Faculty, University of Cairo, Egypt. 132 p.

Bot, A. & Benitez, J. 2005. The importance of soil organic matter. Key to drought resistant soil and sustained food and production. FAO Soils Bulletin 80. Land and Plant Nutrition Management Service, United Nations Food and Agriculture Organization, Rome, Italy. 95 p.

Bouman, B. 2007. A conceptual framework for the improvement of crop water productivity at different spatial scales. Agricultural Systems 93: 43-60.

Braun, A. 2003. The Farmer Research Group (CIAL) as a community based natural resource management organization. In: Pound, B., Snapp S., McDougall, C. & Braun, A. (eds.). Managing natural resources for sustainable livelihoods - uniting science and participation. Earthscan, London & International Development Research Centre (IDRC), Ottawa, Canada. p. 194-196.

Bravo-Ureta, B., Cocchi, H., Solís, D. & Rivas, T. 2003. Un análisis comparativo de tres proyectos de manejo de cuencas en América Central: Informe final. Inter-American Development Bank. Washington D.C., USA. 164 p.

Breman, H., Groot, J. & van Keulen, H. 2001. Resource limitations in Sahelian agriculture. Global Environmental Change 11 (1): 59-68.

Brenner, A.J. 1996. Microclimate modifications in agroforestry. In: Ong, C.K. & Huxley, P.A. (eds.). Tree–crop interactions. A physiological approach. CAB International, Wallingford, UK. pp. 156-186.

Brookfield, H. 2001. Exploring Agrodiversity. Columbia University Press, New York. 608 p.

Buckles, D., Triomphe, B. & Sain, G. 1998. Cover crops in hillside agriculture: Farmer innovation with Mucuna. International Development Research Centre (IDRC), Ottawa, Canada & International Maize and Wheat Improvement Center (CIMMYT), Mexico. 218 p.

Bunch, R., 1982. Two ears of corn. A guide to people-centered agricultural improvement. World Neighbors, Oklahoma City, USA. 24 p.

Cajina Canelo, M. & Faustino, J. 2007. Alternativas de captación de agua, la esperanza de mejores cosechas y la Conservación ambiental: cogestión de actores locales y acción colectiva en la subcuenca del río Aguas Calientes, Nicaragua. Technical report. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica. 44 p.

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. & Rao. I. 2009. Quesungual slash and mulch agroforestry system (QSMAS): Improving crop water productivity, food security and resource quality in the sub-humid tropics. CPWF Project Report. International Center for Tropical Agriculture (CIAT), Cali, Colombia. 76 p.

CENTA (Centro Nacional de Tecnología Agropecuaria y Forestal). 2000. Resultados de validaciones: Cultivos en callejones y acequias de ladera. San Salvador, El Salvador. 40 p.

Centro Humboldt, 2011. Balance Nacional de la Gestión Ambiental en Nicaragua. Report. Centro Humboldt, Managua, Nicaragua. 33p.

Coleman, S.W. & Moore, J.E. 2003. Feed quality and animal performance. Field Crops Research 84: 17-29.

Cong Tu, Ristaino, J. & Shuijin Hu 2006. Soil microbial biomass and activity in organic tomato farming systems: Effects of organic inputs and straw mulching. Soil Biology and Biochemistry 38(2): 247-255.

Corbeels, M., Sakyi, R.K., Kühne, R.F. & Whitbread, A. 2014. Meta-analysis of crop responses to conservation agriculture in sub-Saharan Africa. CCAFS Report No. 12. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). 20 p. Available online at: www.ccafs.cgiar.org (Accessed on 19/09/2014).

Cramb, R.A. 2000. Processes influencing the successful adoption of new technologies by smallholders. In: Stür, W:, Horne, P., Hacker, J.B. & Kerridge, P. (eds.). Working with farmers: The key to adoption of forage technologies. ACIAR Proceedings Series Report 95. Australian Centre for International Agricultural Research (ACIAR), Canberra, Australia. pp.11-22.

Critchley, W & Gowing, J. 2012. Introduction. In: Critchley, W. & Gowing, J. (eds.). Water Harvesting in Sub-Saharan Africa. Earthscan, London, UK. pp. 1-9.

Critchley, W. 1991. New approaches to soil and water conservation. ILEIA Newsletter 7: 1/2

Critchley, W. & Siegert, K. 1991. Water harvesting. A manual for the design and construction of water harvesting schemes for Plant Production. Natural Resources Management and Environment Department, United Nations Food and Agriculture Organization (FAO), Rome. Italy. AGL/MISC/17/91. Available at: www.fao.org/docrep/U3160E/U3160E00.htm#Contents (Accessed on 19/09/2014).

Current, D., Lutz, E. & Scherr, S. 1995. The costs and benefits of agroforestry to farmers. The World Bank Research Observer 10(2): 151-180.

Dabney, S., Delgado, J. & Reeves, D. 2001. Using winter cover crops to improve soil quality and water quality. Communications in Soil Science and Plant Analysis 32:1221-1250.

Dalianis, C., Alexopoulou, E., Dercas N. & Sooter, C. 1996. Effect of plant density on growth, productivity and sugar yields of sweet sorghum in Greece. In: Chartier P., Ferrero, G.L., Henius, U.M., Hultberg, S., Sachau, J. & Winblad, M. (eds.). Biomass for Energy and Environment. Proceedings of 9th European Biomass Conference. Pergamon Press, Oxford, UK. pp.582–587.

De Herrera, A.P., & Sain, G. 1999. Adoption of maize conservation tillage in Azuero, Panama. Working Paper No. 7696. International Maize and Wheat Improvement Center (CIMMYT), Texcoco, Mexico. 34 p.

Deininger, K., Zegarra, E. & Lavadenz, I. 2003. Determinants and impacts of rural land market activity: Evidence from Nicaragua. World Development 31: 1385-1414

Derpsch, R., Friedrich, T., Kassam, A. & Li, H. 2010. Current status of adoption of no-till farming in the world and some of its main benefits. International Journal of Agricultural and Biological Engineering: 3(1): 1-25.

Derpsch, R., Sideras, N. & Roth, C. 1986. Results of studies made from 1977 to 1984 to control erosion by cover crops and no-tillage techniques in Paraná, Brazil. Soil Tillage Research 8: 253-263.

Descheemaeker, K., Amede, T. & Haileslassie, A. 2010. Improving water productivity in mixed crop– livestock farming systems of sub-Saharan Africa. Agricultural Water Management 97: 579-586.

Devendra, C. & Thomas, D. 2002. Crop-animal interactions in mixed farming systems in Asia. Agricultural Systems 71: 27-40.

Ellis-Jones, J., & Mason, T. 1999. Livelihood strategies and assets of small farmers in the evaluation of soil and water management practices in the temperate inter-andean valleys of Bolivia. Mountain Research and Development 19(3): 221-34.

El-Osta, H. S., & Morehart, M. J. 2002. Technology adoption and its impact on production performance of dairy operations. Review of Agricultural Economics 22 (2): 477-498.

Erenstein, O., Sayre, K., Wall, P., Hellin, J. &. Dixon, J. 2012. Conservation agriculture in maize- and wheat-based systems in the (sub) tropics: Lessons from adaptation initiatives in South Asia, Mexico, and Southern Africa. Journal of Sustainable Agriculture 36(2): 180-206.

Farahani, H. J., Howell, T. A., Shuttleworth, W. J. & Bausch, W. C. 2007. Evapotranspiration: Progress in measurement and modeling in agriculture. Transactions of American Society of Agricultural and Biological Engineers 50:1627-1638.

Falkenmark, M., Fox, P., Persson, G. & Rockström, J. 2001. Water harvesting for upgrading of rainfed agriculture: Problem analysis and research needs. SIWI Report 11. Stockholm International Water Institute (SIWI), Stockholm Sweden. 94 p.

FAO (Food and Agriculture Organization of the United Nations) 1993. Soil tillage in Africa. Needs and Challenges. FAO Soil Bulletin No. 69. Natural Resources Management and Environment Department, United Nations Food and Agriculture Organization, Rome, Italy. 190 p. Available at: http://www.fao.org/docrep/t1696e/t1696e00.HTM (Accessed on 19/09/2014).

FAO (United Nations Food and Agriculture Organization) 1994. Water harvesting for improved agricultural production. Proceedings of the Food and Agricultural Organization of the UN (FAO) Expert Consultation, November 1993. Cairo, Egypt. United Nations Food and Agriculture Organization, Rome, Italy. pp. 301-314

FAO (United Nations Food and Agriculture Organization) 2000. Manual on integrated soil management and conservation practices. FAO Land and Water Bulletin 8. United Nations Food and Agriculture Organization, Rome, Italy. 214 p.

FAO (United Nations Food and Agriculture Organization) 2001. Conservation Agriculture: Case Studies in Latin America and Africa. FAO Soils Bulletin 78. Natural Resources Management and Environment Department, United Nations Food and Agriculture Organization, Rome, Italy. 66 p.

FAO (United Nations Food and Agriculture Organization) 2009. World agriculture toward 2030/2050: how to feed the world in 2050 (on line). United Nations Food and Agriculture Organization, Rome, Italy. Available at: www.fao.org/economic/esa/esag/esag-papers/en/ (Accessed on 19/09/2014).

FAO (United Nations Food and Agriculture Organization) 2011. The state of the world´s water resources for food and agriculture: managing systems at risk. Summary report (on line). United Nations Food and Agriculture Organization, Rome, Italy. Available at: www.fao.org/nr/water/docs/SOLAW_EX_SUMM_WEB_EN.pdf (Accessed on 19/09/2014).

Feder, G. & Slade, R. 1986. A comparative analysis of some aspects of the training and visit system of agricultural extension in India. Journal of Development Studies 22(2): 409-428.

Feder, G. & Umali, D. 1993. The adoption of agricultural innovations: A review. Technological Forecasting and Social Change 43: 215-239.

Feder, G., Just, R. & Zilberman, D. 1985. Adoption of agricultural innovations in developing countries: A survey.

Economic Development and Cultural Change 33: 255-298.

Franchini, J., Debiassi, H., Balbinot, H., Tonon, B., Farias, J., Oliveira, M. & Torres, E. 2012. Evolution of crop yields in different tillage and cropping systems over two decades in Southern Brazil. Field Crops Research 137: 178-185.

Fujisaka, S., Holmann, F., Peters, M., Schmidt, A., White, D., Burgos, C., Ordoñez, J.C., Mena, M., Posas, M.I., Cruz, H., Davis, C. & Hincapié, B. 2005 Estrategias para minimizar la escasez de forrajes en zonas con sequías prolongadas en Honduras y Nicaragua. Pasturas Tropicales 27(2): 73-92

Gámez, L.A. 2006. Monitoreando las inversiones se cuantifican los servicios ambientales. Revista Laderas Centroamericana 23: 23–29.

Garforth, C., Angell, B., Archer, J., & Green, K. 2003. Fragmentation or creative diversity? Options in the provision of land management advisory services. Land Use Policy 20: 323-333.

Gaballah, M. S. & Ouda, S. A. 2008. Effect of water stress on the yield of soybean and maize grown under different intercropping patterns. Twelfth International Water Technology Conference, Alexandria, Egypt. Water Technology Association (WTA), Cairo, Egypt. 14 p.

Giller, K., Witter, E., Corbeels, M. & Tittonell, P. 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research 14: 23-34.

Gündel, S. 1998. Participatory innovation development and diffusion: adoption and adaption of introduced legumes in the traditional slash-and-burn peasant farming system in Yucatan, Mexico. GTZ, Eschborn, Germany. 79 p.

Guo Huijun & Padoch, C. 1995 Patterns and management of agroforestry systems in Yunnan. Global Environmental Change 5(4): 273-279.

Guto, S., Pypers, P., de Ridder, N., Vanlauwe, B. & Giller, K. 2011. Socio-ecological niches for minimum tillage and crop-residue retention in continuous maize cropping systems in smallholder farms of Central Kenya. Agronomy Journal 103: 1–11.

Hansen, D., Erbaugh, J. & Napier, T. 1987. Factors related to adoption of soil conservation practices in the Dominican Republic. Journal of Soil and Water Conservation 42(5): 367-369.

Hatfield, J.L., Sauer, T.J. & Prueger, J. H. 2003. Managing soils to achieve greater water use efficiency: a review. Agronomy Journal 93: 271-280.

Hatibu, N., Young, M.D.B., Gowing, J.W., Mahoo, H.F., & Mzirai, O.B. 2003. Developing improved dryland cropping systems for maize in semi-arid Tanzania. Part 1: Experimental evidence of the benefits of rainwater harvesting. Journal of Experimental Agriculture 39 (3): 279–292.

Haycock, N., Burt, T., Goulding, K. & Pinay, G. (eds.) 1997. Buffer zones: Their processes and potential in water protection. Proceedings of the International Conference on Buffer Zones, Oxford, UK, September 1996. Hancock Associated Limited, St. Albans, Herts, UK. 326 p.

Hellin, J. & Schrader, K. 2003. The case against direct incentives and the search for alternative approaches to better land management in Central America. Agriculture, Ecosystems and Environment 99: 61-81.

Hendrickson, J.R., Hanson, J.D., Tanaka, D.L. & Sassenrath, G.F. 2008. Principles of integrated agricultural systems: introduction to processes and definition. Renewable Agriculture and Food Systems 23: 265-271.

Herrero, M., Thornton, P.K., Gerber, P. & Reid, R.S. 2009. Livestock, livelihoods and the environment: understanding the trade-offs. Current Opinion in Environmental Sustainability 1: 111-120.

Herrero, M., Thornton, P.K., Notenbaert, A.M., Wood, S., Msangi, S., Freeman, H.A., Bossio, D., Dixon, J., Peters, M., van de Steeg, J., Lynam, J., Parthasarathy Rao, P., Macmillan, S., Gerard, B., McDermott, J., Seré, C., & Rosegrant, M. 2010. Smart investments in sustainable food production: revisiting mixed crop–livestock systems. Science

327: 822-825

Hillel, D. 2008. Soil in the environment – crucible of terrestrial life. Elsevier, London. 307 p.

Hinchcliffe, F., Guijt, I., Pretty, J. & Shah, P. 1995. New horizons: the economic, social and environmental impacts of participatory watershed development. Vol. 50. Gatekeeper Series, International Institute for Environment and Development, London. 20 p.

Hobbs, P. R. 2007. Conservation agriculture: what is it and why is it important for future sustainable food production? Journal of Agricultural Science: 145: 127-137.

Holmann, F., Argel, P., Rivas, L., White, D., Estrada, R. D., Burgos, C., Perez, E., Ramírez, G. & Medina, A. 2004a. ¿Vale la pena recuperar pasturas degradadas? Una evaluación de los beneficios y costos desde la perspectiva de los productores y extensionistas pecuarios en Honduras. Documento de Trabajo No. 196. Central International de Agricultura Tropical (CIAT), Cali, Colombia. 34 p.

Holmann, F., Rivas, L., Argel, P.J. & Perez, E. 2004b. Impact of the adoption of Brachiaria grasses: Central America and Mexico. Livestock Research for Rural Development 16 (12). Online journal. Available at: http://www.lrrd.org/lrrd16/12/holm16098.htm (Accessed on 19/09/2014).

Howley, P., Donoghue, C. & Heanue, K. 2012. Factors affecting farmers' adoption of agricultural innovations: A panel data analysis of the use of artificial insemination among dairy farmers in Ireland. Journal of Agricultural Science 4(6): 171-179

Hudson, N. 1987. Soil and water conservation in semi-arid areas. Soil Resources, Management and Conservation Service Publication 57. Land and Water Development Division, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 185 p.

Hudson, N. 1995. Soil conservation. 3rd edition. Iowa State University Press, Ames, USA. 391 p.

Humphries, S., Gallardo, O., Jimenez, J., & Sierra, F. 2005. Linking small farmers to the formal research sector: lessons from a participatory bean breeding program in Honduras. Agricultural Research & Extension Network Paper No. 142. The Overseas Development Institute (ODI), London, UK. 16 p.

Hurni, H. & ten other international contributors 1996. Precious earth: From soil and water conservation to sustainable land management. Centre for Development and Environment, University of Bern, Switzerland. 87 p.

Huszar, P., 1999. Justification for using soil conservation incentives. In: Sanders, D., Huszar, P., Sombatpanit, S., & Enters, T. (eds.). Incentives in soil conservation: From theory to practice. Oxford & IBH Publishing, New Delhi. pp. 57–68.

Ibrahim, M. 2013. Pasado, presente y futuro de los sistemas silvopastoriles en América Latina. (Online document). Available at: http://www.iica.int/Esp/regiones/andina/colombia/Documentos%20de%20la%20Oficina/TallerGanaderia/4%20SPS_MUHAMMAD_Colombia.pdf (Accessed 19/09/2014).

Ibrahim, M., Guerra, L., Casasola, F. & Neely, C. 2010. Importance of silvopastoral systems for mitigation of climatic change and harnessing of environmental benefits. In: Abberton, M., Conant, R., Batello, C. (eds.). Grassland carbon sequestration: management, policy and economics. Proceedings of the workshop on the role of grassland carbon sequestration in the mitigation of climate change, Rome, April 2010. Integrated Crop Management Series Vol. 11. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. pp. 189-195.

IICA (Inter-American Institute for Cooperation on Agriculture), ECLAC (Economic Commission Latin America and the Caribbean) & FAO (United Nations Food and Agriculture Organization) 2011. The outlook for agriculture and rural development in the Americas: A perspective on Latin America and the Caribbean 2011-2012 (on line). San Jose, Costa Rica. Available at: www.eclac.org/publicaciones/xml/6/44826/Perspectivas_agricultura2011_inglesweb.pdf (Accessed 19/09/2014).

IITA (International Institute of Tropical Agriculture). 1980. Annual Report, Ibadan, Nigeria. pp. 10-15.

Jansen, H., Rodriguez, A., Damon, A., Pender, J., Cheniern, J. & Schipper, R. 2006. Determinants of income-earning strategies and adoption of conservation practices in hillside communities in rural Honduras. Agricultural Systems 88(1): 92-110.

Joyce, B., Wallender, W., Mitchell, J., Huyck, L., Temple, S., Brostrom, P. & Hsiao, T. 2002. Infiltration and soil water storage under winter cover cropping in California's Sacramento Valley. Transactions of American Society of Agricultural and Biological Engineers 45: 315-326.

Kassam, A., Friedrich, T., Shaxson, F. & Pretty, J. 2009. The spread of conservation agriculture: justification, sustainability and uptake. International Journal of Agricultural Sustainability 7(4): 292-320.

Keating, B.A. & Carberry, P.S. 1993. Resource capture and use in intercropping: solar radiation. Field Crops Research 34: 273-301.

Keller, A. & Seckler, D. 2005. Limits to the productivity of water in crop production. California water plan update. Crop Water Use 4: 177-197.

Kiepe, P. 1995a. No runoff, no soil loss: Soil and water conservation in hedgerow barrier systems. Tropical Resource Management Papers 10, Agricultural University, Wageningen, The Netherlands. 156 p.

Kiepe, P. 1995b. Effect of Cassia siamea hedgerow barriers on soil physical properties. Geoderma 66: 113-120.

Kijne, J.W., Barker, R. & Molden, D. (eds.), 2003. Water productivity in agriculture -limits and opportunities for improvement. Comprehensive Assessment of Water Management in Agriculture Series CABI, Wallingford. 368 p.

Klocke, N., Currie, R. & Aiken, R. 2009. Soil water evaporation and crop residues. Transactions of American Society of Agricultural and Biological Engineers 52(1):103-110.

Knowler, D., & Bradshaw, B. 2007. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy 32(1): 25-48.

Lamm, F., Aiken, R. & Aboukheira, A. 2009. Corn yield and water use characteristics as affected by tillage, plant density and irrigation. Transactions of American Society of Agricultural and Biological Engineers 52(1):133-143.

Lapar, L.A. & Pandey, S. 1999. Adoption of soil conservation: the case of the Philippine uplands. Agricultural Economics 21(3): 241-256.

Lascano, C. 1991. Managing the grazing resource for animal production in savannas of tropical America. Harry Stobbs Memorial Lecture. Tropical Grasslands 25: 66-72.

Lenné J., Fernandez-Rivera, S. & Blümmel, M. 2003. Approaches to improve the utilization of food-feed crops – synthesis. Field Crops Research 84: 213-222.

Lichtenberg, E. 2001. Adoption of soil conservation practices: A revealed preference approach. Working Paper 01-12, Department of Agricultural and Resource Economics, University of Maryland, College Park, USA. 24 p.

Lindner, R. K. 1987. Adoption and diffusion of technology: An overview. In: Champ, B., Highley, E. & Remenyi, J. (eds.). Technological change in post-harvest handling and transportation of grains in the humid tropics. ACIAR Proceedings No. 19. Australian Centre for International Agricultural Research (ACIAR), Canberra, Australia. pp. 144-151.

Liniger, H. & Critchley, W. (eds). 2007. Where the land is greener: case studies and analysis of soil and water conservation initiatives worldwide. World Overview of Conservation Approaches and Technologies (WOCAT). Technical Centre for Agricultural and Rural Cooperation (CTA), Food and Agriculture Organization of the United Nations (FAO), United Nations Environment Program, Centre for Development and Environment (CDE), Bern, Switzerland. 376 p.

Liniger, H., Mekdaschi Studer, R., Hauert, C. & M. Gurtner. 2011. Sustainable land management in practice. Guidelines and best practices for Sub-Saharan Africa. TerraAfrica, World Overview of Conservation Approaches and Technologies (WOCAT) and Food and Agriculture Organization of the United Nations (FAO), Bern, Switzerland. 243 p.

Lithourgidis, A., Dordas, C., Damalas, C. & Vlachostergios, D. 2011. Annual intercrops: an alternative pathway for sustainable agriculture. Australian Journal of Crop Science 5(4): 396-410.

López, K.S. 2008. Evaluación de la calidad del establecimiento y efecto de las prácticas de conservación de suelo y agua sobre la calidad del suelo en laderas de Nicaragua. Thesis. Universidad Nacional Agraria, Nicaragua. 94 p.

Lu, Y., Watkins, K., Teasdale, J. & Abdul-Baki, A. 2000. Cover crops in sustainable food production. Food Reviews International 16: 121-157.

Lutz, E., Pagiola, S. & Reiche, C. 1994. The costs and benefits of soil conservation: the farmer's viewpoint. The World Bank Research Observer 9: 273-295.

Mannering, J. & Fenster, C. 1983 .What is conservation tillage? Journal of Soil and Water Conservation 38(3): 140-143.

MARENA – POSAF II (Programa Socio-ambiental y Desarrollo Forestal). 2005a. Establecimiento y manejo de sistemas silvopastoriles. Programa Socio ambiental y Desarrollo Forestal. Ministerio del Ambiente y los Recursos Naturales, Managua, Nicaragua. 56 p.

MARENA – POSAF II. (Programa Socio-ambiental y Desarrollo Forestal). 2005b. Establecimiento y manejo de sistemas de café ecoforestal. Programa Socio ambiental y Desarrollo Forestal. Ministerio del Ambiente y los Recursos Naturales, Managua, Nicaragua. 62 p.

Marsh, S. & Pannell, D. 2000. Agricultural extension policy in Australia: the good, the bad and the misguided. Australian Journal of Agricultural and Resource Economics 44: 605-627.

Mazoyer, M. & Roudart, L. 2006. A history of world agriculture from the neolitic age to the current crisis. Earthscan, New York, USA. 496 p.

McCarthy, N. 2014. Climate-smart agriculture in Latin America: drawing on research to incorporate technologies to adapt to climate change. Inter-American Development Bank, Office of Strategic Planning and Development Effectiveness, Technical Note 652. Washington, D.C., USA. 65 p.

McCarthy, N., Lipper, L. & Branca, G. 2011. Climate Smart Agriculture: Smallholder adoption and implications for climate change adaptation and mitigation. Mitigation of Climate Change in Agriculture Working Paper 4. United Nations Food and Agriculture Organization (FAO), Rome, Italy. 26 p.

McCartney, M., Rebelo, L., Xenarios, S. & Smakhtin, V. 2013. Agricultural water storage in an era of climate change: assessing need and effectiveness in Africa. IWMI Research Report 152. International Water Management Institute (IWMI), Colombo, Sri Lanka. 37 p.

Mekdaschi Studer, R. & Liniger, H. 2013. Water harvesting: Guidelines to good practice. Centre for Development and Environment (CDE), Bern, Rainwater Harvesting Implementation Network (RAIN), Amsterdam, MetaMeta, Wageningen, The International Fund for Agricultural Development (IFAD), Rome. 210 p.

Mendoza, R.B. & Cassel, D.K. 2002. Hedgerows and their effects on crop productivity and soil loss induced by water and tillage erosion on small run-off plots in the El Pital watershed, Nicaragua. USAID-CRISP, Technical Bulletin No.

SM CRSP2002-01, Texas A&M University, College Station, Texas. 37 p.

Mills, A. & Fey, M. 2004. Frequent fires intensify soil crusting: physicochemical feedback in the pedoderm of long-term burn experiments in South Africa. Geoderma 121(1-2): 45-64.

Mitchell, J., Singh, P., Wallender, W., Munk, D., Horwath, W., Hogan, P., Roy, R., Hanson, B. & Wroble, J. 2012. No-tillage and high-residue practices reduce soil water evaporation. California Agriculture 66(2): 55-61.

Molden, D., Oweis, T., Pasquale, S., Kijne, J., Hanjra, M., Bindraban, P., Bouman, B., Cook, S., Erenstein, O., Farahani, H., Hachum, A., Hoogeveen, J., Mahoo, H., Nangia, V., Peden, D., Sikka, A., Silva, P., Turral, H., Upadhyaya, A. & Zwart, S. 2007. Pathways for increasing agricultural water productivity. In: Molden, D. (ed.). Water for food, water for life: A comprehensive assessment of water management in agriculture. Earthscan, London, UK, International Water Management Institute (IWMI), Colombo, Sri Lanka. pp. 279-310.

Monneveux, P., Quillerou, E., Sanchez, C. & Lopez-Cesati, J. 2006. Effect of zero tillage and residues conservation on continuous maize cropping in a subtropical environment (Mexico). Plant and Soil 279(1-2): 95-105.

Morris, R. & Garrity, D. 1993. Resource capture and utilization in intercropping: water. Field Crops Research 34(3-4): 303-317.

Mt. Pleasant, J. (2006). The science behind the Three Sisters mound system: An agronomic assessment of an indigenous agricultural system in the northeast". In: Staller, J., Tykot, R. & Benz, B. Histories of maize: Multidisciplinary approaches to the prehistory, linguistics, biogeography, domestication, and evolution of maize. Academic Press, Burlington, Massachusetts. pp. 529-537

Muschler, R. & Bonnemann, A. 1997. Potentials and limitations of agroforestry for changing land-use in the tropics: experiences from Central America. Forest Ecology and Management 91(1): 61-73.

Neill, S. P. & Lee, D. R. 1999. Explaining the adoption and disadoption of sustainable agriculture: The case of cover crops in Northern Honduras. Working paper 99-31. Department of Agricultural, Resource, and Managerial Economics Cornell University, Ithaca, New York, USA. 27 p.

Ogindo, H. & Walker, S. 2005. Comparison of measured changes in seasonal soil water content by rained maize-bean intercrop and component cropping in semi arid region in South Africa. Physics and Chemistry of the Earth 30(11-16): 799-808.

Oldeman, L., Haakkeling, R. & Sombroek, W. 1991. World map of the status of human-induced soil degradation. An explanatory note. Global assessment of soil degradation, October 1991. Second revised edition. International Soil Reference and Information Centre and United Nations Environment Programme, Wageningen, The Netherlands.35 p.

Ong, C.K. & Leakey, R. 1999. Why tree-crop interactions in agroforestry appear at odds with tree-grass interactions in tropical savannahs. Agroforestry Systems 45: 109-29.

Ong, C.K. & Swallow, B.M. 2003. Water Productivity in Forestry and Agroforestry. In: Kijne, J.W., Barker, R. & Molden, D. (eds.). Water productivity in agriculture: Limits and opportunities for improvement. CAB International, Wallingford, UK, in association with the International Water Management Institute (IWMI), Sri Lanka. pp. 217-228.

Ong, C.K., Black, C.R., Marshall, F.M. & Corlett, J.E. 1996. Principles of resources capture and utilization of light and water. In: Ong, C.K. & Huxley, P.A. (eds.). Tree–crop interactions – a physiological approach. CAB International, Wallingford, UK. pp. 73-158.

Ouma, G. & Jeruto, P. 2010. Sustainable horticultural crop production through intercropping: The case of fruits and vegetable crops: A review. Agriculture and Biology Journal of North America 1(5): 1098-1105.

Oweis, T., Prinz, D. & Hachum, A. 2012. Water harvesting for agriculture in the dry area. International Center for Agricultural Research in the Dry Areas (ICARDA) & CRC Press/ Balkema, Leiden, The Netherlands. 266 p.

Pachico, D., Burpee, G. & Alfaro, M. 2010. Conservation and regenerative agriculture: Potential for poverty alleviation in El Salvador. Report. Catholic Relief Services, Baltimore, USA. 20 p.

Pannell, D. J., Marshall, G. R., Barr, N., Curtis, A., Vanclay, F. & Wilkinson, R. 2006. Understanding and promoting adoption of conservation practices by rural landholders. Australian Journal of Experimental Agriculture 46: 1407-1424.

PASOLAC (Programa para la Agricultura Sostenible en Laderas de América Central) 2000. Guía Técnica de Conservación de Suelos y Agua. Managua, Nicaragua. 205 p.

Passioura J. & Angus, J. 2010. Improving productivity of crops in water-limited environments. Advances in Agronomy 106: 37-75.

Pattanayak, S., Mercer, D., Sills, E. & Yang, J. 2003. Taking stock of agroforestry adoption studies. Agroforestry Systems 57(3): 173–86.

Peden, D., Freeman, A., Astatke, A. & Notenbaert, A. 2006. Investment options for integrated water-livestock-crop production in Sub-Saharan Africa. Working Paper 1. International Livestock Research Institute (ILRI), Nairobi, Kenya. 51 p.

Peden, D., Tadesse, G. & Misra, A. 2007. Water and livestock for human development. In: Molden, D. (ed.) Water for food, water for life: Comprehensive assessment of water management in agriculture. Earthscan, London, in association with International Water Management Institute (IWMI), Colombo, pp. 485–514

Peden, D., Taddesse, G. & Haileslassie, A. 2009. Livestock water productivity: implications for sub-Saharan Africa. The Rangeland Journal 31: 187-193.

Pelupessy, W. & Ruben, R. 2000. Agrarian policies in Central America. Macmillan Press Ltd., London, UK. 209 p.

Pérez, CJ. 2003. Tecnologías de manejo sostenible de suelos y agua mejoran los ingresos y el empleo rural. Revista Laderas Centroamericana 18: 35-38.

Peters, M., Franco, L.H., Schmidt, A. & Hincapié, B. 2011. Especies forrajeras multipropósito: opciones para productores del Trópico Americano. Publicación CIAT No. 374. Centro Internacional de Agricultura Tropical (CIAT), Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung (BMZ), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Cali, Colombia. 212 p.

Peters, M., Horne, P., Schmidt, A., Holmann, F., Kerridge, P.C., Tarawali, S.A., Schultze-Kraft, R., Lascano, C.E., Argel, P., Stür, W., Fujisaka, S., Müller-Sämann, K. & Wortmann, C. 2001. The role of forages in reducing poverty and degradation of natural resources in tropical production systems. Agricultural Research and Extension Network Paper No. 117. Overseas Development Institute (ODI), London, UK. 16 p.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R. & Blair, R. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267(520): 1117-1123.

Pomareda, C. 2008. Política comercial y seguridad alimentaria en Centroamérica: Opciones e implicaciones. IDB Publications, Inter-American Development Bank, Washington D.C. 60 p.

Posthumus, H. 2005. Adoption of terraces in the Peruvian Andes. Ph.D. Thesis. Wageningen University and Research Centre. Wageningen, The Netherlands. 204 p.

Prasad, M., Simmons, P. & Maher, M. 2004. Release characteristics of organic fertilizers. International Symposium on growing media and hydroponics. ISHS Acta Horticulturae 644. 607 p.

Pretty, J. 1995. Regenerating agriculture: Policies and practice for sustainability and self-reliance. Earthscan, London. 336 p.

Prins, C. 2004. El largo camino de Madeleña en El Salvador: sus rutas y resultados. Recursos Naturales y Ambiente (CATIE) 43: 132-141.

Prinz, D. 1996. Water harvesting: Past and future. In: Pereira, L.S. (ed.). Sustainability of irrigated agriculture. NATO ASI Series E: Applied Sciences (Netherlands), Vol. 312: 135-144.

Prokopy, L. S., Floress, K., Klotthor-Weinkauf, D. & Baumgart-Getz, A. 2008. Determinants of agricultural best management practice adoption: Evidence from the literature. Journal of Soil and Water Conservation 63(5): 300-311.

Pulver, E., Jaramillo, S., Moreira, S. & Zorilla, G. 2012. Transformation of upland to irrigated agriculture through use of water harvesting in Costa Rica, Mexico and Nicaragua. Project report. Latin American Fund for Irrigated Rice (FLAR), Common Fund for Commodities (CFC), International Center for Tropical Agriculture (CIAT), CIAT, Cali, Colombia. 21 p.

Ramírez, O. & Schultz, S. 2000. Poisson count models to explain the adoption of agriculture and natural resource management technologies by small farmers in Central American countries. Journal of Agricultural and Applied Economics 32(1): 21-33

Reardon, T. & Vosti, S.A. 1995. Links between rural poverty and the environment in developing countries: Asset categories and investment poverty. World Development 23(9): 1495-1506.

Rehman, T., McKemey, K., Yates, C. M., Cooke, R. J., Garforth, C. J., Tranter, R. B., Park, J. R. & Dorward, P.T. 2007. Identifying and understanding factors influencing the uptake of new technologies on dairy farms in SW England using the theory of reasoned action. Agricultural Systems 94: 281-293.

Reij, C., Scoones, I. & Toulmin, C. (eds.) 1996. Sustaining the soil: Indigenous soil and water conservation in Africa. Earthscan, London. 260 p.

Reyes-Muro, L., Camacho-Villa, T. & Guevara-Hernández, F. (Coords.) 2013. Rastrojos: manejo, uso y mercado en el centro y sur de México. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Libro Técnico Núm. 7. Pabellón de Arteaga, Aguascalientes, México. 242 p.

Rockström, J., Hatibu, N., Oweis, T.Y., Wani, S., Barron, J., Bruggeman, A., Farahani, J., Karlberg, L. & Qiang, Z. 2007. Managing water in rainfed agriculture. In: Molden, D. (ed.). Water for food, water for life: Comprehensive assessment of water management in agriculture. Earthscan and International Water Management Institute (IWMI), London and Colombo. pp. 315-352.

Rogers, E. 1995. Diffusion of Innovations. The Free Press, New York. 221 p.

Roldán, A., Caravaca, F., Hernández, M., Garcia, C., Sánchez-Brito, O., Velásquez, M. & Tiscareño, M. 2003. No-tillage, crop residue additions, and legume cover cropping effects on soil quality characteristics under maize in Patzcuaro watershed (Mexico). Soil and Tillage Research 72(1): 65-73.

Romero, F., Benavides, J., Kass, M. & Pezo, D. 1994. Utilization of trees and bushes in ruminant production systems. In: Homan, E.J. (ed.). Animal agriculture and natural resources in Central America: strategies for sustainability. Workshop proceedings. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica. pp. 205-218.

Roose, E. 1996. Land husbandry - Components and strategy. Soil Bulletin 70. Soil Resources Management and Conservation Service Land and Water Development Division, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 380 p.

Rosa, H., Barry, D. Kandel, S. & Dimas, L. 2004. Compensation for environmental services and rural communities. Lessons from the Americas and key issues for strengthening community strategies. Fundación PRISMA, San Salvador, El Salvador. 31 p.

Rufino, R.L. 1989. Terraceamento. In: Manual Técnico do Subprograma de Manejo e Conservação do Solo, Curitiba. Secretaria da Agricultura e do Abastecimento, Paraná, Brazil. pp. 218-235.

Russelle, M.P., Entz, M.H. & Franzluebbers, A.J. 2007. Reconsidering integrated crop-livestock systems in North America. Agronomy Journal 99: 325-334.

Ryan, B. & Gross, N. 1943. The diffusion of hybrid seed corn in two Iowa communities. Rural Sociology 8: 15-24.

Saín, G. & Barreto, H. 1996. The adoption of soil conservation technology in El Salvador: Linking productivity and conservation. Journal of Soil and Water Conservation 51: 313-321.

Sanders, D. & Cahill, D. 1999. Where incentives fir in soil conservation programs. In: Sanders, D., Huszar, P., Sombatpanit, S., & Enters, T. (eds.). Incentives in soil conservation: From theory to practice. Oxford & IBH Publishing, New Delhi. pp. 11-24.

Sauer, J., & Zilberman, D. 2010. Innovation behavior at farm level – selection and identification. Paper presented at 114th EAAE Seminar 'Structural Change in Agriculture', Berlin, Germany, April 15th-16th, 2010. 26 p. Available at: http://ageconsearch.umn.edu/bitstream/61354/2/sauer.pdf (Accessed 19/09/2014).

Scheierling, S.M., Critchley, W. R. S., Wunder, S. & Hansen, J. 2013. Improving water management in rainfed agriculture: Issues and options in water-constrained production systems. Water Paper, Water Anchor. The World Bank, Washington D.C., USA. 225 p.

Schellekens, J., Scatena, F.N., Bruijnzeel, L.A. & Wickel, A.J. 1999. Modelling rainfall interception by a lowland tropical rain forest in northeastern Puerto Rico. Journal of Hydrology 225: 168-184.

Scherr, S. 2000. A downward spiral? Research evidence on the relationship between poverty and natural resource degradation. Food Policy 25: 479-498.

Schiere, H.B., Baumhardt, R.L., Van Keulen, H., Whitbread, A.M., Bruinsma, A.S., Goodchild, A.V., Gregorini, P., Slingerland, M.A. & Hartwell, B. 2006. Mixed crop-livestock systems in semiarid regions. In: Peterson, G.A., Unger, P.W. & Payne, W.A. (eds.). Dryland agriculture. American Society of Agronomy Monograph Series No. 23. Madison, WI, USA. pp. 227-291.

Schmidt A., Eitzinger, A., Sonder, K. & Sain, G. 2012. Tortillas on the roaster (ToR) - Central American maize–bean systems and the changing climate. Full technical report. Catholic Relief Services (CRS) Baltimore, Maryland, USA, Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia, Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT), México, D.F. 127 p.

Schrader, K. 2002. Anreize zur nachhaltigen Bodennutzung in Zentralamerika. Eine Analyse direkter materieller Anreize in Projekten der ländlichen Regionalentwicklung in Bergregionen El Salvadors, Honduras' und Nicaraguas. Geographica Bernensia G 69. Institute of Geography, University of Berne, Berne, Switzerland. 283 p.

Scopel, E. 1996. Estudio de sistemas de cultivo sostenibles y productivos con labranza de conservación en maíz de temporal en México: Informe de actividades científicas 1994 & 1995. Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT), Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias (INIFAP), Mexico City, Mexico. 31 p.

Scopel, E., Tardieu, F., Edmeades, G. & Sebillotte, M. 2001. Effects of conservation tillage on water supply and rainfed maize production in semiarid zones of west-central Mexico. International Maize and Wheat Improvement Center (CIMMYT), Texcoco, Mexico. 18 p.

Segura, E. 1999. Contribución de las tecnologías agroforestales a la economía y bienestar de los pequeños productores en tierra de ladera en El Salvador. Tesis. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba, Costa Rica, 89 p. Available at: http://web.catie.ac.cr (Accessed on 19/09/2014).

Sheng, Y.P. 1989. Evolution of a Three-Dimensional Curvilinear-Grid Hydrodynamic Model for Estuaries, Lakes, and Coastal Waters: CH3D. In: Spaulding, M.S. (ed.). Estuarine and Coastal Modeling. American Society of Civil Engineers, Reston, Virginia, USA. pp. 40-49.

Shultz. S., Faustino, J. & Melgar, D. 1997. Agroforestry and soil Conservation: Adoption and profitability in El Salvador. Agroforestry Today 9: 16-17.

Sinclair, T.R. & Gardner, F.P. 1998. Environmental limits to plant production. Principles of ecology in plant production. CAB International, UK. 200 p.

Singh, O., Sharma, A., Singh, R &, Shah, T. 2004. Virtual water trade in dairy economy: Irrigation water productivity in Gujarat. Economical and Political Weekly 39(31): 3492-3497.

Solís, D., Bravo-Ureta, B. & Quiroga, R. 2006. The effect of soil conservation on technical efficiency: Evidence from Central America. Selected paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Long Beach, California, July 23-26, 2006. American Agricultural Economics Association (New Name 2008: Agricultural and Applied Economics Association). Available at: http://EconPapers.repec.org/RePEc:ags:aaea06:21345. (Accessed 19/09/2014).

Steiner, K. 1996. Causes of soil degradation and development approaches to sustainable soil management. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Margraf Verlag, Eschborn, Germany. 178 p.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. & de Haan, C. 2006. Livestock's long shadow: Environmental issues and options. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 390 p.

Steduto, P., & Albrizio, R. 2005. Resource use efficiency of field-grown sunflower, sorghum, wheat and chickpea: II. Water use efficiency and comparison with radiation use efficiency. Agricultural and forest meteorology 130(3): 269-281.

Steduto, P., Hsiao, T.C. & Fereres, E. 2007. On the conservative behaviour of biomass water productivity. Irrigation Science 25: 189-207.

Stocking, M. & Tengberg, A. 1999. Soil conservation as an incentive enough - experiences from southern Brazil and Argentina on identifying sustainable practices. In: Sanders, D., Huszar, P., Sombatpanit, S. & Enters, T. (eds.). Incentives in soil conservation: From theory to practice. Oxford & IBH Publishing, New Delhi. pp. 69-86.

Stocking, M. 2002. Diversity: A new strategic direction for soil conservation. Proceedings of 12th ISCO Conference, May 26-31, 2002. Ministry of Water Resources, Beijing, China. pp. 53-58.

Swinton, S.M. 2000. More social capital, less erosion: Evidence from Peru's Altiplano. Selected paper for presentation at the American Agricultural Economics Association, Tampa, FL, USA, July 30-August 2, 2000. Department of Agricultural Economics, Michigan State University, East Lansing, Michigan, USA. 19 p.

Szott, L., Ibrahim, M. & Beer, J. 2000. The hamburger connection hangover. Cattle, pasture, and land degradation and alternative land use in Central America. Technical report. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica. 71 p.

Tanner, C.B. & Sinclair, T.R. 1983. Efficient water use in crop production: research or re-search? In: Taylor, H.M., Wayne, J.R. & Sinclair, T.R. (eds.). Limitations to Efficient Water Use in Crop Production. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, Wisconsin, USA. p. 1-27.

Tarawali, S., Herrero, M., Descheemaeker, K., Grings, E. & Blümmel, M. 2011. Pathways for sustainable development of mixed crop livestock systems: Taking a livestock and pro-poor approach. Livestock Science 139: 11–21.

Thierfielder, C. & Wall, P.C. 2011. Reducing the risk of crop failure for smallholder farmers in Africa through the adoption of conservation agriculture. In: Bationo, A., Waswa, B., Okeyo, J.M., Maina, F. & Maguta Kihara, J. (eds.). Innovations as key to the green revolution in Africa - Exploring the scientific facts. Springer, Netherlands. pp. 1269-1277.

Thompson, M. 1992. The effect of stone retention walls on soil productivity and crop performance on selected hillside farms in southern Honduras. Project report. Texas A&M University, College Station, Texas, USA. 48 p.

Thornton, P., Kruska, R.L., Henninger, N., Krisjanson, P.M., Reid, R.S., Atieno, F., Odero, A.N. & Ndegwa, T. 2002. Mapping poverty and livestock in the developing world. International Livestock Research Institute (ILRI), Nairobi, Kenya. 124 p.

Thurow, A.P., Thurow, T.L. & Hector, S.R. 2004. Considerations for targeting soil conservation investments in Honduras. Environment and Development Economics 9: 781-802.

Thurow, T.L. & Smith., J.E. 1998. Evaluación de métodos de conservación de suelos y agua aplicados a las tierras de ladera cultivadas en el sur de Honduras. Agencia para el Desarrollo Internacional. Programa de Investigación Colaborativo de Manejo de Suelo de la Universidad de Texas A&M. Boletín Técnico No. 98-2. 22 p.

Trenbath, B.R. 1976. Plant interactions in mixed cropping communities. In: Papendick, R., Sanchez, A., Triplett, G. (eds.). Multiple cropping. ASA Special Publication 27. American Society of Agronomy, Madison, WI., USA. pp. 129-169.

Tsubo, M., Walker, S. & Ogindo, H. 2005. A simulation model of cereal-legume intercropping system for semi-arid regions. Field Crops Research 93(1): 10-22.

Valbuena, D., Homann-Kee Tui, S., Erenstein, O., Teufel, N., Duncan, A., Abdoulaye, T., Swain, B., Mekonnen, K., Germaine, I. & Gérard, B. 2014. Identifying determinants, pressures and trade-offs of crop residue use in mixed smallholder farms in Sub-Saharan Africa and South Asia. Agricultural Systems: Available at: http://dx.doi.org/10.1016/j.agsy.2014.05.013 (Accessed on 19/09/2014).

van Donk, S.J., Martin, D.L., Irmak, S., Melvon, S., Petersen, J.L. & Davison, D.R. 2010. Crop residue cover effects on evaporation, soil water content, and yield of deficit-irrigated corn in west-central Nebraska. Transactions of American Society of Agricultural and Biological Engineers 53(6): 1787-1797.

Van Noordwijk, M. & Ong, C.K. 1999. Can the ecosystem mimic hypotheses be applied to farms in African savannahs? Agroforestry Systems 45: 131-158.

Vanlauwe, B., Wendt, J., Giller, K.E., Corbeels, M., Gerard, B. & Nolte, C. 2014. A fourth principle is required to define conservation agriculture in sub-Saharan Africa: the appropriate use of fertilizer to enhance crop productivity. Field Crops Research 155: 10-13.

Verhulst, N., Nelissen, V., Jespers, N., Haven, H., Sayre, K., Raes, D., Deckers, J. & Govaerts, B. 2011a. Soil water content, maize yield and its stability as affected by tillage and crop residue management in rainfed semi-arid highlands. Plant and Soil 344(1-2): 73–85.

Verhulst, N., Sayre, K.D., Vargas, M., Crossa, J., Deckers, J., Raes, D. & Govaerts, B. 2011b. Wheat yield and tillage–straw management system × year interaction explained by climatic co-variables for an irrigated bed planting system in northwestern Mexico. Field Crops Research 124: 347-356.

Wall, P.C. 2007. Tailoring conservation agriculture to the needs of small farmers in developing countries: An analysis of issues. Journal of Crop Improvement 19(1-2): 137-155.

Wallace, J.S., Jackson, N.A. & Ong, C.K. 1999. Modelling soil evaporation in an agroforestry system in Kenya. Agricultural and Forest Meteorology 94: 189-202.

Wallace, J.S., Young, A. & Ong, C.K. 2004. The potential of agroforestry for sustainable land and water management. In: Bonell, M. & Bruijnzeel, L. A. (eds.). Forests, water and people in the humid tropics: past, present and future hydrological research for integrated land and water management. Cambridge University Press, Cambridge, UK. pp. 652-670.

Wani, S. P., Singh, P., Boomiraj, K. & Sahrawat, K.L. 2009. Climate change and sustainable rain-fed agriculture: challenges and opportunities. Agric. Sit. India 66 (5): 221–239.

Welchez, L.A. 1999. Mejoramiento en relación al uso de tecnologías de producción en laderas del sur de Lempira, Honduras, C.A. Revista Laderas Centroamericana 5:11–16.

Wilkins, R.J. 2008. Eco-efficient approaches to land management: a case for increased integration of crop and animal production systems. Philosophical Transactions of the Royal Society - Biological Sciences 363: 517-525.

Willey, R.W. 1990. Resource use in intercropping systems. Agricultural Water Management 17: 215-231.

Wilson, T. 2007. Perceptions, practices, principles and policies in provision of livestock water in Africa. Agricultural Water Management 90: 1-12.

Winters, P., Crissman, C. & Espinosa, P. 2004. Inducing the adoption of conservation technologies: lessons from the ecuadorian andes. Environment and Development Economics 9: 695-719.

Witter, S., Robotham, M. & Carrasco, D. 1996. Sustainable adoption of conservation practices by upland farmers in the dominican republic. Journal of Soil and Water Conservation 51(3): 249-254.

Zinn, Y., Lal, R. & Resck, D. 2005. Changes in soil organic carbon stocks under agriculture in Brazil. Soil and Tillage Research 84(1): 28-40.

Zurek, M.B. 2002. Induced innovation and productivity-enhancing, resource-conserving technologies in Central America: The supply of soil conservation practices and small-scale farmers' adoption in Guatemala and El Salvador. Ph.D. thesis. Justus-Liebig-Universität Giessen, Germany. 237 p.