Rainfed systems intensification and scaling of water and soil management

Four case studies of development in family farming

Editors: Jennie Barron & Anna Tengberg | 2023

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ECAF European Conservation Agriculture Federation
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SIWI

Rainfed systems intensification and scaling of water and soil management: four case studies of development in family farming

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Publishing year: 2023, Uppsala
Publisher: Department of Soil and Environment, SLU
ISBN printed version: 978-91-8046-892-3
ISBN electronic version: 978-91-8046-893-0
DOI: https://doi.org/10.54612/a.4nbusqmc4l
Layout: Cajsa Lithell
Cover photo and photo on page 6, 16 and 43: Jennie Barron

This report was updated 2023 -11-23. The original version contained the following errors: page 115, figure 16 Legend , CT (yellow) and CA(green) chnged to , (legend) CA (yellow) and CT(green).

Content

Preface

Food systems need to become more productive and nutritious for a growing global population, whilst being environmentally sound, and withstanding climate change. Rainfed agriculture is therefore a critical production system that holds large potential to sustainably intensify globally and locally, but often lacking attention and investments

This report provides evidence of action in rainfed agricultural systems for four case studies of scaling best practises in small and medium size farming in India, Central America, Ethiopia and Brazil. The aim is to provide knowledge for future investments and scaling of sustainable intensification in rainfed production that holds evidence on both yield and income gains, whilst improving field to landscape ecosystem services.

The cases present the initial issues, the actions and practises promoted on-farm, outlining the investment sources and actors involved, over period of 10-30 years to show impact to scale.

This report was developed under grant agreement with FAO (ref number 342559). Additional support was provided by SLU. We are grateful for the support and dialogue by various external expertise during the work.

Keywords: Adoption soil; Climate resilience; Farming systems; Landscape; Rainfed agriculture; Scaling agricultural development; Soil and water management; Sustainable intensification; Water management; Water scarcity

Case studies

This report include the following studies:

- Introduction to compilation of case studies of rainfed systems intensification *(Barron, J., A. Tengberg)*

- Scaling water smart agriculture to improve the productivity and resilience of rainfed smallholder production systems in Mesoamerica *(Turmel, M-S., Rosenow, K., Schmidt, A., Aburto Sanchez, E. & Hicks, P.)*

- Scaling-up agriculture water management interventions for building system resilience in Bundelkhand region of Central India *(Garg, K.K., Anantha, K.H., Barron, J., Singh, R., Dev, I., Dixit, S. & Whitbread, A.M.)*

- Sustainable land management with conservation agriculture for rainfed production: The case of Paraná III watershed (Itaipu dam) in Brazil *(Mello, I., Roloff, G., Laurent, F., Gonzalez, E. & Kassam, A.)*

- Scaling-up of agriculture water management interventions in Ethiopian highlands: Status, issues and opportunities *(Mezegebu, G. D., Anantha, K.H., Garg, K.K. & Amede, T.)*

Introduction to compilation of case studies of rainfed systems intensification

Jennie Barron Swedish University of Agricultural Sciences (SLU) and Anna Tengberg , Stockholm International Water Institute (SIWI)

1. Introduction

Rainfed crop and pasture systems dominate agricultural practises globally. They support over 60% of biobased food and over 95% of feed and pasture for animal-sourced food including dairy and eggs. Globally, these production systems constitute 1.25 gigahectares (Gha) of rainfed cropland and 3.5 Gha of rainfed pastureland, and are home to approximately 500 million smallholder farmers (Lowder et al., 2016; Samberg et al., 2016). Rainfed agriculture is highly dependent on climate vagaries and farming practises. Limited rainfall and poor soil(land) management still limit rainfed production capacity. This locks rainfed systems at low yield levels and contributes to the loss of a range of ecosystem services, such as regulation of water runoff, sediment transport, and sequestration of soil organic matter. The impacts are felt across farmer incomes, food security, water security and the resilience of landscapes. New assessments suggest that by 2050 water scarcity will be the cause of production capacity reductions on over 10% of crop land and 11% of pastures (Fitton et al., 2019; FAO SOFA2020). This water scarcity will also increase food import dependencies, particularly in Africa, the Middle East and China, but also in more developed regions such as Europe. Water scarcity, faced by farmers in rainfed production systems, undermines their production capacity and yields, increases risk, and challenges efforts to intensify. Yet, rainfed farming has evolved in the last 20 years, and in some regions it has actually accelerated progress on production capacity, farmer incomes and combating environmental challenges. In this compilation, we provide four examples of intensification of rainfed systems. These serve as emerging evidence that positive change can be achieved. The cases focus on both the context and the process of change, in practices and technologies, of the respective rainfed farming systems. They also describe the process of moving from minor pilots to large-scale, outscaled practises for development. The purpose is to identify impact pathways that will increase the production capacity of rainfed systems. Another key aim is to scale up sustainable, resilient practices that improve farmer livelihoods, while enhancing ecosystem goods and services. This compilation of cases were developed to support the SOFA 2020 report on Managing Water for Sustainable Food Systems (FAO SOFA2020).

2. Material and methods

The cases compiled in this background report were selected to represent a wide variety of rainfed farming systems and processes (Figure 1). The main selection criteria were that: i) the case has at least some documentation, and evidence, of a change in farming practises to substantiate development of the specific rainfed production system, and ii) the case goes beyond the research domain, and can describe piloting, or scaling, of practises introduced by farmers and other actors in the landscape context. We focus on case studies that support evidence of the water and soil management technology and innovation changes in farmer practises. For the aspect of ii) piloting and scaling, we classify the cases along the

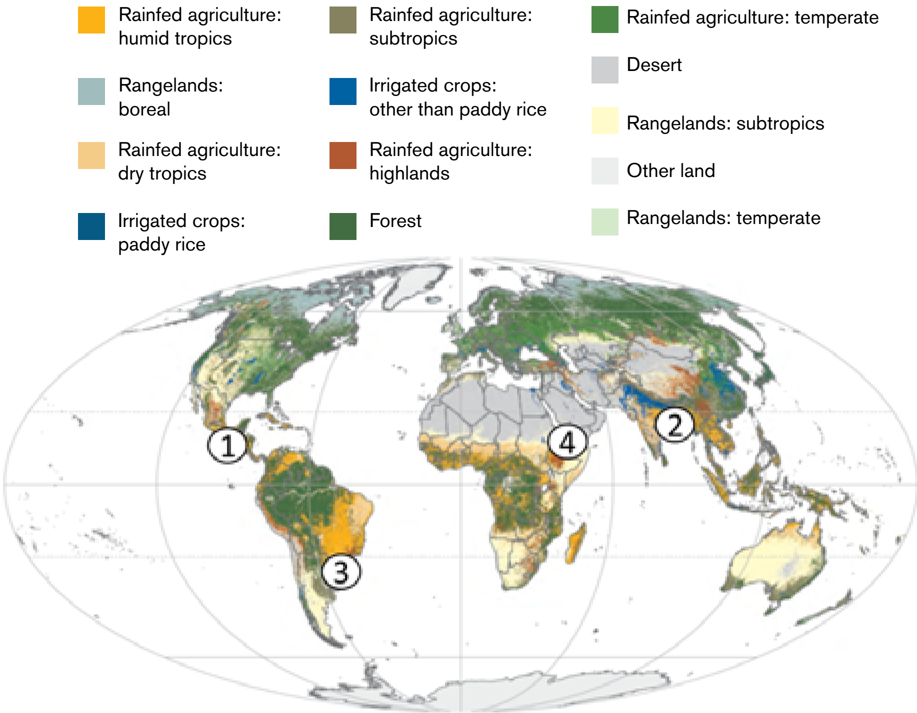

Figure 1 : Global map with the four cases studies of rainfed crop an pasture systems intensification in this report 1) Watersmart agriculture in Meso-America, 2) Integrated participatory water harvesting and watershed development in Bhundelkand region , India, 3) Parana Watershed development through conservation agriculture in Southern Brazil, and 4) national programs of sustainable land management practices, Ethiopia (Source map: FAO, 2011)

research-for-development continuum, described by Thornton et al. (2017). This continuum assumes a process from research and innovation (of a technology/product/tool/approach), to piloting, scaling, and ultimately to broad adoption and practice (i.e. the majority of farmers, or other land custodians, implement this practice/technology) (Figure 2). These cases would, according to this framework, be classified as being in the stages of piloting-scaling and broad adoption. This is also in

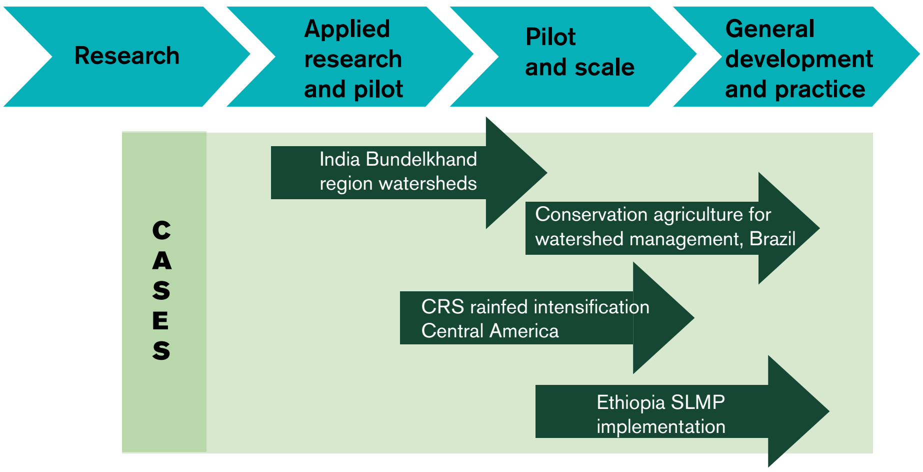

Figure 2: Case studies for rainfed systems intensification along a research-to-development continuum (framework adapted after Thornton et al., 2017)

line with transition theory, and the four stages of socio-technical transitions, from pre-development of technologies and approaches at the niche level, followed by take off and acceleration, to regime shift and stabilization at the landscape level (Geels, 2002; Wieczorek, 2018).

The four cases are presented in Table 1. These represent cases transitioning from research and development (India case study by Garg et al., 2020), into piloting (Central America, by Turmel et al., 2020) and scaling processes (Ethiopia by Mezegebu et al., 2020,; Brazil by Mello et al., 2020). The cases provide examples of a range of agro-ecological zones, with processes of rainfed systems intensification, in a development and policy context, spanning a 10-30 year period.

3. Summary of findings

Even though these cases on sustainable intensification of rainfed systems are highly diverse in terms of contexts, they display a set of similarities and potential lessons to be learned.

Active management of rainfall for resilience building

The cases all stem from a recognition that in rainfed farming systems neither improved wellbeing, nor a sustainable environment are achievable, unless rainfall is managed more actively and creatively. Managing rainfall is therefore a must in order to ensure that other investments in crop management pay off.

Table 1: Description of case studies of rainfed systems intensification

Location	Rainfall agro-climatic regime	Dominant production systems	Type of case interventions	Reference
India: Bundelkhand region (Uttar Pradesh, Madra Pradesh)	Tropical semi-arid; long-term average rainfall: 850mm y^{-1} (400-1200mm y^{-1})	Smallholder farming. Single and double cropping: cereal, beans /mixed for market, complemented with dairy. Rainfed and supplemental irrigation	Research for development and scaling process 2006-2019	Garg et al., 2020
Ethiopia: national	Semi-arid to temperate wet sub-humid. Long-term average rainfall: 400-2000 mm y^{-1}	Smallholder farming. Single and double cropping: teff, maize, beans /mixed for subsistence and market, complemented with livestock. Rainfed	National rural development strategy for sustainable land management 2005-2018	Mezegebu et al., 2020
Meso-America: El Salvador, Guatemala, Honduras , Nicaragua	Tropical semi-arid to dry sub-humid; Long-term average rainfall: 900-1400 mm y^{-1}	Smallholder farming. Single and double cropping: maize, beans /mixed for subsistence and market. Rainfed	International NGO, scaling best practices with farmers 2015 - 2019	Turmel et al., 2020
Brazil: Paraná State with links to Paraguay	Sub-tropical humid climate without marked dry season. Longterm average rainfall: 1400 mm y^{-1}	Smallholder farming. Two to five commercial crops a year, depending on elevation: soybeans, maize, wheat and sunflowers as well as livestock.	Long-term participatory strategy to improve land management in the Paraná III basin, to reduce sedimentation in the Itaipu dam	Mello et al., 2020

For example, in the case of Bundelkhand region, India (Garg et al., 2020), a long tradition of water harvesting through the *haveli* system (Box 1) did not meet needs, due to rapid changes in social and climatic factors. Both the traditional *haveli*s and additional soil and water conservation structures were improved to allow for crop rotations that enhanced water use, through rainfed farming and increased use of supplemental irrigation. Water harvesting and soil conservation measures were combined with soil nutrient management, specifically designed to fit regional soil conditions. These combined measures enabled better utilization of water available in the landscape for income generation. Data in the case study suggests enhanced crop yields of 30–50%, and cropping intensity improvements of 80–150%, through the use of supplemental irrigation, new tank storage and the redesigned *haveli* system.

In Ethiopia, the challenge of land degradation and the need to retain rainfall, have been recognized since the 1970s through various national initiatives. From 2005, these technologies have been scaled to, at a minimum, 800 000 ha (2.5% of Ethiopia's crop land) through the comprehensive field to watershed effort under the national Sustainable Land Management Programme (SLMP) phases 1 and 2. New research and impact assessments suggest that it may have positively affected several regulating ecosystem services significantly, and led to reduced erosion and surface runoff. There has also been an increase in national rainfed yields, although this cannot be solely attributed to implementation of SLMP1 and 2 (Mezegebu et al., 2020). Nonetheless, it is likely the result of several associated factors such as increased fertilizer use, improved seeds (albeit there is room for further improvement), and improved crop management and timeliness by farmers.

In the case of the Central America rainfed systems, the fundamental issue is to foster infiltration and retention of soil moisture for rainfed crops, in systems subject to increasing rainfall variability and degraded soils (Turmel et al., 2020). Interventions detailed in this case study are still in the pilot stage, facilitated by an international NGO across four countries in Central America. Again, it works with soil health to manage rainfall more productively. Soil management, building organic matter through conservation tillage practices, is a key intervention. This is complemented by improved soil information for precision farming practices based on knowledge about soil nutrients.

Land in the Paraná III watershed in Brazil has been protected by anti-erosive contour bunds and terraces to stop and retain runoff and improve infiltration into the Oxisols between the bunds. However, the introduction of conservation agriculture, which spread throughout the watershed in the 1990s, was more effective in maintaining high infiltration rates and minimizing runoff and erosion, as well as raising productivity. The Agricultural Research Institute of Paraná State (IAPAR) together with Itaipu Binancional, a public enterprise, created the concept of a "no-tillage system with quality" to promote no tillage, soil cover and crop rotation, that should be adopted as an integrated package to qualify as conservation agriculture. In 2017, 89% of the agricultural cropland was managed under no-tillage systems. These systems achieve yield levels comparable to conventional tillage systems, while conserving soil moisture and sequestering carbon at rates ranging from 0.1–0.5 t/ha/year. As a result of the adoption of conservation agriculture, crop yields have shown continued increases. Since 1996 there has been about a 40% increase in soybean yields and 70% in maize yields.

Participation, inclusiveness and consultative approaches

All the cases reported here demonstrate explicit efforts in participatory, inclusive and consultative approaches, including the gender dimension, when taking new practices into use. This has not always been the norm, as shown in the Bunderkhand case (Garg et al., 2020) and the Ethiopia SMLP case (Mezegebu et al., 2020). In the Bunderkhand case, farmers have been consulted, and even led implementation of activities, in various ways. Gender is considered, and where appropriate, men and women are engaged separately in piloting and scaling activities. In the Ethiopia case, monitoring of results is gender disaggregated. For example, in the SLMP activities, 17-40% of households are female-headed, and are reported to have been benefiting from the various technologies and practices promoted (Mezegebu et al., 2020) (section 3.1). In the Paraná III watershed in Brazil, it has been demonstrated that a community-based soil and water conservation program can be developed in a socially equitable manner. This combines the interests of smallholders and large-scale farmers in a mutually reinforcing and self-empowering manner. However, achieving broad participation and inclusion takes time. It is important to integrate iterative learning processes, that are informed by adequate monitoring and assessment, when moving to scale.

Partnerships for co-production of knowledge and innovation

One element, in the selected cases, is critical to improving technologies and practices in the respective farming systems. This is the active inclusion of research capacity for co-production of new knowledge and innovation, together with farmers and key public, private and civil society agricultural institutions. In all the multi-stakeholder partnerships, research institutions and/or universities, have been instrumental in supporting the pilot and scaling efforts. In the Central America water smart initiative, partnerships with national and overseas researchers have provided new tools and data collection approaches. These have been used to identify soil health constraints, and thereby improve nutrient management of the rainfed systems (Turmel et al., 2020). This was also a critical contribution in the Bundelkhand case (Garg et al., 2020), where soil nutrient constraints impeded water productivity. With soil testing, through the support of ICRISAT researchers, and soil nutrient score cards, farmers were able to better benefit from the improved rainwater management introduced, by also applying fertilizers targeted to specific soil conditions. This was so effective that they switched to higher value crops.

In the case of Bundelkhand, researchers also proved instrumental in the adoption and revitalization of soil and water conservation, and of water harvesting structures. The traditional systems of *havelis*, and new soil bunds, needed design improvements to improve capacity and to strengthen the structural works, given new rainfall extremes (Garg et al., 2020). These improved designs better met farmer needs and were therefore easier to promote among the communities. Paraná was one of the pioneer states in Brazil in no-tillage research and development. Between 1977 and 1991, agricultural research conducted by IAPAR, in partnership with GTZ, proved that production systems based on no-tillage and cover crops were efficient in the control of water erosion, and also led to increased infiltration and improved soil moisture. This research has been coupled with technology development, in partnership with public and private enterprises. For example, no-till seeders for smallholders and biogas digesters (Mello et al., 2020).

Governance and institutional arrangements

Increasingly, there are national policies and institutions with links to multilateral agreements and global commitments that support local action towards intensification in rainfed systems. As shown here, intensification through water and soil management in rainfed systems often have both livelihood and ecosystem service benefits. These align with various national, regional and global agendas such as Agenda 2030, notably UN SDG 2 on Zero Hunger, UN SDG 6 on Clean Water, UN SDG 13 on Climate Action, and UN SDG 15 on Life on Land. In addition, some practices can contribute to carbon sequestration if it involves re-vegetation (Garg et al., 2020; Mezegebu et al., 2020) and building soil organic matter, such as no-tillage and conservation agriculture (Turmel et al., 2020; Mello et al., 2020). In the case of Ethiopia (Mezegebu et al., 2020) and Bundelkhand region (Garg et al., 2020), the current discourse, and approaches, evolved over more than 50 years. It also takes time to move from pilot to full-scale implementation. In the Bundelkhand case, piloting and scaling has been an ongoing process since 2005, evolving though various partnerships, until 2018 when the Government of Uttar Pradesh endorsed the case study concept as described by Garg et al. (2020). If the ambition is to scale up, there is a need to allow the intervention to develop over time, and to commit to investments spanning more than just a few years of project intervention. In addition, capacity building and education are key in the creation and institutionalization of an enabling environment for water smart agriculture, as shown in Central America (Turmel et al., 2020). The Paraná II watershed case demonstrates the need for a multi-sectoral, and socially inclusive, management approach to continuity and change. Several sectors cooperated in the program including; energy, water, agriculture, environment, social development, health, and education. The community development framework, created for the watershed, has been vital to the economic, social and environmental achievements of the initiative. Moreover, based on the cooperation between Itaipu hydropower and watershed development programs, the land and water related developments on the Brazilian side of the Itaipu reservoir also occurred across the border in Paraguay (Mello et al., 2020).

4. A proposed impact pathway for rainfed systems intensification

Even with current efforts in agriculture and rural development, the pace will not be sufficient to meet either accelerated food demand or rural development needs, goals agreed in Agenda 2030 and the Paris climate agreement. Water scarcity is rapidly increasing the challenges posed to achieving sustainable intensification of agriculture through irrigation, yet rainfed systems can be a " best bet" investment both for livelihoods and the environment. Rainfall and soil resource management practices, at farm and landscape levels, are well researched for multiple agro-ecologies and farm systems. These four cases provide evidence of how this knowledge has been put into practice to achieve enhanced crop productivity and benefit farmers, as well as resulting in landscape environmental gains. In the four cases analyzed, there are emerging lessons to be learned for regions which are dominated by rainfed agriculture. These cases can inform an agenda for integrated rural development in rainfed dominated landscapes, especially in current low-yielding smallholder farming

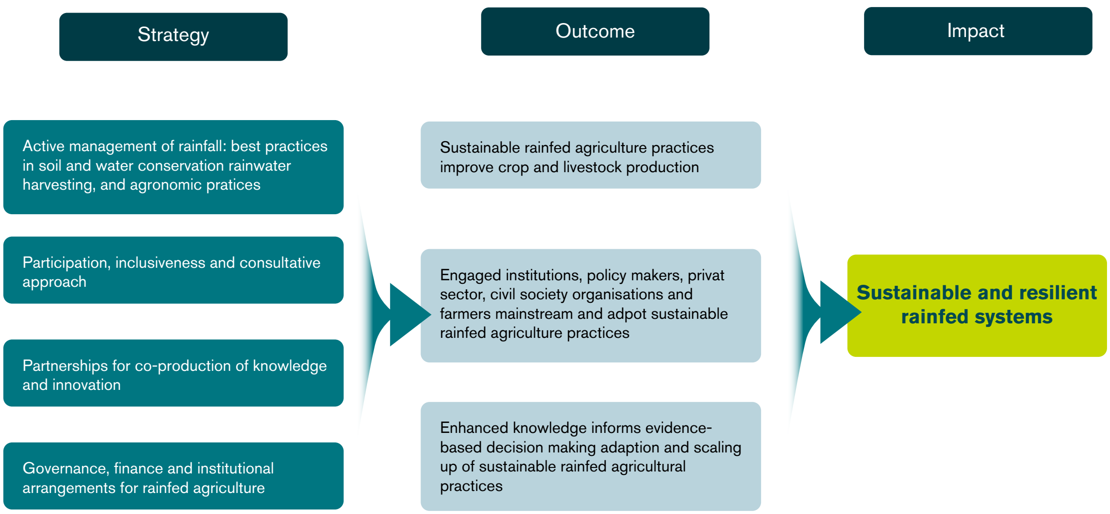

Figure 3: Generic impact pathway for piloting and scaling approaches to improved sustainability and resilience of rainfed systems.

systems. The generic, simplified impact pathway that is emerging from analysis of these different cases from India, Ethiopia, Central America and Brazil, brings together various factors to deliver co-benefits for livelihoods and the environment (Figure 3). As such, this impact pathway offers opportunities to accelerate the transition from piloting of technologies and approaches at the local or watershed level, to broader adoption at the landscape or national level.

The impact pathway these case studies point to include a number of key elements:

- The first step is to consider rainfall and soils in a coordinated way (using best practices in soil and water conservation, rainwater harvesting and agronomic practices), in combination with new technology and data, to assess options and implementation strategies in time and space.

- A process design that integrates technologies with agronomy, and which is implemented with participatory and consultative approaches, is likely to be more successful since it can adapt to local demands and contexts. Involving research and knowledge partners throughout can assist in supporting: i) innovation and new and improved practices and technologies, ii) systematic monitoring for learning, and iii) capacity building of farmers and the extension service.

- Multi-stakeholder partnerships can play a key role in producing new knowledge, and supporting the learning processes necessary for developing a shared understanding of both the challenges and opportunities inherent in rainfed systems. Partnerships also contribute to continuous learning that informs adaptive management. Stakeholder participation, at various levels, is necessary in order to achieve inclusiveness and transparency, and can also provide platforms for participatory and user-friendly monitoring.

- Strengthened governanc, access to finance and institutional arrangements create conditions for sustainable scaling in rainfed systems, but scaling is a complex process that goes beyond policy and governance alone. Farmers need access to finance, for example micro-credits, to invest in improved practices. Intersectoral collaboration, tailored to country, region and partner needs, is required to support scaling of best practices on the ground.

Rainfed systems, in water scarce areas, are high risk for farmers due to current and future rainfall variability and change, and also because of current and past soil-land management practices. Yet, they hold opportunities for low risk/high gain investments for development, in collaboration with farmers. Monitoring and learning has often been weak and inconsistent, but increasingly information is now available. A more systematic study could provide comprehensive insights to inform robust action and investments across rainfed systems, especially focusing on low-yielding, water scarce and degraded landscapes.

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Acknowledgements

This report is a background document is developed to support the FAO State of Food And Agriculture (SOFA) 2020: Overcoming water challenges in agriculture. Funding was in full supported by FAO. We thank the authors of case studies for their contributions.

Scaling water smart agriculture to improve the productivity and resilience of rainfed smallholder production systems in Mesoamerica

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*Refer to acknowledgements for full list of CRS country teams that carried out the body of work described in this case study.

In memory of Luis Alvarez Welchez who dedicated his life to helping Central America's smallholder farmers restore their soil and water resources.

Summary

Soil and water resource degradation coupled with an increasingly extreme and variable climate threaten the food security and livelihoods of millions of smallholder farmers in the Dry Corridor of Central America and southern Mexico. Water Smart Agriculture (WSA) is an approach that increases agricultural productivity through the restoration of soil and water resources. The main objective is to build the climate resilience and productivity of smallholder farming in this critical sub-region, The Water Smart Agriculture Program for Mesoamerica[1] has partnered with a network of public and private agricultural institutions, local organizations and smallholder farmers in Nicaragua, El Salvador, Honduras, Guatemala and Oaxaca, Mexico. Together they are scaling up processes to validate and catalyze broad adoption of tools, methodologies and practices that build soil health and increase the productivity, profit, and resilience of smallholder rainfed agriculture. Over 3,000 smallholder farmers across the region are implementing on-farm trials that validate that water-smart practices, including conservation agriculture, integrated soil fertility management, and cover cropping, improve soil health. In doing so they translate into significantly increased rainwater productivity and economic benefits, often within the first season. This WSA evidence base underlies a scaling strategy to strengthen the capacity of partner institutions, extensionists, promoters and farmers to experiment, innovate, adopt and scale WSA. Close to 100 partners and ally organizations, from landscape level programs to local civic organizations and ministries of agriculture, now offer WSA tools, methodologies and services that reach over 90,000 farmers. These results are extremely promising and serve as the foundation of a region-wide movement to transform rainfed agriculture in Mesoamerica by scaling WSA to 500,000 smallholder farms within the next decade.

[1]*https://asa.crs.org/en/*

1. Introduction

Food insecurity, low agricultural productivity and natural resource degradation are intimately linked in rural Central America and southern Mexico where an estimated 2.3 million smallholder farmers form the backbone of the rural economy (Instituto Nacional de Estadística, 1997; Harvey et al., 2018; FAO, 2020).

These predominantly rainfed systems produce 66% of the basic food crops of Mesoamerica on 71% of the agricultural land (Siebert and Döll, 2010). For the CA4 – El Salvador, Guatemala, Honduras, and Nicaragua – the proportion of rainfed rises to 92% (Beekman et al., 2014). Over half of all smallholder farms produce maize and beans – regional staples that form the foundation of the regional diet yet provide a meager livelihood. More than half of these farmers live below the poverty line and 30% are extremely poor (van der Zee Arias et al., 2012). The 350,000 smallholder coffee growers of the region also suffer high levels of food insecurity (Caswell et al., 2012).

The topography, soils and climate of Central America are highly variable. The region hosts humid, tropical and cloud forest habitats that receive as much as 7500 mm/a of rainfall, and sub-tropical savannahs and drylands that receive as little as 400 mm/a. High ecological heterogeneity has inspired equally diverse agricultural systems, as farmers have adapted to location-specific characteristics. With over 70% of the land area considered "mountainous" with hills and slopes and a prevalence of poor-quality soils, Central America is a difficult place to farm (Zurek, 2002). With the majority of agriculture dependent on rainfall, the agricultural cycle is defined by the bimodal rainfall pattern of the region with the first growing season, *primera*, sown with the onset of rains in May or June and a second planting, *postrera*, initiated in September. While maize and beans are grown in both seasons, maize predominates in *primera* and beans in *postrera*. In higher rainfall areas, farmers may also plant beans and vegetables in a third season, *apante*, that relies on residual soil moisture and light rains from December to March.

Photo 1: Agriculture dominated landscape on the hillsides of Nicaragua (Axel Schmidt, 2014)

In between the *primera* and *postrera* planting cycles is a recurrent mid-season dry spell called the *canícula* where rainfall is significantly reduced for several weeks. The magnitude, length, intensity and start and end dates of the *canícula* have historically been highly variable and were not well understood, or studied (Verbist et al., 2018). Today, however, the *canícula* is the most serious climate risk factor for rainfed farming in Central America, a threat that is growing as the changes in climate conditions increase in severity, length, and variability, endangering both the *primera* and *postrera* cropping seasons. Climate models predict that the *canícula* will increasingly start earlier and last longer (Maurer et al., 2017).

Photo 2: Degraded hillside agricultural land in the dry season in Guatemala. Maize residues are consumed by livestock leaving the soil bare (M.S. Turmel, 2017)

A more intense and erratic *canícula* is among several impacts of the changes in climate conditions already suffered in Mesoamerica, one of the regions in the world most affected by, and vulnerable to, these changes (Schmidt et al., 2012; Donatti et al., 2019; Eckstein et al., 2019). Current trends, including increasingly irregular rainfall, more frequent and intense drought, and intermittent extreme precipitation events are predicted to continue to worsen over the next decades as the region becomes significantly hotter and drier (Hannah et al., 2017). These changes have been felt most acutely in the Dry Corridor, a sub-region of dry, tropical forest running along the Pacific side of Central America. The Dry Corridor has been defined over the past 10 years as one of the regions in the world most susceptible to increasing climate variability (FAO, 2017). Large areas of Central America experienced moderate to severe drought conditions in six of the eleven years from 2009 to and including 2019. Severe and widespread drought events in 2009, 2015 and 2018 left as many as three million people in need of humanitarian assistance due to crop loss (FAO, 2017; FAO, 2018).

High levels of deforestation and soil and water resource degradation exacerbate the vulnerability to climate variability as the ecosystem has diminished capacity to protect and regulate itself. An estimated 75% of agricultural land in Central America suffers from human-induced soil degradation, among the highest in the world (Oldeman, 1991). Agricultural mismanagement in turn contributes to the deterioration of water resources through reduced infiltration, increased runoff and flooding, desiccation of springs, creeks and wells, and destabilization of slopes leading to erosion and landslides. These consequences impact not only rural communities, but also semi-urban and urban populations downstream.

Over past decades, agricultural production in the region has not kept up with population growth. The minimal agricultural growth of the region was driven by unsustainable increases in total agricultural land area, through the conversion of forests to cropland and pastures on hillsides, and due to fragile tropical forest soils. From 1970 to 2005, there was a rapid expansion of agricultural land in Central America, increasing from 28 to 42% of total land area. Expansion did not slow until the late 1990s, as remaining land was increasingly unsuitable for agriculture, and environmental concerns inspired new policies and programs to address land degradation, the consequences of which were becoming increasingly apparent (Zurek, 2002; Bossio et al., 2008).

The persistence of slash and burn agricultural practices with shortened or eliminated fallow periods, tillage, and increasing agrochemical use on the region's erosion-prone hillsides has degraded soil and water resources and kept productivity very low. Average maize yields in Central America are about 2.3 t/ha, the lowest average yields in the world outside of sub-Saharan

Africa. Researchers suggest that while potential yield could be as high as 10 t/ha, a conservative yield target for Central America should be at least 4.5 t/ha (Hengsdijk and Langeveld, 2009; Eash et al., 2019). There is great potential to reduce this yield gap through increasing water productivity. Even in the driest areas of Central America the total amount of water is not the key limiting factor for improved yields. Rather, the restoration and sustainable management of agricultural soils is fundamental to resolving the multi-faceted economic and environmental problems associated with smallholder agriculture in the region (Zurek 2002; Schmidt et al. 2012). Furthermore, water harvesting for supplemental irrigation offers underexploited opportunities for reducing drought risk in smallholder hillside operations where surface and ground water irrigation systems are often economically and technically unfeasible (CRS, 2015).

Erosion and soil degradation have been long-term concerns in Central America. There have been many projects and programs promoting soil management, particularly in the 1990s. Overall adoption of recommended practices, however, has been low (Zurek, 2002; CRS, 2015; Speratti et al., 2015). The heterogeneity of local conditions has challenged scaling of soil management solutions as the success of a practice in one location does not guarantee its transferability to others. In addition, the gradual onset of soil degradation and a lack of location-specific soil information can make it difficult for farmers to recognize the problem. The slow return on investment in terms of tangible, on-farm benefits can discourage farmers from sustaining practices once project incentives are withdrawn, and some capital and effort-intensive practices such as terraces may never be profitable. Other recommended solutions such as agroforestry and silviculture can be very complex and knowledge-intensive, again with very slow

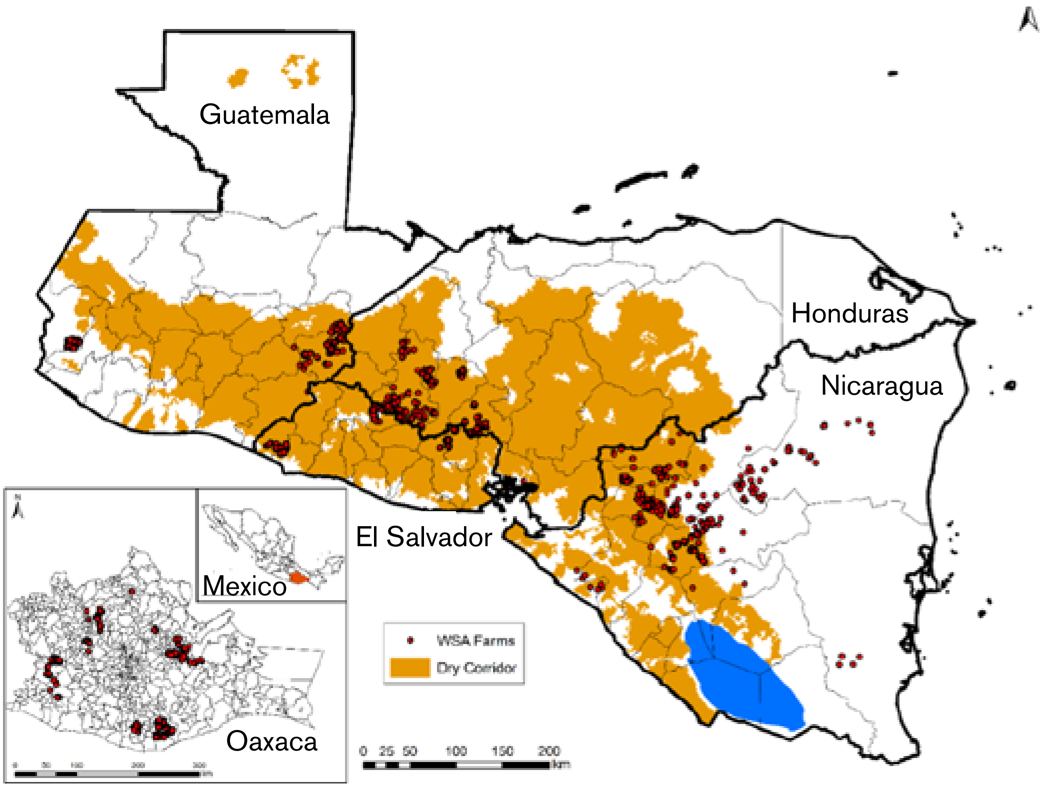

Figure 1: Distribution of WSA farms across the dry corridor of Central America and Oaxaca, Mexico

returns on investment. In fact, a failure to look at the cost-effectiveness and profitability of the practices has been a serious deterrent to adoption (Bravo-Ureta et al., 2003; Prins, 2004; Howley et al., 2012).

Nowhere is the nexus of social and environmental crisis more obvious, wide-spread, and urgent than in the smallholder rainfed agriculture sector. As climate variability intensifies the existing challenges that smallholders face in Central America and southern Mexico, the news is not all bad. The Water Smart Agriculture Program for Mesoamerica has over the last 5 years built solid evidence that the restoration of soil and water resources to increase water and agricultural productivity is a viable short and long-term solution to the economic and environmental problems associated with smallholder rainfed agriculture. Here we will present the evidence from farmer fields and describe how these positive findings are scalable with partnerships and policy support. A more food-secure and prosperous future for the most vulnerable rural populations in the region is not only possible but is already growing in the fields of an increasing number of water-smart farmers in Central America and southern Mexico (Figure 1).

2. Water smart agriculture

Water Smart Agriculture increases agricultural productivity, and thus food security, in the low yielding rainfed agriculture systems of Mesoamerica through soil restoration to improve rainwater productivity. The greatest gains, for overall water productivity, come from the ability to maximize rainwater harvesting through improved rainwater infiltration and subsequently improved soil moisture retention (Molden et al., 2009). WSA focuses primarily on "green water", which refers to infiltrated rainfall, stored as soil moisture and available for plant uptake (Falkenmark and Rockström, 2006). Green water is therefore often defined as the actual evapotranspiration from vegetation necessary to produce a given amount of biomass and crop yield. Soil and water management, combined with timely management of crops, offer potential for substantial yield gains and provide significant opportunities for producing more food with the same amount of water (Falkenmark et al., 2009; Rockström et al., 2009).

Advanced soil management is essential for increased water retention and plant water availability - "managing soil to manage water" as proposed by Barron (2012). WSA integrates soil management practices, such as plant residue retention on the soil surface (mulch management) and minimal to zero tillage, to keep soil permanently covered. Permanent soil cover protects soils from erosion, reduces unproductive evaporation, and moderates soil temperature. Cover crops (rotations/intercropping) build soil organic matter. Integrated soil fertility and plant nutrient management increase biomass production and yields, and work in synergy with the other practices to increase rainwater productivity. Plant 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. Hatfield et al. (2001) estimate that water use efficiency can be increased by 15-25% through adequate nutrient management and that soil management, as discussed above, can further increase water use efficiency by 25-40%. In general, WSA also applies location-specific agronomy best practices to adjust and manage adequate plant density, plant and row spacing, and crop canopies, which further boost yields and water productivity (Schmidt et al., 2012; Eash et al., 2019). Thus, there is significant potential to improve the productivity of smallholder rainfed agriculture through enhanced soil, nutrient, and agronomic management.

By enhancing rainwater productivity, WSA also mitigates the susceptibility of crops to the adverse effects of frequent dry spells (Rockström et al., 2002; Barron et al., 2003) and reduces inter-seasonal crop yield variability associated with increasingly erratic climatic patterns. Moreover, implementing water-smart practices increases soil water retention and nutrient conservation by reducing soil losses associated with water erosion, thus reducing overall crop production risks. Hence, increases in yields associated with water-smart practices go far beyond simply bridging the yield gap caused by water deficits (Lebel et al., 2015) in smallholder rainfed farming systems, in drought prone environments.

WSA is a location-specific and knowledge-intensive approach. Smallholder agricultural systems and production contexts vary greatly across Central America and southern Mexico. Soil conditions do as well. There is no one-size-fits-all recipe to the challenges faced by farmers in the region. For this reason, the WSA program places information and knowledge at the center of the program. The WSA program supports farmers to make critical farm management decisions with data provided by soil tests and analyses, observations of on-farm soil conditions, and maps of soil properties and functions. Assessments of soil conditions are facilitated through practical group learning events (Farmer Field Schools) where formal (science) and informal (local) information and knowledge are merged in a continuous participatory learning process. Farmer analysis and interpretation skills, and farmer-to-farmer knowledge sharing, are strengthened during the learning process. The resulting information and insights enable farmers not only to select and adapt improved soil management practices to their local conditions, but also to make informed management decisions about their entire farming system.

3. The potential of WSA in rainfed smallholder systems

The WSA program uses an evidence-based approach to participatory, on-farm research to validate and adapt water-smart practices to local conditions, on smallholder farms, in Central America and Oaxaca. Through a continuous and iterative learning process, the WSA program refines field recommendations for nutrient management, cover cropping, residue management, diversification and agroforestry options. These are tailored to available resources that improve system management and increase productivity, profitability, and resilience. Participatory research demonstrations provide proof of concept from the farmer perspective and serve as living classrooms for capacity building and outreach activities.

From 2016-2020, over 3,000 partner farmers have planted side-by-side demonstrations in the main Mesoamerican agricultural systems, including maize-bean based, basic grains systems, coffee agroforestry and pastures. Working with local WSA trained technicians, farmers established water-smart practices on an innovation plot side-by-side to a comparison plot with their current practices (Photo 3). Practices were established in a stepwise method to build up the system's productivity and ensure short- and long-term gains for farmers. For example, in the basic grains systems, the WSA program first addressed soil fertility limitations and improved nutrient management (further details described in the following paragraphs of this section), providing immediate yield benefits. Over the following two years, farmers then transitioned into conservation agriculture, cover cropping and agroforestry. Results were monitored through a common set of well-established, WSA soil health[2] and economic indicators collected by farmers and local extension organizations. Soil analyses (macro

Photo 3. WSA on-farm trial comparing the farmer practice where residues are grazed, and soil left bare during the dry season (right), and conservation agriculture with a jack bean (Canavalia ensiformis) cover crop (left) (M-S. Turmel, 2017).

Photo 4: Maize fields at Jujutla municipality, Ahuachapán, El Salvador (CRS, 2015).

and micronutrients, pH, Al, cation exchange capacity) were conducted in all farms to establish nutrient management guidelines. Soil moisture was monitored during the growing season at key moments in the crop cycle in a subset of 800 farms (gravimetrically or volumetrically using TDR (time-domain reflectometry)). Yield samples were measured in each WSA and comparison plot, and production costs were recorded by farmers and local technicians to calculate productivity and income.

Rainwater productivity improvements with WSA

Rainwater productivity (RWP) is the volume of crop produced per amount of rainfall and is an indicator of how efficiently an agricultural system uses rainwater. Improvements in soil health and fertility have led to consistently higher yields, soil water retention and RWP in WSA innovation plots over farmer standard practice comparisons. In basic grain systems, water productivity has been higher with WSA since the first harvest in 2016, and has steadily increased with each year of WSA practices (Figure 2). The maize growing seasons in 2016, 2018 and 2019 were all relatively dry, with average precipitation of 702mm during the rainy season from May to August, while 2017 was a relatively good year for rainfall quantity and distribution.

In the first year, WSA increased maize yields by an average of 497 kg ha^{-1}, and RWP increased from an average of 3.4 kg ha^{-1} mm^{-1} in the farmer comparison to 4.1 kg ha^{-1} mm^{-1} in the WSA plots. This initial increase in RWP can be mostly attributed to improved crop nutrition, the principal practice implemented in the first year. These immediate results highlight the opportunity to improve the productivity of rainfed systems with integrated nutrient management practices. In the following "good year", the majority of WSA farms entered into conservation agriculture and further surpassed the comparison by 809 kg ha^{-1}. RWP rose to 4.4 kg ha^{-1} mm^{-1}, 0.9 kg ha^{-1} mm^{-1} more than the comparison. Even though seasonal rainfall was low in 2018 and 2019, both yield and RWP continued to increase in the following years. This was because farmers began to realize medium-term positive feedback from WSA practices, such as conservation agriculture and cover crops that require more time to improve soil health and soil moisture retention. By 2019 WSA maize RWP reached 5.2 kg ha^{-1} mm^{-1}, 1.5 kg ha^{-1} mm^{-1} more than the comparison. These RWP values are comparable to other tropical smallholder conservation agriculture maize systems around the world (Rockström et al. 2009), however yield potential estimates for the Dry Corridor region are upward of 4.5 kg ha^{-1}, indicating potential to further improve RWP (Eash et al., 2019).

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[2]*Established indicators of soil health used in WSA include: soil macronutrient availability, pH, soil organic matter, infiltration, bulk density, earthworms and soil cover (Karlen et al., 1997).*

The WSA program collected production costs[3] and income data during the four cycles in a subset of 253 on-farm basic grains experimental plots (paired WSA innovation plot vs. comparison plot with farmer current practice). Though not as severe as 2018, the 2019 agricultural cycle was affected by drought conditions, and yields were reduced by up to 50% in some regions. Even though seasonal weather conditions were not ideal, most WSA farmers obtained acceptable harvests and net income due to the improved practices that conserved soil moisture. Average maize yield with WSA was 3474 kg/ha (considered a good yield for smallholders in the region because of climatic conditions), nearly one ton higher (986 kg/ha) than the comparison. WSA bean yields were 1604 kg/ha (considered an excellent yield for smallholders in the region), over half a ton (547 kg/ha) higher than the comparison. This represented a 40% increase in maize and a 52% increase in beans over the comparison. WSA also significantly improved maize and bean net income. Average maize net income with WSA was US$513/ha, over double the comparison net income (US$242/ha) (Figure 5). WSA bean net income was US$916/ha, more than twice that of the comparison (US$431/ha). Farmers generally grow both crops in one year (maize in *primera* and beans in *postrera*) thus the average total income from the WSA maize-bean system is US$1429/ha compared to only US$673/ha in the comparison. To put this in the local context, the additional income of US$755/ha is equivalent to 7.5 months wages from farm labor (based on a US$5/day and 20 day/month). These results demonstrate the potential of water-smart practices to improve the productivity and economic viability of smallholder rainfed systems in Central America.

The role of soil fertility management in improving the productivity of rainfed systems

In addition to rainfall variability, soil fertility is one of the main factors limiting crop production in Central America. According to the baseline soil analysis of our WSA plots, 66% of farmers had at least one severely limiting soil fertility problem:

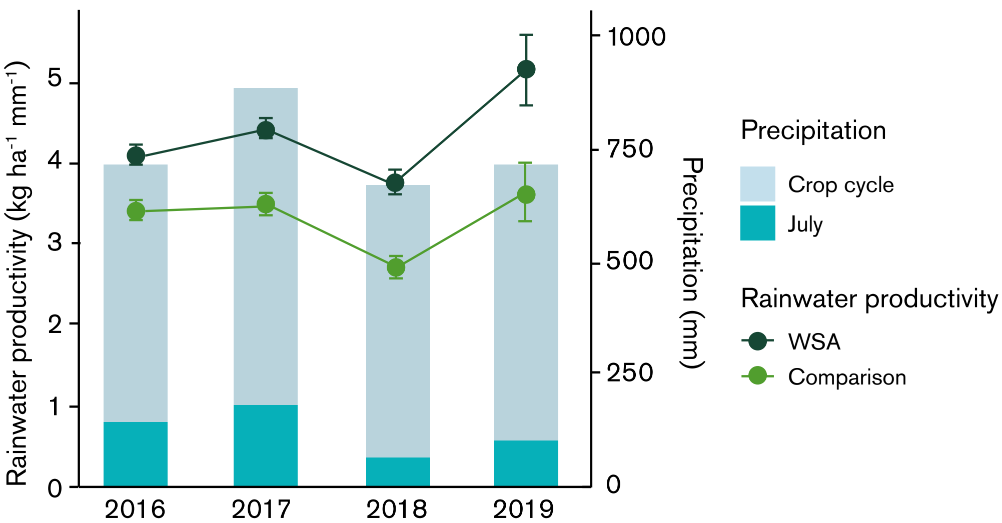

Figure 2: Rainwater productivity of maize in WSA and comparison plots in the Dry Corridor over the past four years: 2016-2019 (N=1291 farmers). Precipitation during the maize season (May-August) and July (when the canicula dry spell typically occurs) is shown.

[3] *Production costs included inputs, family and hired labor, and other services.*

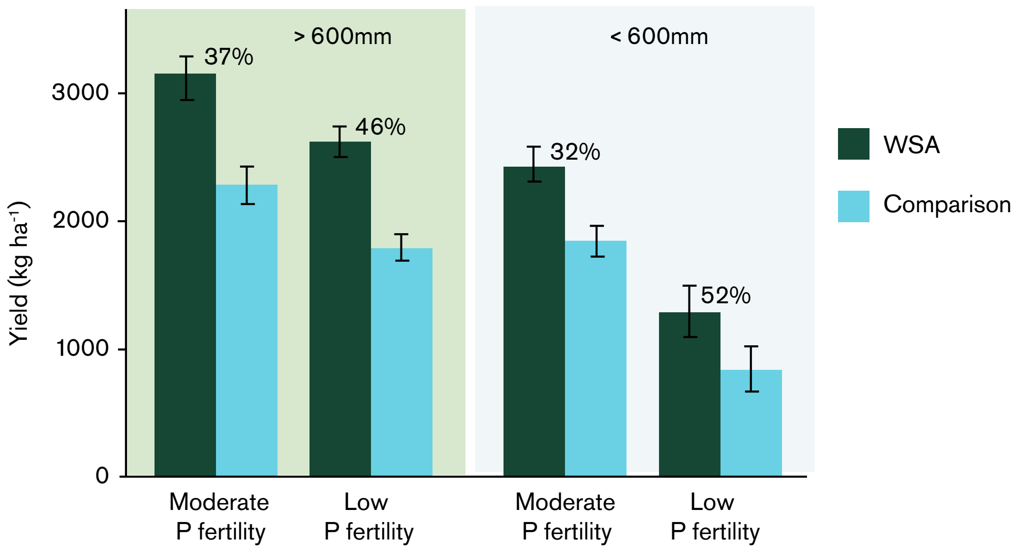

Figure 3: Maize yield in soil fertility (phosphorus) limiting, and water limiting, sites in 2018 (N=973 farms. The percent increase with WSA above the comparison is show above each pair of bars.

soil acidity, low soil organic matter, low cation exchange capacity or low nutrient concentration. 37% of farms had very low phosphorus (P) levels of less than 5 ppm; (Olsen P) (Havlin et al. 2005; SEMARNAT, 2002), one of the main nutrients that can limit crop production in tropical soils. Improved plant nutrition not only increases root growth and the drought tolerance of the crop but also contributes to the production of more plant biomass, that when left as residue protects the soil and conserves moisture for the next cropping cycle. An integrated approach to soil management that involves soil fertility management, and practices to improve water capture and retention, is essential to improve productivity and drought resilience.

Water-smart practices provided the greatest relative yield improvements (over 50% increase) on farms where both soil fertility and water were limiting (Figure 3). In water-limited conditions but without soil P limitation, WSA improved yields by 32%. Without severe water limitation, farmers still benefit from improvement soil fertility and conservation practices, improving yields by 46% in P limited soils and 37% is soils with moderate P fertility. The average family in Central America needs 1000kg of maize per year to meet their food requirements. The average farm area for basic grains is one hectare (based on CRS Country Programs 2019, unpublished data), thus a yield of 1000kg ha^{-1} is approximately the minimum production required to be maize secure. Results from 2018 showed that farmers limited by both water (<600mm) and soil fertility conditions (low phosphorus) could not meet this minimum production level with their current production practices. For farmers with less than one hectare to farm, the challenge is even greater. When WSA practices were used, on average yields were above this critical threshold in a drought year.

Water smart agriculture during the 2018 drought

In 2018 the Central American Dry Corridor suffered a severe drought in the main, *primera*, maize growing season. The drought was the result of a prolonged *canícula* that started early in July and continued into August. It caused yield reductions and crop loss on over 300,000 ha of maize and bean production in the region (FAO, 2018). July rainfall was only 80mm, less than half the average July rainfall of 222mm (Figure 4) (Funk et al. 2014), and some areas where WSA demonstration plots were located suffered from 20 to 45 days without rain. The 2018 rainy season was characterized by abundant rainfall during maize planting, in the last week of May, followed by a significant drop in precipitation in July and early August. This created drought conditions during important stages of maize crop growth, when rainfall was much less than maize physiological requirements. The *canícula* usually occurs during the beginning of the reproductive stage of the maize plant cycle, known as silking. Maintaining sufficient soil moisture during that period is crucial for good maize yields.

With at least two full years of WSA practices on demonstration plots in all five countries, the 2018 drought was the first test of WSA performance under extreme weather. Overall, approximately 10% of the WSA plots located in the most severely affected areas (>30 days drought) had complete crop failure. Under these extreme drought conditions, maize cannot survive despite the best WSA management practices implemented. In regions where the drought was less than 30 days and farmers were able to obtain a harvest, results from the WSA plots in all five countries show that maize under WSA management was more tolerant to drought and produced significantly greater yields (P<0.0001, t-test; Figure 5). WSA maize yields were on average 41% higher, and 80% of all demonstration farmers produced at least 15% more, on WSA plots compared to conventional practice. The World Food Program estimated that as a result of the 2018 drought, 2.2 million people were affected by yield loss and 1.4 million were left food insecure (WFP, 2019). Based on 2018 data, at least 33% more farmers in the Dry Corridor would meet their basic maize production needs in a severe drought year if they implement WSA management practices.

It takes several years of intensive restoration efforts, that include nutrient management, increasing biomass inputs, minimizing soil disturbance and maintaining continuous soil

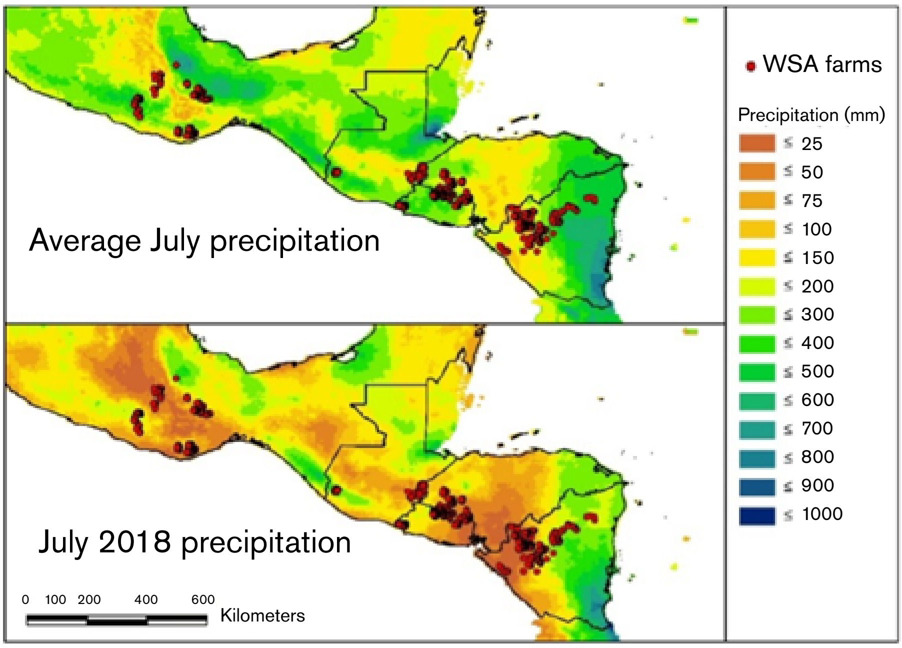

Figure 4: July average precipitation vs. July 2018 precipitation (mm), location of the WSA plots identified by red circles (based on CHIRPS precipitation data; Funk et al., 2014).

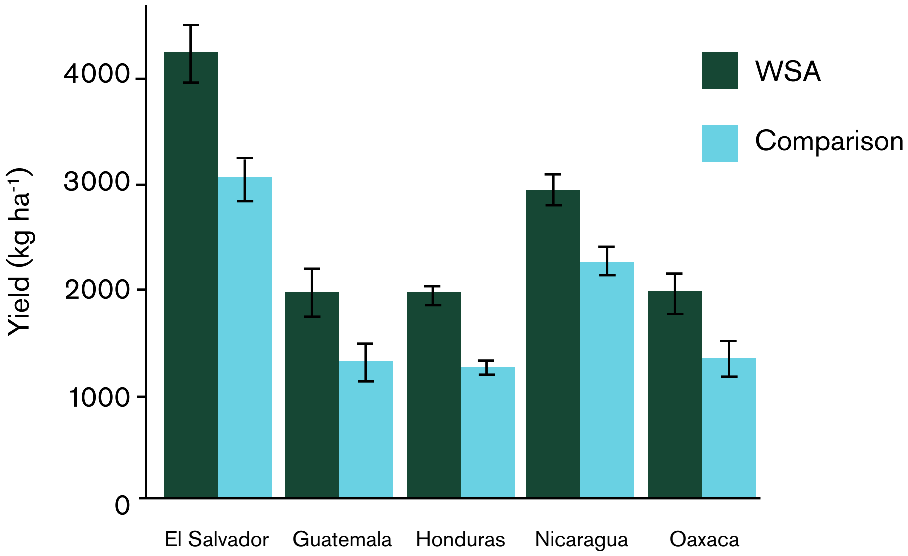

Figure 5: Average maize yield with 95% confidence intervals of the mean in 2018 WSA plots vs. comparison plots (n=1065).

cover with residue or cover crops, to achieve improvements in the ability of soil to capture and store more water. Crop residue retention is a key WSA practice to increase soil health and soil moisture retention (Turmel et al., 2015). During the 2018 drought, WSA farmers in Nicaragua had been implementing conservation agriculture, with permanent vegetative cover on the soil (cover crop or crop residue retention), for at least 3 years. This is in contrast to the conventional practice that can include tillage and does not maintain permanent soil cover with residue or cover crops (Photo 3). Soil moisture results from these farms demonstrated the associated benefits of increased soil moisture vis a vis their comparison plots during the *canícula* period of the *primera* season (Figure 6). Under the drought conditions of the extended *canícula* period of 2018, WSA plots had on average 7.6% more volumetric soil water. With each additional year of WSA practices, as WSA farmers increased soil cover with maize and bean crop residues and cover crops, further improvements in soil health optimize the capacity of the soil to infiltrate and retain moisture.

Farmer perceptions of WSA and adoption potential

Overwhelmingly positive farmer perceptions of WSA impacts, and the expansion of WSA practices on their farms, predict the high likelihood of long-term adoption of WSA practices by Dry Corridor farm communities. At the end of the 2019 basic grains cycle, farmers

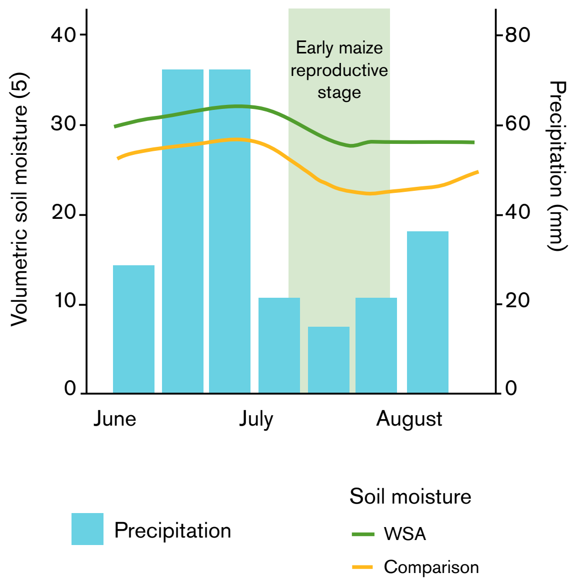

Figure 6: Average increase in volumetric soil moisture (%) in WSA plots vs. comparison plots, during the 2018 primera season in Nicaragua (N=44 farms). Average 2018 precipitation in the plots is show by the blue bars, and the early reproductive stage is indicated.

were surveyed on their perceptions of the impacts of WSA practices and the adoption of the practices on their farms. Over 80% of the 1454 WSA farmers surveyed reported improvements in production, livelihoods, food security, soil quality and drought resilience (Figure 7). The small percentage that reported no change or worse for yields, food security or income cited the main reasons as: higher levels of soil degradation, overall yields are low, small production area, and poor access to inputs. Although WSA has begun to improve soil, water and productivity on these farms, many farmers continue to struggle to produce and earn enough from basic grains. Continued support for soil restoration should form part of an integrated approach to improve the long-term viability of these systems.

WSA farmers have expanded the area under water-smart practices beyond their original WSA demonstration plots to the rest of their farm, a strong indication that farmers are adopting the practices. To date, 75% of the WSA basic grains farmers have converted 100% of their basic grain production land to WSA practices. Conservation agriculture has been widely expanded, with 73% of farmers now applying all three principles (permanent cover, minimal or no-till, diversification/rotation) on 100% of their basic grains land. The expansion of integrated soil fertility management based on 4R has been more limited, with only 60% of farmers applying the 4R on 100% of their basic grains land. Although farmers are pleased with the results based on the perceptions survey, limited access to inputs does not permit expansion to a greater area. The WSA program is piloting several methods to improve farmer access to inputs including local private service providers linked to savings and loans groups, group purchase in bulk, and local production of fertilizers to reduce costs. Approximately 50% of farmers are using cover crops on their WSA plots, and 57% of them have doubled the area of cover cropping from the original WSA plot area. Challenges with cover crop selection and seed supply have slowed expansion, however, farmers that introduce cover crops to their systems have been enthusiastic about the benefits. These results indicate an overall acceptance of WSA practices, especially residue retention in conservation agriculture that is strongly viewed as beneficial for drought resilience. Overall, these on-farm results indicate

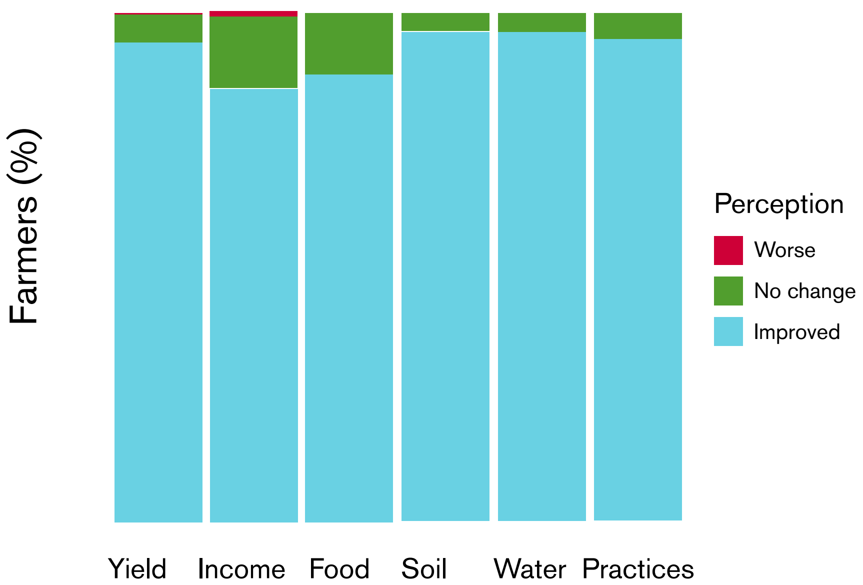

Figure 7: Basic grains farmer reported perceptions of the WSA practices and their impact on yield, income, food, drought resilience (water) and overall satisfaction with practices (n=1454).

Photo 5: Farmers in Guatemala learning the Visual Soil Field Assessment Methodology (CRS, 2018).

that WSA is an important part of the solution and that there is great potential for continued scaling of WSA in the region.

Closing the information gap on soils

Effective soil management requires appropriate and detailed soil information to take cost-effective management and investment decisions not only on-farm, but also at national or regional administrative and political levels. Central America is generally a "data-poor environment", particularly in terms of soil information. To address this need for improved soil information, the WSA program worked with local, national and regional partners to compile a practical, effective, and cost-efficient standardized suite of tools and methodologies. These include respective detailed documentation for farmers, promotors, and field technicians to facilitate a more precise assessment of the status of the soils in Central America. Standard soil sampling and laboratory analyses were combined with field-based tools for soil moisture[4] , infiltration measurement (Bouwer, 1986) and soil acidity assessments[5]. Visual methodologies were also applied, e.g. the Visual Soil Testing tool (McGarry, 2006), to facilitate fast and easy on-farm access to soil information.

Improved soil information is essential for the application of the overall soil management approaches of WSA, e.g. 4R Soil Stewardship (IPNI, 2012), in combination with the integrated soil fertility management (ISFM) approach (Sanginga and Woomer, 2009), and the principles of conservation agriculture (FAO, 2001).

Soil maps are also an important tool for soil information. Existing Central American soil maps are often small-scale, covering only parts of the region. Traditional soil surveys are prohibitively expensive in terms of budget, human resources, time, and available funds. In order to overcome this regional soil information gap, and to facilitate improved evidence-based decision-making from farm to national levels, the WSA program established a digital soil mapping (DSM) platform. The aim was to build the capacity of national institutions to produce detailed maps of soil types, soil properties and soil functions[6]. Capitalizing on existing legacy soil data of any kind, scale, and date, and the still available non-documented expert knowledge in the target countries, WSA applied a DSM knowledge-based inference approach based on soil formation processes and soil-landscape relationships. A versioning approach was also developed similar to the Tier concept of the GlobalSoilMap (2015) allowing for the creation of new and improved versions as more data is made available (Owens et al.,

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[4]*https://www.specmeters.com/soil-and-water/soil-moisture/fieldscout-tdr-meters/tdr-150-soil-moisture-meter-with-case/*
[5]*https://www.hannainstruments.co.uk/hi-981030-soil-ph-tester.html*

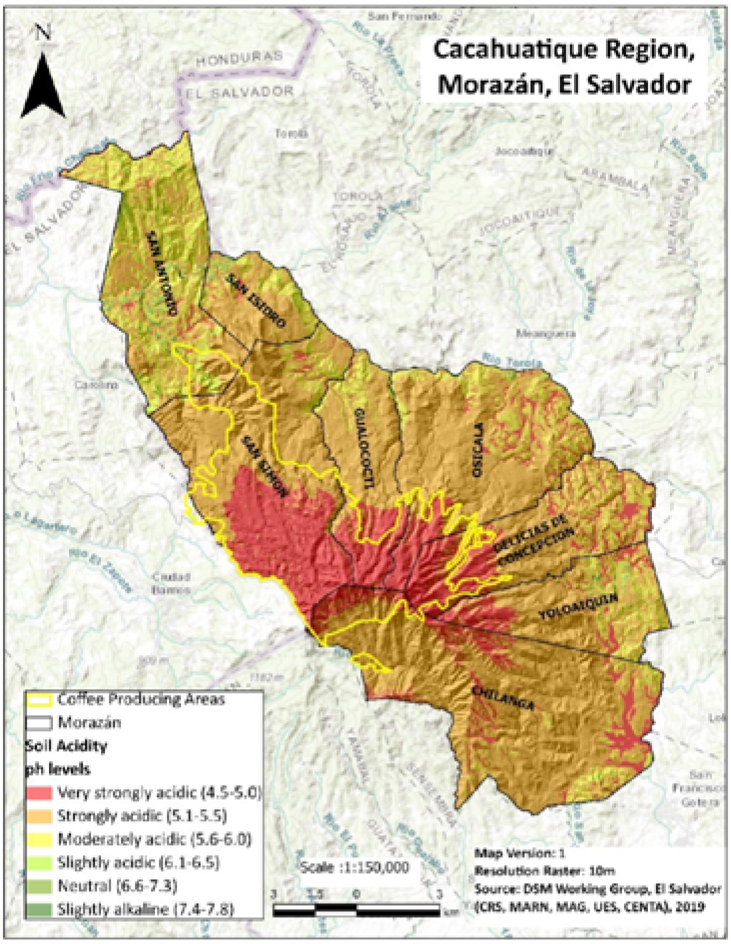

Figure 8: Soil acidity map (pH levels) for the Cacahuatique region, Morazán, El Salvador, showing impacts of long-term application of acidifying fertilizer types (e.g. ammonium sulphate).

2020). In addition, the WSA program has helped build the DSM technical capacity of a group of institutions in each country. These groups have used DSM to produce first versions of over 140 soil property and function maps for the Dry Corridor of Central America, providing important information for decisions on the application and targeting of soil management recommendations throughout the region (see Figure 8 for an example of a soil property map informing soil and soil fertility management of coffee in El Salvador). Thus, DSM of soil functions is a vehicle for scaling.

After presenting the map, local authorities (local farm input subsidies) and farmers changed not only their investment in fertilizer type but also based their soil fertility management on the 4R approach. Results show significant increases of coffee yields (green coffee) from 263 kg/ha (control plot) to 720 kg/ha (WSA plot) exceeding the national yield average of 302 kg/ha. Decisions made on informed bases (e.g. simple soil property maps) pay off.

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[6] Soil functions are defined as a set of soil properties that characterize a soil population and that are linked to multiple use purposes for a defined landscape (Owens et al., 2020)

4.Taking WSA to scale

Designed to reach scale

The WSA program's ambitious goal of revitalizing smallholder rainfed agriculture in El Salvador, Honduras, Guatemala, Nicaragua and southern Mexico envisioned large-scale transformation and deep impacts that require the commitment and collaboration of key public, private and civil society agricultural institutions in each country (Figure 9). It is these organizations that make up the underlying structures, and supporting mechanisms, of the smallholder agricultural sector whose collective action is essential for sustainable scaling of WSA (Wild et al., 2017; Woltering et al., 2019). The complexities of this social structure could not be solely addressed by common approaches to scaling, using concepts such as dissemination, diffusion, adoption and transfer of technologies and practices. To date these methods have failed to achieve large-scale adoption and transformation (CRS, 2015; Wigboldus et al., 2016; Wild et al., 2017). For the WSA program, scaling is a development process for expanding, learning, adapting and enhancing the organizational capacities of key institutions to serve a large number of farmers. Supporting them to successfully apply water-smart practices to increase their productivity through the restoration of soil and water resources (Millar and Connell, 2010). Moving beyond the project logic, the WSA program employed a collaborative approach to work with key, permanent agricultural institutions. The aim was to understand the underlying social, political, and economic systems, the incentives, and respective behaviors of all actors involved (Westley et al., 2014) and to catalyze their appropriation of, and investment, in water-smart approaches, methodologies and services for smallholders. In this way, the WSA program is building capacity at multiple levels to take WSA to scale.

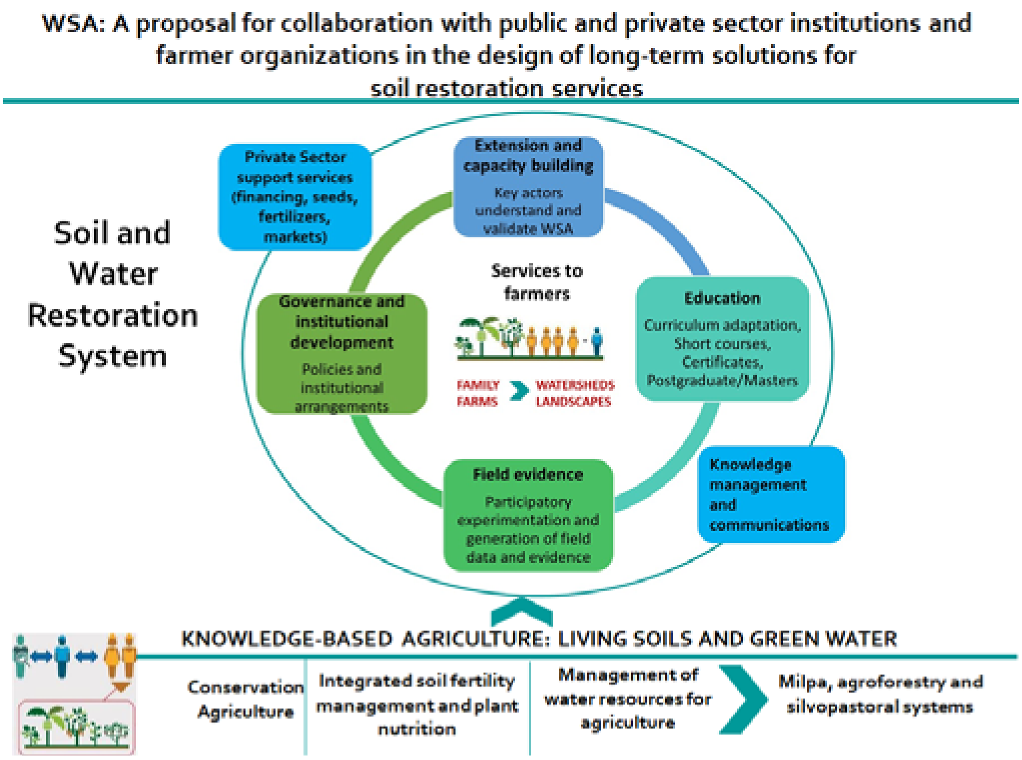

Figure 9: WSA collaborative model to build sustainable soil and water restoration systems.

Photo 6: WSA in Nicaragua, interagency (FAO-IICA-CRS) field trip (CRS Nicaragua, 2019).

Institutionalization and creating an enabling policy environment

The theory of change for scaling WSA is guided by three major understandings:

1. Creating conditions for scaling is as important as actively trying to scale. In the case of WSA, scaling cannot happen without creating a level of institutional development that allows key agricultural institutions to undertake and maintain a sustainable scaling process (WHO, 2010; Woltering et al., 2019).

2. Scaling is a nonlinear complex process that involves a range of potential leverage points (Wigboldus et al., 2016). Tailored strategies by country, territory, and partner were designed to seize opportunities and tackle challenges at different scales and levels.

3. Impact at scale is a joint social construction with the permanent actors who will sustain change over time (Faustino and Booth, 2014). Multi-stakeholder partnerships and platforms have been instrumental to achieving the institutional capacity to effectively accompany farm families and communities in restoring soils at scale (Brouwer and Woodhill, 2015).

The WSA program's collaborative approach has followed an impact pathway of four interlinked stages of working toward scale. This is an adaptation of several methods (Cooley, 2016) that is founded on the principles of co-creation, co-management and co-investments, with and between stakeholders, to gain appropriation and ensure political viability:

1. Raising awareness, building support, and engaging institutional partners and allies.

2. Learning and validation of the WSA approach, methodologies, and tools.

3. Institutionalization through appropriation and use of the WSA approach, methodologies and tools in their programming, budgets, and decision-making.

4. Scaling, transformative processes where institutions and systems in agriculture change rules, norms, and culture based on the WSA approach.

After more than four years of embracing complexity and learning by doing (Faustino and Booth, 2014), the WSA program has built a strong foundation for sustainable scaling in Central America and southern Mexico. The building blocks include; a critical mass of trainers, facilitators and leaders for scaling WSA through capacity building; the institutionalization of approaches, methodologies, and tools; networks and platforms coordinating action to improve services to farmers; incorporation of WSA in policies, programs, and projects; and leadership teams of key agricultural institutions actively working to do agricultural development differently. To date, more than 60 key organizations and 20 multi-actor platforms have institutionalized and invested in WSA and are now immersed in stage 4 scaling processes (Figures 10 and 11). Among WSA program partner organizations, 39% have strengthened extension capacities, 38% have developed governance and institutional capacities, 10% have improved curricula (academic), 9% have participated in field data generation and 4% are private sector companies providing services. Context-tailored operative models to catalyze collaboration include territorial-led networks in Honduras, Guatemala and Mexico (bottom-up model), and national public sector-led policies and programs in Nicaragua and El Salvador (top-down), although there are elements of both in all five countries. Scaling progress is ongoing, with major adjustments to extension systems in Guatemala (ANACAFE)[7] and El Salvador (CENTA), and grassroots farmers organizations in Nicaragua (MAONIC) and Mexico (CEPCO, CEDICAM).

Building capacity to implement and sustain WSA

The WSA program scaling strategy relies on permanent local, national and regional agricultural institutions to appropriate, advance, and ultimately scale WSA. The success of this strategy requires that targeted institutions have knowledgeable experts, committed leaders, and a critical mass of agricultural professionals and farmers who have the skills and drive to lead, adapt and evolve WSA in response to the constantly changing context. Divestment out of agricultural research, extension services and education over the last decades has created major capacity gaps, and weakened public agricultural research institutions, reducing their effectiveness and efficiency (CEPAL et al., 2009; IICA, 2012). In response, the WSA program has focused on building adaptive leadership and technical capacity at multiple levels from the farm field to university laboratories and ministries of agriculture.

The WSA program strategy seeks to prepare institutions, technical staff, and farmers to implement and scale WSA through a competency-based capacity building approach. The WSA program developed a competency model that consolidates WSA training approaches, and curricula from across the region, into a single framework that clearly defines the skill, knowledge, attitudes, and behavior requirements for successful implementation of WSA. The framework is a practical tool that supports WSA program capacity building, and influences objectives through:

- guiding training content and establishing minimum standards for WSA implementation;
- ensuring that training content addresses the concrete behavior change that will lead to successful implementation of WSA in farmer fields;

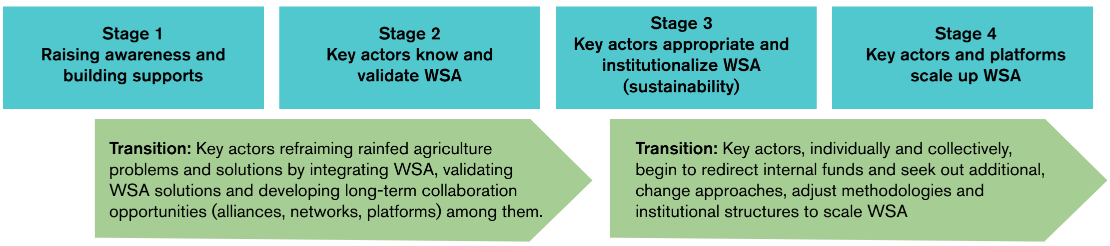

Figure 10: WSA impact pathway by stages, for advancing institutionalization of WSA to transform rainfed agriculture in Mesoamerica.

[7] *For full names refer to Figure 11*

Photo 7: Collaborative planning work with CRS, ANACAFÉ, COUNTERPART and IICA, in Guatemala (CRS Guatemala, 2019).

- providing a highly practical tool to evaluate training impacts on behavior change and to identify gaps that inhibit adoption of WSA practices;
- guiding the insertion of WSA content into university and professional training curriculums; and
- supporting clear communication of what WSA is and how it is practiced.

Integral to WSA program capacity building approaches is that how training is delivered is just as important as the content. WSA is knowledge-based agriculture that transcends the input-intensive, technology transfer models of the past. The knowledge-intensive model emphasizes that data, evidence and innovation processes are critical to adapting WSA practices to the highly variable local conditions across the region. The knowledge-based, adaptive practice of WSA requires skill development which is best acquired through participatory, hands-on methodologies, that leverage existing expertise and direct it toward development of the required competency and behavior change. The WSA program recognized early on that the traditional methods of extension and soils education, coupled with the weaknesses of the regional educational systems, presented a major challenge to widespread adoption of WSA. Transitioning from an extension system, that uses educational methods based on rote memorization and one-size-fits-all technical packages of practices and inputs, to a system that emphasizes data collection and analysis to calibrate site-specific farm management recommendations is a massive leap, requiring behavioral change in all actors involved.

The WSA program has applied the competency development strategy with multiple methodologies at different levels including: a) on-farm experimentation and evidence building through Farm Field Schools (FFS); b) training of trainers (ToT) for extensionists and promoters (lead farmer that carries out extension activities), c) curricula modernization and expansion for agriculture vocational schools, undergraduate degree programs, and training courses, and d) development of a postgraduate Masters' degree program for the next generation of WSA leaders.

Farm Field Schools (FFS) for WSA demonstration and evidence

The WSA program field teams have made effective use of the FFS methodology to train farmers and develop the experimentation and innovation skills required for adoption and continual adaptation of WSA practices. WSA FFS demonstrations are designed to build evidence. Experimentation with an innovation, in direct comparison to traditional practices, is fundamental to the program's strategy. The FFS structure aims to create a culture of experimentation and analysis of data among producers, with a lead farmer or promoter hosting a demonstration plot and neighboring farmers replicating those innovations that are suitable for their own farms. Such on-farm experimentation is a vital skill that will be increasingly important as producers seek ways to respond to changing weather conditions and more volatile markets. This experimental approach has been extremely successful in helping WSA farmers understand why certain practices fail and others succeed. This understanding, in turn, has helped foment adoption of the practices by neighbors, growing well-beyond the immediate FFS participants. For example, in the northern Nicaragua municipality of Yalaguina, an FFS network has developed into a watershed-wide scaling of WSA practices. The WSA program started the first FFS in that area in 2015 with 12 farmers. By the end of the year, there were 33 participating farmers, and an equal number of innovation plots where the farmers were implementing WSA practices on a portion of their land. By the end of 2017, 90 families were participating and over 160 hectares were under WSA soil restoration practices. By 2019, residue soil cover was the norm rather than the exception and the area had recovered water resources that had been dry for years.

In addition, WSA demonstration farms and complementary investigations, implemented in coordination with FFS and university partners, are used to host training classes, field days, informational tours and press conferences. A variety of actors, ranging from other NGOs, the private sector and government agencies, have used the visible evidence in farmers' fields, and farmer testimonies, to learn, showcase and convince. At the same time, the data generated is informing scientific and popular publications, conference presentations, and news articles that take WSA messages to a much wider audience. This includes farmers, the general public, and funding and program decision-makers, supporting WSA scaling.

WSA training of trainers (ToT) – towards a new extension paradigm

While the FFS and demonstration plot approach can drive farmer-to-farmer scaling and generate wide interest in WSA, the program was challenged to develop approaches that would allow the WSA program team to work collaboratively with several institutions simultaneously, and sum their collective reach toward scaling WSA with a large number of farmers. The WSA ToT in soil and water management methodology was designed to answer this challenge by strengthening extension services so that they can scale WSA, emphasizing the pedagogic skills conducive to interactive communication and facilitation of knowledge dialogue between technicians and farmers (McIntyre et al., 2009; WSA-CRS, 2020). The WSA program, and partners, worked together to design and adapt a training curriculum with five core modules: soil sampling and analysis; integrated soil fertility management; dynamics of soil acidity; permanent cover and biomass; and soil and water conservation practices. The WSA ToT methodology provides effective content and methods, based on the "Farmer First" approach, which focuses curriculum on what is essential for farmers to know, and delivering it in ways that are easily understood and can be replicated by farmers. Sixty organizations (public, private and social) are participating in ToT processes in Mesoamerica, generating a critical mass of 9,000 trainers, among facilitators, technicians, and promoters with the institutional support to deploy training throughout their extension networks to

Photo 8: Farmer First training of facilitators, technicians, promoters and farmers is implemented on-farm (CRS, 2019).

reach many more farmers and communities. For several of the large public institutional partners, the collaborative ToT process has inspired revision of their technical assistance systems that were not structured to achieve scale. Innovations include WSA competency-based training, and certification programs for extensionists, as well as the development of promoter networks to extend their extension reach.

Education to cultivate WSA's future leaders

The next generation of "WSA-savvy" agricultural professionals is now receiving training, or will soon enter training, in agricultural universities, technical schools and professional programs with curriculums that have been adapted to include WSA approaches. These future professionals will provide the foundation for continued mainstreaming, and scaling, of WSA in agricultural development in their countries over time. The WSA program worked collaboratively with the National Agrarian University of Nicaragua (UNA), the University of San Carlos in Guatemala, the University of El Salvador (UES), and the National Autonomous University of Honduras (UNAH), to develop the Regional Master of Science for Integrated Soil Management in Tropical Environments (MISAT). The MISAT curriculum stresses sustainable soil management with conservation agriculture and integrated soil fertility management. The number of MISAT graduates is expected to surpass 100 within 10 years, and will form a solid foundation for agricultural research and leadership to take WSA into the future in Central America.

The WSA program has also successfully collaborated with several universities to insert WSA concepts and training into national masters and bachelor curriculums. In El Salvador, UES revised three Master of Science programs (Natural Risk Management, Sustainable Agriculture, Watershed Management) to include up-to-date and relevant soil and water management science and practice. In Nicaragua, the Catholic University for Dryland Tropical Agriculture (UCATSE) and the Nicaragua National Autonomous University (UNAN) in Leon and Estelí incorporated WSA into their agricultural degree curriculum and continuing education programs. In Honduras, the UNAH officially inserted soil and water management competencies into their curriculum for undergraduate

PUBLIC SECTOR ALLIES

Centro Nacional de Tecnología Agropecuaria y Forestal de El Salvador (CENTA), Instituo Nicaraguense de Tecnologia Agricola (INTA), Ministerio de Agricultura, Ganadería y Alimentación (MAGA) Zacapa and Chiquimula in Guatemala, Dirección de Ciencia y Tecnología de Honduras (DICTA), Network of Professional Technical Institutes (IFP regional Network), Comisión Nacional para el Conocimiento y Uso de la Biodiversidad de Mexico (CONABIO), Instituto Nicaragüense de Estudios Territoriales (INETER)

PUBLIC-PRIVATE

Instituto Hondureño Del Café (IHCAFE), Asociación Nacional del Café de Guatemala (ANACAFE), National Soil Alliances in Nicaragua and El Salvador, Multiactor group for Digital Soil Mapping in the five countries, National System of Agricultural and Forestry Extension of Honduras, Extension Commites in Guatemala, Local Coffee committes in Honduras, Landscape restoration platforms in El Salvador

ACADEMIA

Universidad Nacional Agraria de Nicaragua (UNA), Universidad Católica del Trópico Seco de Nicaragua (UCATSE); Universidad Nacional Autónoma de Honduras (UNAH), Escuela Superior del Café de Honduras (ESCAFÉ-IHCAFE) and Technical Community Institutes Network in Honduras; Centro Universitario de Oriente de Guatemala (CUNORI), Colegio EFA in Guatemala; Universidad de El Salvador. Escuela Nacional De Agricultura de El Salvador; The education platform in South of Mexico (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), Benemérita Universidad Autónoma de Puebla (BUAP), Instituto Tecnológico del Valle de Oaxaca (ITVO), Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional Unidad Oaxaca (CIIDIR-IPN), Universidad Autónoma Benito Juárez de Oaxaca (UABJO), Chapingo, CERTIMEX). Universidad de San Carlos de Guatemala (USAC), Digital Soil Mapping team from University of Arkansas & USDA, Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), Centro Internacional de Agricultura Tropical (CIAT), Facultad Regional Multidisciplinaria, Estelí (FAREM), Universidad Nacional Autonóma de Nicaragua (UNAN-Leon)

TERRITORIAL/LOCAL ACTORS

Asociación para el Manejo Integrado de Cuencas de la Paz y Comayagua (ASOMAINCUPACO), Comité Central Pro Agua y Desarrollo Integral de Lempira (COCEPRADIL), Comité Central Pro-Agua y Desarrollo Integral de Intibucá (COCEPRADII), EUROSAN OCCIDENTE in Honduras; Raices Projects-Landscape Restoration platforms in El Salvador; San Jose La Arada Municipality; Grupo Autónomo para la Investigación Ambiental (GAIA), Sistema Comunitario para el Resguardo y Manejo de la Biodiversidad (SICOBI), Kukoj, Centro de Desarrollo Integral Campesino de la Mixteca (CEDICAM), Coordinadora Estatal de Productores de Café de Oaxaca (CEPCO), Mancomunidad La Montañona, Asociacion de Cuencas del Golfo de Fonseca (ACUGOLFO), Asociación para la Diversificación y el Desarrollo Agrícola Comunal de Nicaragua (ADDAC), Fundación de Investigación y Desarrollo Rural (FIDER). Unión de Cooperativas Agropecuarias (UCA-San Ramon), Movimiento de Productoras y Productores Agroecológico y Orgánicos de Nicaragua (MAONIC), Promotora de Desarrollo Cooperativo de Las Segovias (PRODECOOP)

PRIVATE SECTOR AND NGOS

Caritas, Adego, Fondo de Inversión Ambiental de El Salvador (FIAES); Nitlapan, R-UTZ, CCM, ANF, FABRETTO Foundation and Soil Lab Network in Nicaragua; Inter-American Institute for Cooperation on Agriculture (IICA) -Procagica in Honduras, Guatemala, El Salvador and Nicaragua; Cooperativa Mixta Cosecha Verde Limitada (Comicovel) in Honduras, Counterpart

Figure 11: Key actors of the Mesoamerica region engaged with the WSA program, toward a regional soil restoration movement.

agronomy degrees. The WSA program has also contributed to diploma programs for practicing professionals to ensure a focus on soil and water management in Honduras, El Salvador and Nicaragua.

A region-wide WSA movement for rural prosperity

The WSA program scaling strategy has sought to catalyze the necessary institutional changes and enable key agricultural stakeholders to collaborate and provide the necessary tools and services to farmers to inspire a Mesoamerican movement for resilient rural prosperity, through the restoration of soil and water resources. The WSA program engages partner institutions in the co-creation and adaptation of methodologies and tools, working together toward a shared vision of supporting farmers in their constituencies to successfully adopt WSA practices. With success, the program will create a lasting and positive impact on farmers and institutions leading to restoration of the soils and water that sustain rainfed agriculture, families, and territories in rural Mesoamerica.

A landscape approach to scaling WSA

Agricultural landscape restoration programs are incorporating WSA practices in their natural resource management plans to scale the practices across entire landscapes. The Agriculture Landscape Restauration Initiative (ALRI-Raíces), known as *Raíces*, in El Salvador is delivering impact at scale in terms of agricultural livelihoods, resilient rural economy and environmental restoration based on water-smart practices. The program focuses on investment for smallholders, while also working with large scale producers to influence practices on their land. A key part of the program stimulates economic opportunities for farmers and

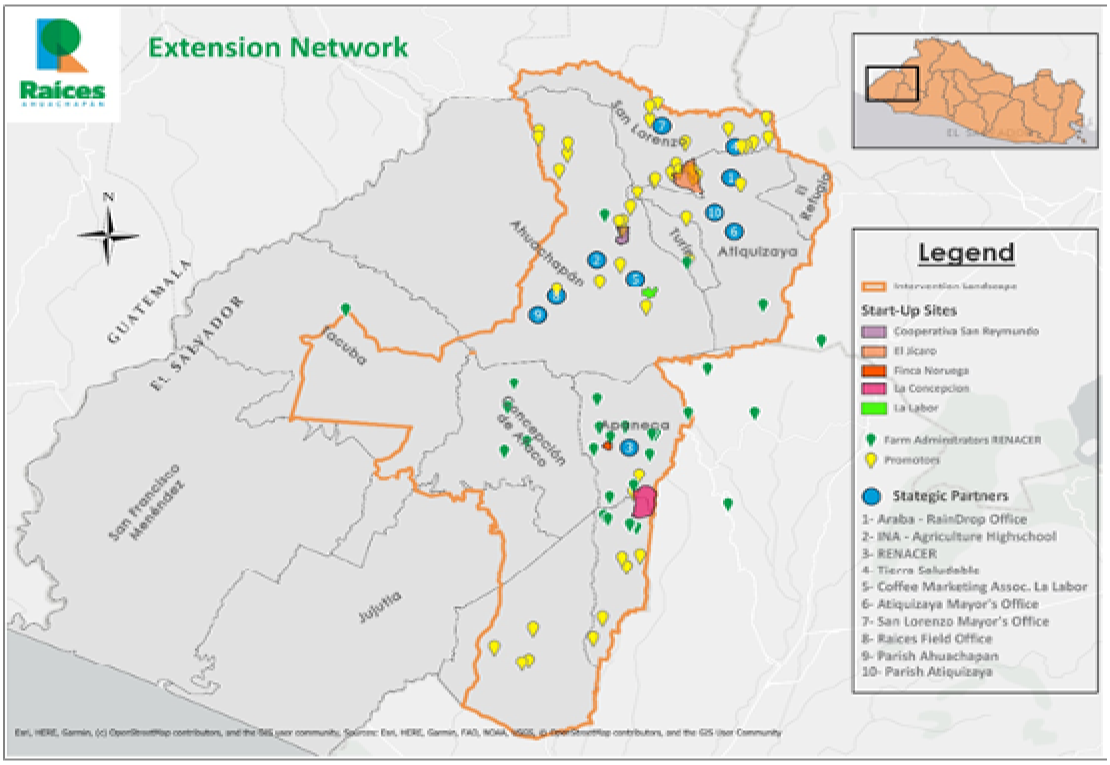

Figure 12. Location of Farmer Field Schools, and five restoration zones start-up sites. The total target area is about 55 000 hectares.

young people, built on principles of productive landscapes and improved ecosystems services. The strengthening of social and political capital for managing agriculture landscape restoration is the foundation for the implementation, sustainability, and scalability of this initiative. This includes research (e.g. monitoring WSA metrics), providing recommendations for public policies and investments, producing policy and scientific publications, and participation in national and international meetings and events to exchange learning and share project results and impacts.

The ALRI-Raíces program is organized across five start-up sites (Figure 12), targeting a total land area of 55,000 ha. The program has trained a robust extension network of trainers and promoters, and a critical mass of farmers, demonstrating success in multiple cropping systems and effective environmental restoration in critical ecosystems. Primary crops include basic grains (maize, beans, and sorghum), coffee, jocote fruit, pasture, and sugarcane. The program uses the Farmer Field School methodology, based on the "Farmer First" ToT method, to support farmers in implementing WSA practices on their farms. This framework emphasizes the participatory learning dynamic between farmers, promoters and extensionists, explicitly based on the premise that farmers learn by doing and will only adopt new practices (i.e. WSA) if; (a) those practices solve real problems, and (b) farmers have tested and validated these practices on their own farms.

A key indicator for ALRI-Raíces is the number of hectares with increased vegetative cover, achieved through growing cover crops, managing crop residues, no-burning, planting live barriers, and planting permanent vegetation on farms or conservation areas. To date, WSA practices are being applied on 975 ha across the ALRI-Raíces territory. An important lesson from both the WSA program and ALRI-Raíces is the combination of managing vegetative cover with soil fertility management.

Cover cropping is one of the key WSA practices being promoted in ALRI-Raíces, however the availability of seed in the region limits scaling up of this practice. The initiative has stimulated the local cover crop seed system by contracting local promoters and partners to produce and package popular varieties such as cowpea (*Vigna unguiculata*) and jack bean (*Canavalia ensiformis*). ALRI-Raíces has also supported the development of a local company dedicated to providing agricultural services around conservation agriculture including training, no-till machinery services (seeding and cover crop rolling/crimping) and cover crop seed.

A territorial approach to scaling WSA

In late 2017 CRS, with local and international partners, initiated a long-term program in El Salvador to promote WSA at a territorial scale, funded by the Howard G. Buffett Foundation (HGBF). The Agriculture Landscape Restauration Initiative (ALRI) has ten -year timeframe (2017-2027), located in the far western region of El Salvador.[7] As is typical of most parts of Central America, agriculture is the predominant land-use in the ALRI in the territory, with maize, beans, and sugarcane systems occupying most the valleys and coastal plains, and diversified shade-grown coffee dominating high-elevation mountain areas. The area is also part of a transboundary river/watershed (Rio Paz) shared with Guatemala. Land and water resources in the territory are highly degraded with high levels of soil erosion and contamination of surface waters as a result of unsustainable farming practices.[9] The territory includes some of the poorest and most food insecure communities of El Salvador.[10]

[8]*See: Working Definition of Agricultural Landscape Restoration. CRS 2019.*
[9]*PRISMA, Dinámicas Territoriales en el departamento de Ahuachapan, El Salvador. September 2018, https://crsorg-my.sharepoint.com/personal/paul_hicks_crs_org/Documents/6.ALRI-Raices/FAO State of Agriculture/296fc7_fdc2a0da43f94f9aafe80064279c4a1c.pdf (raices.sv)*
[10]*See Integrated Food Security Phase Classification Acute Food Insecurity Analysis. IPC, 2021: https://www.ipcinfo.org/fileadmin/user_upload/ipcinfo/docs/IPC_El_Salvador_AcuteFoodInsecurity_2020Nov2021Aug_English_summary.pdf*

ALRI, known locally as RAICES, focuses on smallholders across a range of farming systems. The program also works with larger-scale producers, where farm activities impact critical water resources. The program goal is to promote WSA practices on at least 10,000 hectares and protect and restore key water resources in the territory, aiming to reach about 7000 farmers.

The program exceeded the midterm performance milestones (as of this publication). By early 2023, about 3,500 farmers were applying WSA practices on more than 4,000 hectares.

The scaling strategy for ALRI has evolved since the start of the program, as field teams had to adjust the complications of COVID-19 restrictions for travel and meetings. The strategy has focused on (a) promoting WSA practices on a critical mass of farms, (b) empowering lead farmers and other community leaders to organize, and (c) building capacity of local leaders territorial planning and governance. Relevant to the WSA case study described above, we highlight three key principles in the ALRI scaling strategy that have proven effective over the past five years, including:

- Focus on a few priority WSA practices that generate early results for improving farmers' productivity, income, and resilience.
- Invest in a critical mass of field promoters (champion farmers) as a foundation for a robust multi-actor network of farmers and community leaders.
- Strengthen the capacity of local, permanent actors in territorial planning and governance.

Below we provide details and lessons related to each of these three principles.

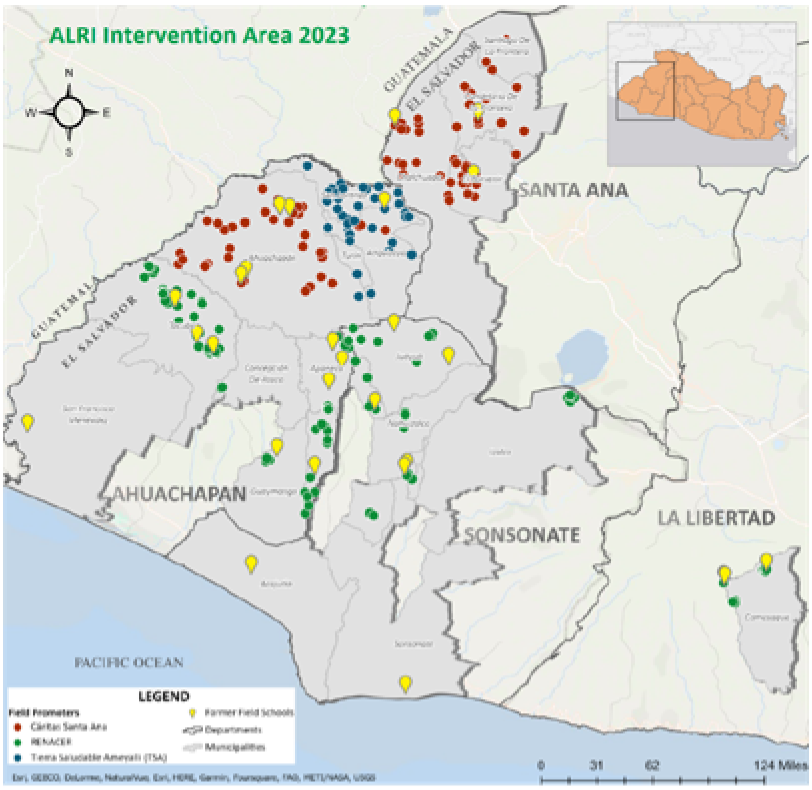

Figure 13. The combined scaling of water smart agricultural (WSA) practises with Farmer Field Schools (FFS) across parrtership initatives of Caritas Santa Ana, RENACER, and Tierra Saludable Amenyalli (TSA), for multiple regions of El Salvador (Data by CRS, 2023).

A). Focus on a few priority WSA practices – "the vital few" - that generate early results for improving farmers' crop productivity, income, and resiliency.

The first principle is to focus on a few priority WSA practices - "the vital few" - that generate early results for improving crop productivity, farm income, and resiliency. This principle has proven important and effective in focusing clear messages for training/extension for farmers and partners organizations across multiple farming systems across the territory.

The "vital few" WSA practices that have proven crucial for generating benefits to farmers in the short- and medium-term are:

- Incorporate cover crops in farms, to serve as soil cover and green manure.
- Manage crop residues to maintain permanent soil cover and increase soil organic matter over time.
- Apply the 4R approach to integrated soil fertility management (described in the WSA case study above).[11]
- Manage pH with basic amendments, as most soils in the ALRI landscape are very acidic.

We have found that when farmers start with the combination of cover crops, 4R soil fertility management, and pH corrections, they are able to see benefits within the first cropping cycle. In the second and third year (cropping cycles), farmers see clear benefits in soil health and weed suppression, and apply significantly less fertilizer and virtually no herbicides. As a result, farm production costs have decreased significantly. For example, in 2022, farmers used less than 50% of nitrogen fertilizer versus previous years (45kg/ha in 2022 versus 90kg/ha), while increasing productivity (see details below). In coffee and maize, the most common crops amongst participating farmers, crop quality has increased, contributing to increased market prices and farm income.

Photo 9: Raul Martinez, San Juan Buena Vista, El Salvador, 2022. Intercropping Mung Bean (Vigna radiata) as cover crop and green manure in maize. Photo by CRS Staff.

The baseline, pre-project yield for maize on hillside farms was 1.9 metric tons per hectare (mt/ha), which was similar to the national average for smallholder farmers. In the 2022/2023 crop cycle, average yields for hillside farmers were 3.5 mt/ha, and all farmers surveyed had yields above the baseline. The number of maize farmers surveyed was 1,342, accounting for all hillside maize farmers participating in the program.

Table 1: ALRI summary maize yield data 2022/23 season for ALRI-supported farmers

Crop	Slope	# of farmers surveyed	Baseline Yield Average (mt/ha)	Average yield ALRI in 2022 (mt/ha)	Stand. Dev. (mt/ha)
Maize	Hillside	1342	1.9	3.5	1.3

[11] *See Nutrient Stewardship 4R: https://nutrientstewardship.org/4rs/*

These "vital few" WSA practices are necessary as a first step for farm restoration, but they are not sufficient for a real transformation of farming systems and landscapes. The ALRI theory of change is that once farmers have learned and successfully applied the "vital few" WSA practices on their farms, they have a new "baseline" of knowledge and experience, which enables them to explore and experiment with other technologies and practices that respond to challenges specific to their farms. This stepwise learning and farmer experimentation is motivated by a robust farmer extension network, see below.

B). Invest in a critical mass of field promoters (champion farmers) as a foundation for robust multi-actor extension network.

The second principle is to invest in training a critical mass of field extensionists and field promoters (or champion farmers) to form the foundation of a multi-actor extension network. Building from the lessons from the WSA program, ALRI uses a modified version of the WSA Trainer of Trainers methodology (described above) to train field extensionists and promoters. This methodology emphasizes the participatory learning dynamic between farmers, promoters, and extensionists, explicitly based on the premise that farmers learn by doing and are more likely to adopt new practices (i.e., WSA) if (a) those practices solve real problems and (b) farmers have tested and validated these practices on their own farms.

We set out to form a critical mass of field technicians and promoters based on a premise that the potential to scale in the medium- and long-term can be achieved more effectively through an "organic" process of farmer-to-farmer learning model versus an overly structured and top-down "transfer of technology" model. Therefore, the training of field promoters focused on the "vital few" WSA practices (discussed above) using a Farmer-Field School (FFS) approach where field technicians and promoters test and demonstrate WSA practices on their farms and invite other farmers to learn and experiment on their own farms, or more commonly, on part of their farms.

The multi-actor extension network supported by ALRI includes about 50 professional trainers and extensionists (from various government and NGO agencies) who have trained and supported about 400 field promoters, each of whom works with an average of 8 to 10 farmers (for a reach of about 3200 farmers as of early 2023).

Over the past several years, we have learned that some extensionists and promoters are more effective than others in leading and supporting farmers through the FFS methodology, so it is key to constantly update and upgrade participants' skills. To build the capacity of extensionists and promoters, ALRI organizes seasonal training events - "technical field schools" - designed for this purpose. These field schools serve as spaces for peer learning where the top performing field extensionists and field promoters lead learning sessions on farms with their peers.

Starting in 2021, the network of field promoters organized themselves into a "Farmer Promoter Network." Representatives of the Farmer Promoter Network participate on a newly formed Landscape Management Council (see below).

The structure and strategy of the extension model has evolved based on experience and recommendations from the government and NGO partners that form part of the multi-actor extension network. This co-design process has helped these agencies to take ownership of the model, adopt or adapt it for other projects beyond ALRI.

C). Strengthen the capacity of local, permanent actors in territorial planning and governance.

ALRI is designed to stimulate economic opportunities for farmers and improve ecosystem services. An essential piece of the scaling strategy is strengthening local capacity for planning and managing agriculture restoration at a territorial scale. Given the predominance of agriculture in the territory and degraded state of land and water resources, the program theory of change is that as WSA expands throughout the territory,

improvements in agricultural practices will improve associated ecosystem services, such as water quality and soil conservation. As farmers demonstrate improvements on farms and at a territorial scale, and as local leaders in the territory organize and develop capacities for planning and management, they will have the foundation for broader *landscape-scale* interventions.[12]

We highlight two key points relevant this principle First, ALRI has focused on building the organizational capacity of local leaders, institutions, and organizations. The emphasis is on local, permanent actors versus supporting outside agencies that work in the landscape temporarily as project implementers. Most NGO staff employed by ALRI are themselves from communities where the program is carried out. The premise is that this network of local leaders will continue to work together beyond the life of the donor-funded program (which will expire in 2027), carrying forward the technical knowledge, capacities, and relationships (social capital) generated during the program.

Second, in 2021 leaders from more than 50 farmer organizations, community-based organizations, community water boards, and NGOs in the landscape (territory) formed a Landscape Management Council (LMC). The LMC has developed a landscape management strategy with priorities defined by its members. One of the LMC's most important and vocal groups is the Farmer Promoters Network, which has advocated for investing in sustainable agriculture and fostering agricultural markets as part of the Landscape Management Strategy.

It is too early to report on the results and long-term impacts of these landscape processes, but we expect that by empowering local leaders and giving farm leaders a role in decision-making at a territory level, there is greater potential for scaling WSA and promoting agricultural landscape restoration beyond the life of the program. We will be monitoring and reporting on these processes through the remainder of the program.

[12] *See CRS 2019.*

5. Lessons learned and recommendations to further scale up WSA in Mesoamerican smallholder rainfed agriculture

There is considerable potential to improve the productivity and resilience (stability) of smallholder rainfed agriculture in Central America and southern Mexico with basic water-smart agriculture practices.

- Field experience and research across Mesoamerica show that by managing soil and applying appropriate basic agronomic practices, farmers can significantly improve yields and mitigate the impacts of changing climate. Agronomic practices that make the biggest difference are those which: (a) improve soil health, (b) optimize plant nutrition, and (c) increase water productivity.

- Ensuring farmers see benefits in the short-term supports buy-in and adoption, while longer-term benefits accumulate. WSA increased maize and bean yields by 26% in the first year and yields continued to rise through years 3 and 4 as soil health improved.

- A stronger R&D and investment focus in the region on improved rainwater productivity in rainfed agriculture (71% of farming in Mesoamerica) would significantly improve food security for the most vulnerable populations in the region, especially those living in rural areas who depend on rainfed agriculture for their food and livelihoods.

An evidence-based approach provides the foundation for local learning and adoption.

- Evidence from the field is essential to guide decision making by farmers, organizations, and policy makers.

- Working with local organizations and farmers to co-create evidence promotes the appropriation and use of new knowledge in decision making.

- Selection of key indicators that are linked to the desired change, respond to the practices being implemented, and are easily measured and interpretable by local organizations and farmers, support evidence-based adaptation. Limit the number and complexity of indicators so as not to overwhelm field technicians with data collection.

- A standard soil assessment field toolbox for farmers and technicians is needed to enable easy and cost-effective soil characterization and comparability of data.

Build capacity with the right organizations and farmers to achieve scale.

- Collaborate with permanent actors that have the most potential to scale and sustain WSA and support them to build their capacity to access and use information and data, solve problems and make water-smart decisions.

- While the WSA program has successfully strengthened organizational technical capacity through training and validation of tools and methodologies, ongoing efforts to scale require greater emphasis on the organizational development and social networking that will help WSA program partners and allies more effectively and efficiently reach more farmers with quality services.

- The how of training is equally as important as the content. Field extensionists and promoters need training in how to facilitate innovation processes with farmers.

There is a need for innovative public and private models to provide WSA tools and services.

- Institutional infrastructure to reach farmers is costly, and resources for extension are limited.

- The region needs innovative models to provide WSA services to many farmers at relatively low cost. Developing and strengthening the capacity of promoter networks to support extension services, including local private service providers, are promising models in development.

- Local and reliable seed systems for cover crops must be developed.

- Smallholder access to micro-financing creates opportunities for investment in new technologies.

A systems approach is required to address complex socioeconomic and agroecological challenges.

- Farmers manage complex farming systems, not plots, and in Central America and southern Mexico most farms integrate crops and livestock. Thus, WSA must widen its focus from the plot to integrated management of the farming system. There are many beneficial synergies between crops and livestock that can be further developed, especially solutions for the trade-offs between crop residue for soil enhancement and dry season livestock feed.

- Water harvesting for supplemental irrigation, to reduce overall production risks and enable diversification into cash crops, will need much greater focus and investment as rainfall becomes more erratic and the *canícula* longer and more severe.

- The full potential of cover crops is still to be realized through further diversification (species) and the optimization of temporal and spatial integration in the farming systems.

Create conditions for scaling and institutionalization.

- Scaling is a complex development process that demands a flexible and reliable flow of financing. In a context where the overall funding environment for agriculture in Central America is shrinking, achieving scale becomes more challenging. Donors often choose to invest in short-term results at the cost of long-term transformative and sustainable change.

- Scaling is a complex social process requiring organizations to develop the institutional capacity and social capital to work more efficiently and effectively in supporting many farm families over time. In various countries and territories these capacities are weak or non-existent and need to be developed and strengthened, a process that takes time.

- The WSA program experience shows the importance of developing coalitions, partnerships, platforms, and networks. Many multi-actor platforms have integrated WSA goals into their strategies and planning but require additional support to successfully put those plans into action and sustain them over time.

Conclusions

Mesoamerican smallholder farmers can significantly improve the productivity and climate resilience of their rainfed agricultural systems by applying appropriate water-smart agriculture practices that restore soil health and increase rainfall productivity. Since 2015, the WSA program has been working to inspire a Mesoamerican movement for resilient rural prosperity by scaling WSA to reach 250,000 smallholder farmers with services that support increased agricultural productivity through the restoration of soil and water resources. The program has been designed from the outset to seek impacts at scale, through an innovative implementation model, that emphasizes engagement with key agricultural institutions both in research and practice to catalyze their appropriation of, and investment in, water-smart approaches, methodologies and services for smallholders. The program to date has been a productive laboratory of experimentation, innovation, and learning that has produced significant results in a relatively short period of time. However, further support for R&D and scaling is required to reach impact at scale, where WSA becomes the new normal for smallholder rainfed agriculture in Mesoamerica.

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Acknowledgments

The Water Smart Agriculture Program for Mesoamerica and the Agriculture Landscape Restauration Initiative (ALRI) in El Salvador were made possible by the continued financial support and vision of The Howard G. Buffett Foundation. The work described in this Case Study has been carried out by the dedicated CRS WSA teams in Honduras: Luis Welchez, Miguel Flores, Carlos Zelaya, Gisela Cabrera, Marco Trejo, Carlos Bonilla; Nicaragua: Jorge Castellon, Rodolfo Valdivia, Ariel Espinosa, Juan Ortiz, Roger Rodriguez, Jorge Martinez, Felipe Pilarte; El Salvador: Jaime Tobar, Jose Cristóbal Escobar, Douglas Saleh, Quirino Argueta, Fernando Vásquez, Luis Torres, Norma Minero; Guatemala: Jayron Zaldaña, Andrés Búcaro, Silvia Salazar, Marisol Amador, Jorge Oliveros, Dan McQuillan; Oaxaca: Marco Antonio Gonzalez, Severiano Martinez, Miriam Arcos, Cecilia Suarez; Regional: Jose Angel Cruz, Mar Martin, Juan Carlos Trejo, Monica Mata, Hugh Aprile; and the CRS ALRI team in El Salvador: Adam Keough, Francisco Casares, Daniel Torres, Herman Rosa, Deborah Barry. Likewise, we want to acknowledge the work of our numerous partners and collaborators listed in Figure 11. Special thanks to Fernando Vásquez (CRS-Salvador) and Kai Sonder (CIMMYT) for their collaboration on the maps.

Scaling-up agriculture water management interventions for building system resilience in Bundelkhand region of Central India

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Summary

This case study provides evidence for combating drought, and achieving sustainable crop intensification, in rainfed areas of Bundelkhand region, Central India. The Garkundar-Dabar and Parasai-Sindh watersheds were developed as proof of concept by the Indian Council of Agriculture Research-Central Agroforestry Research Institute (ICAR-CAFRI) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) between 2006 and 2016. This study indicates pathways for harnessing the potential of rainfed areas by implementing various agricultural water management (AWM) interventions. Rainwater harvesting measures, especially rejuvenation of the *haveli* system (traditional rainwater harvesting system of the region), along with various *in situ* water harvesting interventions, were found promising for addressing water scarcity and strengthening various ecosystem services. Water harvesting measures, improved agricultural practices (such as balanced fertilizer application, introduction of climate-smart crop cultivars, weed and pest management) and supplemental irrigation, enhanced crop yield by 30-50% and cropping intensity from 80 to 150%. Enhanced groundwater availability (2-2.5 m additional head) helped to reduce crop risk, through the availability of supplemental irrigation and enhanced cropping intensity, as large areas of fallow land were converted to cultivation. AWM interventions also helped to enhance base flow (35-42 days to 110-122 days), control floods, soil erosion and land degradation (by about 33%), and enhance land and water use efficiency (40-70%). Since 2017, lessons from these model watersheds have been scaled up in all seven districts of Uttar Pradesh Bundelkhand region, by an ICRISAT-led consortium. This study explores the potential of rainfed areas that are achievable through the adoption of AWM interventions. It suggests that the role of extension, through capacity building and exposure of various stakeholders to AWM, is key to harnessing the potential of drylands. In order to further scale up such innovations to the entire region, it is important to involve knowledge generating and knowledge dissemination institutes, along with central and federal machineries. Involvement of private and non-governmental organizations as well will help achieve system level outcomes.

1. Introduction

India is one of the fastest developing economies in the world, with large human resource availability. Agriculture is the major source of livelihoods for about 55% of the workforce. The country has 142 million ha of cultivable land. About 55% of this is under rainfed systems, which provide about 45% of India's food requirements (GoI, 2015). Rainfed agricultural lands suffer largely from water scarcity, land degradation and low productivity, which coincide with widespread poverty and malnutrition (Rockstrom and Karlberg, 2009). To address such problems, India has since the 1960s adopted a holistic approach of integrated natural resource management for sustainable crop intensification, with the introduction of river valley projects to ensure food security. This has evolved over time with new lessons and experiences. Between 1970–80, the focus was mainly landscape protection and erosion control, with the implementation of field bunding as an *in situ* soil conservation measure.

This benefited the community, but due to its compartmental nature the full potential benefits were not realized. As the approach followed was contractual, community participation was lacking. This is crucial for the sustainability of AWM interventions. The approach was modified in subsequent decades (1990s), and a water conservation component was also included. A number of rainwater harvesting structures were constructed, which generated benefits in terms of increased groundwater recharge and crop intensification. Although there was increased groundwater availability, farmers in rainfed areas were cultivating traditional, poor yielding crop cultivars. To improve the productivity of small and marginal farms a new productivity enhancement concept was introduced in the late 1990s. This was crucial to addressing food insecurity along with crop intensification. Further, to ensure participation and address equity in benefit sharing, efforts were made to include the landless and women (Figure 1).

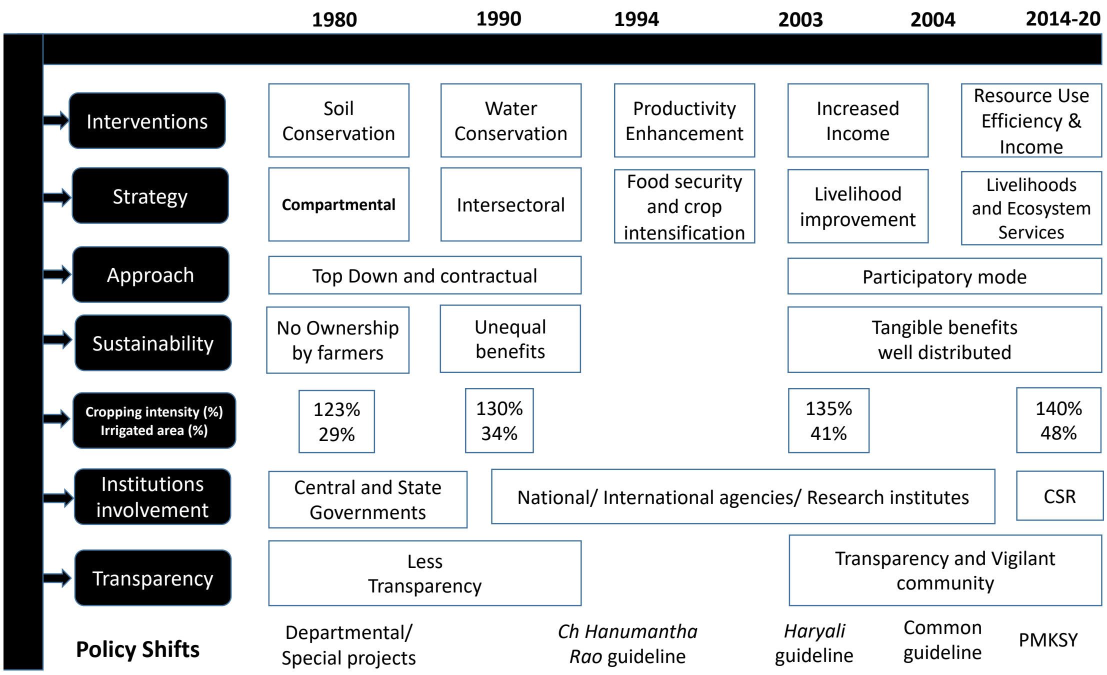

Figure 1: Journey of watershed management programs in India since 1980
Source: Authors' elaborations based on literature review

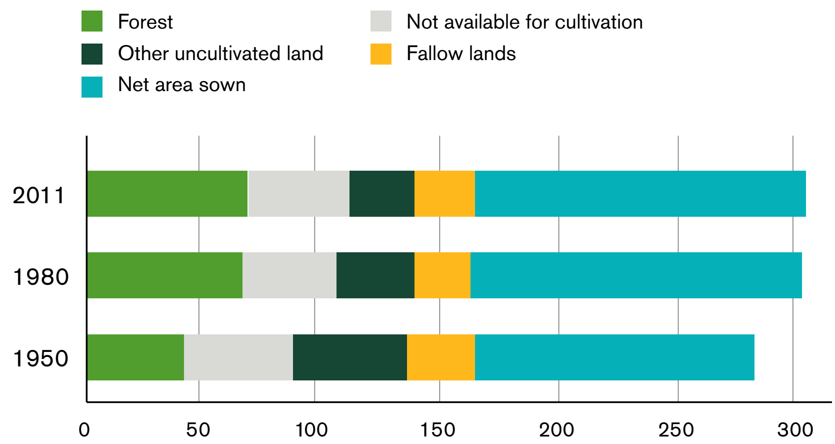

Figure 2: Land use, or land cover status, in India from 1950 onwards (in million ha). Total geographical area of the country is 328.27 m ha. However, this figure only shows areas for which land use statistical data is available (Data source: GoI, 2015).

With the aim of addressing social equity, the Government of India enacted a corporate social responsibility law in 2013. This requires every company with a net worth of about 80 million USD or more, to spend 2% of total earnings on social welfare programs such as education, health, sanitation, and agriculture (GoI, 2014). After realizing the potential of such investments for improved natural resource management, a significant amount of corporate social responsibility (CSR) funds began to be diverted to AWM interventions.

Figure 2 shows the change in land use, or land cover status, in India from 1950 onwards. The net sown area has been increased from 118 million ha in 1950, to 140 million ha in 1980, by converting fallow and wasteland to cultivation. Further, permanent pasture land has increased from 6.68 million ha to 11.97 million ha between 1950 and 1980, and slightly decreased by 2011.

Figure 3 describes the change in source-based net irrigated area in India since 1950. It is evident that the total irrigated area in the country has

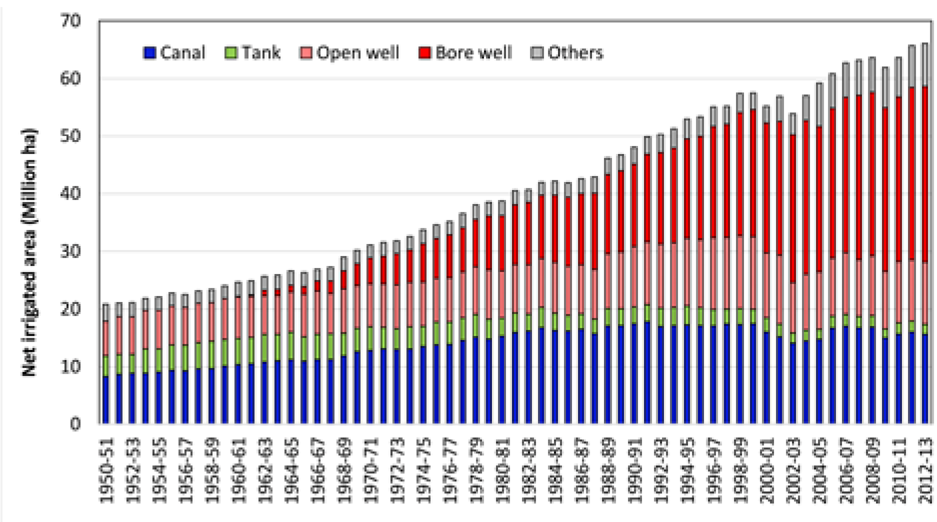

Figure 3: Change in source-based net irrigated area (million ha) in India between 1951 and 2013 (Data source: GoI, 2015)

increased from 20 million ha in 1950 to about 65 million ha in 2013. Until 1970 irrigation sources were surface and open wells or tanks. Despite a huge public investment made in order to enhance surface irrigation (major reservoirs, canal command areas), this contributed merely 18 million ha out of the 65 million ha net area irrigated in 2013. Groundwater resources (open and borewells) contributed nearly 40 million ha, largely through farmer led private investments. With increases in pump technology and energy subsidies, large amounts of rainfed areas have been brought under supplemental irrigation. As such there are no areas left that are completely rainfed. Large-scale welfare schemes by the Government of India (e.g., watershed programs, Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), etc) have also supported such developments[1]. Therefore, in this study a rainfed system is not only referring to completely rainfed, but also capturing supplemental irrigation.

A number of impact studies that have been undertaken by different agencies. These reveal that 99% of watershed works generate a benefit-cost ratio of more than one. However, there is a skewed distribution. High performing watershed projects are from knowledge-based institutions in which needs based, science led interventions were implemented (Joshi et al., 2008, Wani et al., 2008, 2011, 2020; Garg et al., 2011, Singh et al., 2014). Watersheds representing medium rainfall, ranging from 700-1000 mm, performed relatively better, as interventions addressed water scarcity and these watersheds were not prone to floods. However, there is huge scope for improvement in designing and implementing interventions. For example, increasing climate variability must now be addressed when designing them. This study of a rainfed dominated, agro-ecological landscape in the Bundelkhand region, describes innovations in AWM interventions at the community and watershed scale. It details interventions, actions, and outcomes in terms of rainfed production and productivity, alongside selected social and environmental impacts. Based on this case, the scaling up approach to intensify rainfed agro-ecological landscapes, which ICRISAT and partners have been involved in since 2006, is then discussed.

2. Bundelkhand region, Central India

Bundelkhand is a hotspot of water scarcity and land degradation, vulnerable to climate variability. The total area of the region is 2.94 million ha, of which 69% is net sown area, 8% (0.236 million ha) under forest, with the rest under non-agricultural use, barren or cultivable waste (Gupta et al., 2014). The region has experienced severe drought conditions in six of the last ten years. Long term weather data, monitored at Jhansi station (a district of Bundelkhand), shows that annual average rainfall in the study region is 877mm (standard deviation, σ = 251mm), about 85% falling between June and September. The number of rainy days during the monsoon, and non-monsoon, periods are on average 42 and 13, respectively. As shown in Figure 4, long-term data analysis reveals that average annual rainfall has decreased from 950mm (1944-1973), to 847mm (1974-2004). This reduction was mainly due to the decreased number of low (0-10mm) and medium (30-50mm) rainfall events (Figure 4). Similarly, the total number of rainy days in a year also decreased. This has had an adverse impact on the regional scale water balance, especially in terms of groundwater recharge (Singh et al., 2014). It also has severe implications for the rainfed production system, in terms of a bias towards events of greater volume and intensity, and fewer events per season, affecting soil moisture patterns for crop growth.

A study undertaken by Rao et al. (2013) on climate change in the Bundelkhand region showed that about 581,000 ha, which had previously experienced a semi-arid, moist climate, has shifted towards a drier climate (both semi-arid dry and typical arid climates) as shown in Figure 5. Jalaun and Jhansi districts have witnessed great changes in climate between 1961-1990 and 1991-

[1] *https://www.india.gov.in/my-government/schemes*

2013. Jalaun has lost all its semi-arid moist areas (233,000 ha), which have become drier, 167,000 ha becoming semi-arid dry climate areas, and 66,000 ha becoming typic arid climate. Perhaps this is the first time that the typic arid climate type has been seen in Jalaun district. Hamirpur district also witnessed about 2,000 ha changing to typic arid climate. Jhansi district also shows a large shift with 213,000 ha of semi-arid moist type becoming semi-arid dry type. Lalitpur and Chitrakoot districts also show increasing dryness. Out of seven districts, only two (Mahoba and Banda) show a slight increase in wetness. They have more areas under semi-arid moist climatic type now compared with the period between 1961-90. This affects about 9.6 million people in the Mahoba and Banda region (~0.35 million households) (Gupta et al., 2014).

Agriculture, and related sectors, are the main rural population livelihood sources (Shakeel et al., 2012). A diverse cropping system is followed in Bundelkhand; groundnut, black gram, sesame, and millet are the main crops cultivated during the *Kharif* season (June/July-October/November). Wheat, chickpea, barley, mustard, and lentils are grown during the *Rabi* season (November/December-February/March) (refer to crop calendar in Table 1). Due to undulating topography, poor groundwater potential, high temperatures and highly variable rainfall, agricultural productivity is very low (0.2–2.0 t ha^{-1}). Most areas are single cropped, completely under rainfed conditions, during the two cropping seasons. Bundelkhand is largely dependent on groundwater resources for domestic and agricultural use. Water levels in open and dug wells (4-8 m deep) deplete very fast after the monsoon (November-May). Communities suffer from water scarcity, especially in summer. Bundelkhand has 44% of cropland under irrigation, out of which 41% is under surface irrigation schemes (canal command area), and 59% irrigated through groundwater sources (dugwells and borewells) (Gupta et al., 2014).

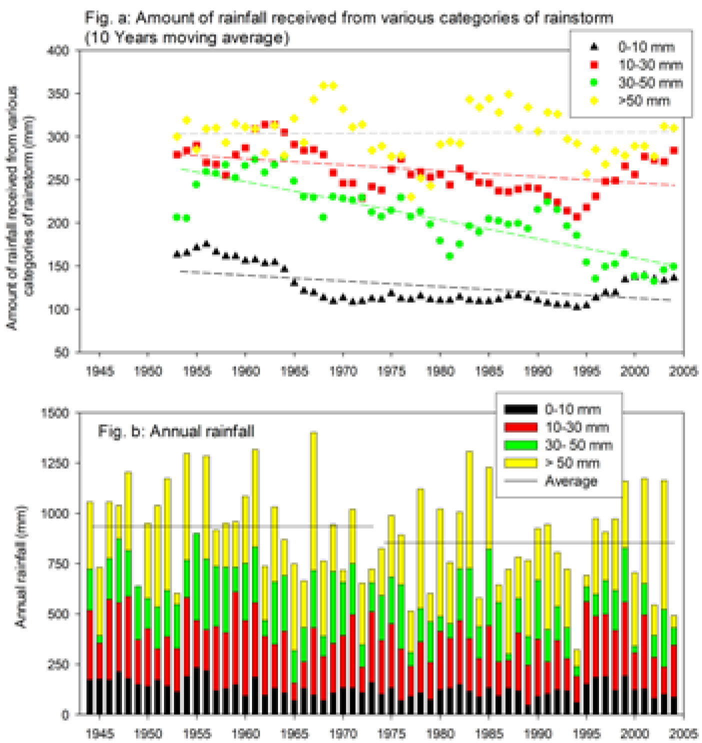

Figure 4 (a): Moving average (10 years) of rainfall received from different categories of rain events between 1945 and 2004; (b) Comparing annual rainfall between 1945-1974 and 1975-2004
(Data source: India Meteorological Department, 2005;)

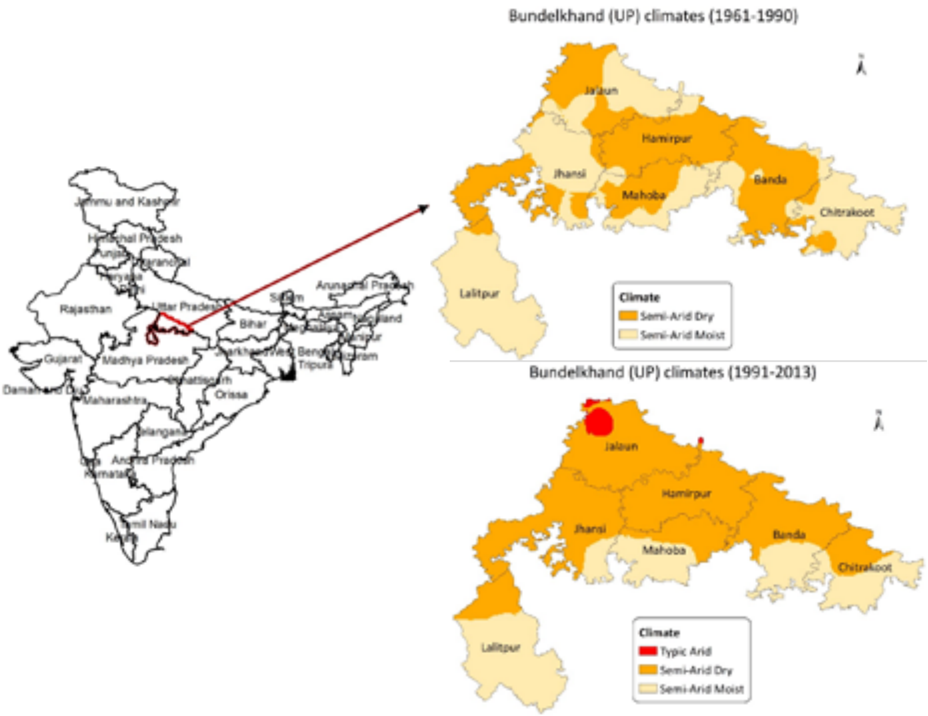

Figure 5: Change in climate patterns at district level in the Bundelkhand region (Source: Rao et al., 2013)

The socio-economic status of Bundelkhand is characterized by high poverty (30-55% across districts), low literacy rates (57%, and women's literacy is a mere 43%), and high vulnerability of women and landless people, due to adverse climatic conditions (NITI Aayog, 2016). The operational landholding size in Bundelkhand is 1.53 ha. About 77% of land owners own just 39% of the land (NITI Aayog, 2016), which shows the skewed distribution among the farming community.

A large gender equity gap exists Bundelkhand. Women are deprived of basic opportunities as they are largely engaged in domestic chores (fetching drinking water long distances, cattle management, collecting fuel wood, preparation of dung cakes, etc.) and affected by drudgery. Due to the lack of livelihood opportunities, a large portion of the male population migrates to nearby cities or to secure labour work (mining, masonry, or as a security guard or driver) leaving women and livestock behind. This has led to various socio-economic shocks affecting women, with a high rate of drudgery. Further, the nutritional status of women and children is very poor, leading to poor health (Varua et al., 2018; Mitra and Rao, 2019; Padmaja et al., 2020).

Inappropriate policies relating to natural resource management have led to failures in formal and informal institutions and a lack of collective action. Results include; defunct traditional rainwater harvesting systems (*haveli* system), weakening of the agro-pastoral system, inequitable distribution of the benefits derived from natural resources, and the loss of various ecosystem services (declining base flow, deforestation, land degradation) (Sahu et al., 2015; Meter, et al., 2016; Reddy et al., 2018).

In order to meet local and national food and water security ambitions, alongside rural development targets, there is a need to improve the rainfed dominant livelihood systems. The situation is a complex mix of climatic and environmental changes, alongside policy and social inertia (or in some cases collapse). Mobilizing capital and knowledge to progress from this state is particularly challenging in rainfed systems.

3. Pilot sites for rainfed systems intesification

This study presents the experience of two mesoscale watershed pilot projects, in the Bundelkhand region, which were then followed by scaling up initiatives (Figure 6). The Garkunder-Dabar (GKD) watershed is located in the Tikamgarh district of Madhya Pradesh. Interventions there were conceptualised and implemented by ICAR-CAFRI between 2006 and 2011. The Parasai-Sindh (PS) watershed interventions were implemented jointly by ICRISAT and ICAR-CAFRI between 2012 and 2016. Both watersheds are part of the Betwa river catchment of the Yamuna sub-basin. Yamuna is one of the tributaries of the Ganges (Ganga) River in Northern India, a large portion of the sub-basin lies in Bundelkhand region. The location of Bundelkhand is such that it acts as a gateway between the north and south of India, and it has previously acted as political hub (Tyagi, 1997). A large number of the inhabitants of the Bundelkhand region are mainly dependent on rainfed crops, and livestock based activities. Approximately 33% of the total geographical area is covered by degraded forest, grazing land and wasteland (UPWSRP, 2001). Due to undulating topography, high temperatures, and poor and erratic rainfall, agricultural productivity in the region is poor.

The total geographical area of the GKD watershed is 850 ha. Of that, 264 ha is agricultural land, the rest covered by deciduous forest or wasteland. The PS watershed is 1250 ha, 90% of which is under agricultural use. The topography of the GKD watershed is steep with slopes ranging from 2-15%, whereas slopes in the PS watershed are relatively flat (1-3%), see Table 2a.

Soils in the region are reddish to brownish red in color (Alfisols and Entisols), shallow (10-50cm),

Table 1: Crop calendar for major crops in Bundelkhand region; Kharif season coincides with the monsoon whereas the Rabi season coincides with winter (Source: Singh et al, 2014; Garg et al., 2020)

Season	Crops	Crop Duration (days)	Irrigation status	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Kharif	Black gram	70-75	Rainfed												
	Sesame	70-75	Rainfed												
	Millet	90-100	Rainfed												
	Groundnut	110-120	Rainfed												
	Sorghum	120-130	Rainfed												
	Pigeonpea	200-240	Rainfed												
Rabi	Mustard	110-130	Rainfed												
	Lentil	110-130	Rainfed												
	Chickpea	120-130	1-2 irrigations												
	Field pea	120-130	1-2 irrigations												
	Barley	120-130	2-3 irrigations												
	Wheat	120-140	3-5 irrigations												

coarse gravelly, light textured with low water-holding capacity in the root zone (80-100mm/m), and low levels of nitrogen, phosphorus and organic carbon. Groundwater is the primary water source for domestic and agricultural use. Borewells do not work in these areas due to the hard rock aquifers (granite) and poor specific yields (<1%). Landscape topography, land use and demographic details of study watersheds are shown in Tables 2a and 2b.

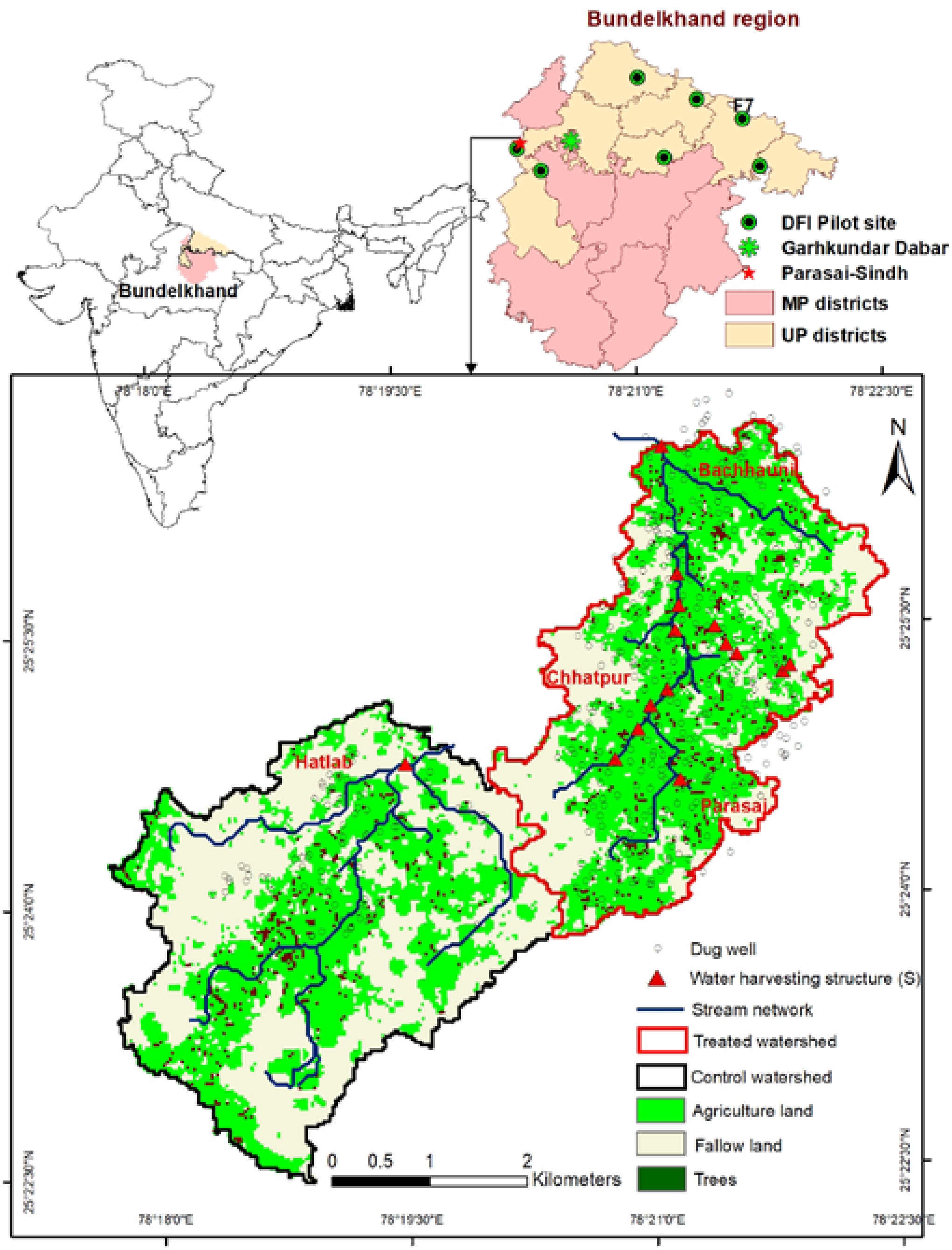

Figure 6: Location of pilot watersheds in Bundelkhand region (Source: Garg et al, 2020)

Table 2a: Landscape topography, land use and demographic details, along with socio-economic and environmental impact indicators of the GKD and PS watersheds, and nearby control watersheds (Garg et al, 2020; Singh et al, 2014)

Indicator	**Garhkundar-Dabar Ws (treated)**	**Control** **Shivrampur Ws**	**Parasai-Sindh Ws (treated)**	**Control**
State	Madhya Pradesh	Madhya Pradesh	Uttar Pradesh	Madhya Pradesh
District	Niwari (erstwhile Tikamgarh)	Niwari (erstwhile Tikamgarh)	Jhansi	Jhansi
Villages	Garhkundar, Shivrampu, Rautiana, Dabar, Sakuli, Ubaura	Shivrampur, Dabar	Parasai, Chhatpur Bachhauni,	Hatlab
Project period	2006-2011	2006-2011	2012-2016	2012-2016
Location (Lat/Long)	270 27`N; 780 53` E		25º 23’ 47.6” N; 78º 22’ 33.0” E	
Watershed area (ha)	850	298	1246	1100
Population	980	325	3000	2800
No. of households	152	36	417	395
Land use				
Agriculture	260	136	1105	950
Degraded forest	506	125	6	26
Wasteland (Scrub land)	40	16	66	45
Other	44	20	69	79

Table 2b: Other impact indicators of GKD (2006-2011) and PS (2012-2016) watershed, and nearby control watersheds (Data source: Singh et al., 2014; Garg et al, 2020)

Indicator	**Garhkundar-Dabar Ws (treated)**	**Control** **Shivrampur Ws**	**Parasai-Sindh Ws (treated)**	**Control**
No. of days baseflow received	110	35	122	42
Average annual soil loss (t/ha)	1.5-6.5	3-11.5	1-4.3	4-13.6
Storage capacity of *ex situ* WHS (m^3)	25000	5000	115000	15000
Harvesting ratio to total storage capacity	8.2 – 9.5	2-3	3 to 7	1.5-3
No. of dug wells	116	42	388	296
Average depth (m)	8.7 (std 2.4)	8.7 (std 2.2)	9.2 (std 1.5)	10.5 (std 1.6)
Average water table depth (m)	4.6	3.3	4.9	2.9
Average pumping hours	125	62	156	86
% wells dry in December	1.7	21	3	19
% wells dry in May	3	38	5	32

4. Rainfed crop systems innovations and practices promoted

Multiple technologies and practices were introduced in consultation with; farmers, the community and the research team. Based on consultations, some existing technologies were improved, and others were introduced as new practices to the area. Here we list the principal strategies and social approaches, relating to farming system technologies, used to achieve agricultural intensification of the rainfed systems.

In situ and *ex situ* water conservation measures

Soil and water conservation practices are categorised into: *in situ* measures, and *ex situ* measures. *In situ* measures enhance soil moisture availability, and reduce non-productive evaporation through various agronomic and engineering interventions. These facilitate the harvesting of rainfall where it falls. Contour farming, field bunding, terracing, broad bed furrow, and mulching are examples of *in situ* measures. *Ex situ* measures are interventions that harvest and store surface runoff at different landscape scales, through the construction of low-cost, water harvesting structures such as farm ponds, tanks, check dams, percolation tanks and the *haveli* system.

Field bunding and agroforestry

In situ water harvesting (e.g. contour/graded bunds) enhances soil moisture availability and controls soil erosion (Garg et al., 2011; Singh et al., 2014). Larger fields are divided into smaller sizes, such that the runoff velocity is reduced, and a fraction of the runoff is harvested across the field bunds. The cross section of these bunds is about 0.8-1.0 m^2. Field outlets, with stone pitching, were constructed to guide the disposal of excess runoff. Deciduous teak trees, a suitable species, were planted at the base of the field bund, at three meter intervals, to strengthen the bund and also as an additional, long-term income source income for farmers.

Rejuvenation of *haveli* tanks

A number of public welfare programs (PMKSY, Watershed Development Program, MGNREGA) are being implemented to mitigate droughts. Recognising the importance of the *haveli* structures, which comprise a traditionally built tank to collect surface runoff, significant efforts were made by farmers in collaboration with project team to repair and maintain them. However, during heavy downpours earthen embankments were eroded, despite the thick embankment walls, because soils in this region have poor binding ability (having course texture and poor in organic matter). Rodent burrowing also led to embankment damage. Thousands of such structures, currently defunct, are found in Bundelkhand. These hold large untapped potential for rainwater harvesting (Shah, 2003). To capitalise on these, ICAR-CAFRI and ICRISAT introduced the core-wall concept, beneath the entire *haveli* embankment wall, and built safe outlets at suitable locations, to dispose of excess runoff. A reinforced cement stone wall, with a foundation up to 2m deep, was built to a suitable height for harvesting surface runoff. The core wall was then covered with soil, so that it is not exposed to harsh weather, enhancing its stability and lifespan. Identification of appropriate sites, adoption of suitable designs appropriate to the location, hydrology and other safety parameters, were important aspects of rejuvenating the *haveli* system.

Generally, *haveli*s occupy only 2-3% of the village landscape, and submerge upstream areas during the rainy season. Provision to draw water from the *haveli* structure is given so that after September/October farmers can empty the tank and utilize the fields for *Rabi* cultivation. The productivity of the *haveli* fields is relatively high since they hold more moisture, humus and nutrients. Increased groundwater availability also helps in intensifying cropping to a large extent. The life expectancy of the structure can be greater than 50 years, when constructed in stone, and with proper provision for draining excess rainwater.

Table 3 compares the unit harvesting cost of different structure types (*ex situ*). *Haveli* structures are found to be more cost effective, as they harvest surface water and also have a long life span compared to other structures, such as farm

Table 3: Comparative analysis of the unit cost of different types of water harvesting structures (Source: Authors' elaborations based on primary data collection)

Structure type	Harvesting capacity (m^3)	Unit harvesting cost (USD/m^3)	Life span (years)
Haveli structure	30000-50000	0.40	> 50
Farm pond	300-1000	1.25	15-20
Check dam -ICRISAT/CAFRI	1500-5000	4.00	20-30
Check dam - Govt. Dept.	1500-5000	10.00	5-10

ponds and check dams. Construction of *haveli* submerge 2-3% of community or private land, so the stakeholders must agree to implement them. During the monsoon period this land is submerged. However, farmers then have the opportunity to cultivate post-monsoon crops, with the benefits of residual moisture and increased decomposed organic carbon levels, resulting in greater productivity (Sahu et al., 2015).

Construction of check dams

To enhance groundwater recharge, a series of check dams along the drainage line were constructed following the ridge to valley approach. These check dams are reinforced stone masonry structures, nearly 1.5-2 meters in height, with a rectangular weir to dispose of excess surface runoff during flood events. Storage capacity of these structures is between 2000m3 and 10,000m3 depending on drainage density, topographical features and stream width.

Famer participatory demonstrations

There is a yield gap in rainfed crop production in Bundelkhand region, which can be bridged through various land, water, nutrient and crop management interventions. For example, the average yield between 2010 and 2014 obtained in Bundelkhand was 2180kg ha^{-1}, compared with 2988kg ha^{-1} in Uttar Pradesh overall, and 3060kg ha^{-1} across India. Similarly, chickpea yield in Bundelkhand during the same period was 770kg ha^{-1}, compared to 950kg ha^{-1} in Uttar Pradesh overall, and 940kg ha^{-1} across India. Many farmers in Bundelkhand follow conventional crop management practices, due to lack of knowledge, poor infrastructure, poor affordability and risk aversion. To raise their awareness, and knowledge, of improved practices, ICRISAT and partners demonstrated best management practices, with farmer participation (including women and youth), with the aim of fostering higher productivity. A number of best agronomic management practices were introduced and showcased. This included soil testing for soil nutrient management, improved crop cultivars, and integrated pest, disease and weed management, which all operate to maximize the benefit of improved soil moisture status. In Bundelkhand, mechanization in agriculture is not widely practiced and therefore, needs-based mechanization interventions, such as use of zero-tillage and laser land leveler, were also introduced. This has reduced labour and the energy cost of irrigation application, and also enhanced water use efficiency. Moreover, use of a zero-tillage, multi-crop planter helped reduce seed quantity use and the cost of cultivation, as well as encouraging line sowing, and most importantly encouraged better utilization of residue soil moisture available in the surface soil layer. More than 250 farmer participatory demonstrations, on various best management practices, were undertaken to support the capacity of farmers to adopt improved technologies.

Box 1: Renovation of *havelis*: bringing a lost tradition to life

Between the 10th and 13th century, the Chandela dynasty of Bundelkhand region took keen interest in conserving water as a means of supporting livelihoods and the development of the region. To address water scarcity and recharge groundwater, they established a network of several hundred tanks, called *havelis*. These structures were constructed in a toposequence, with 50-100 meter earthen embankments, 5-8 meters wide, in such a way that they harvest surface runoff (Shah, 2003; NITI Aayog, 2016).

Almost every village in Bundelkhand has, for a long time, had a traditional *haveli* rainwater harvesting tank system. *Havelis* were built 2-3 meters high, across the stream network, depending on the catchment area. Runoff generated from the catchment is harvested during the monsoon and used for multiple purposes by the village community. This facilitates groundwater recharge, harvests rainwater, and also provides water for supplemental irrigation in nearby fields. Once the monsoon recedes, the impounded rainwater is drained out and the tank area prepared for cultivating Rabi crops, using the residual soil moisture. Traditionally, the community periodically took care of the maintenance of tank bunds, de-silting, repair of water outlets, and scheduling of water releases. Water drained from *haveli* tanks was used by downstream farmers for pre-sown irrigation, and surplus water was released through the drainage network. The productivity of *haveli* fields is 15-25% higher in general than nearby fields, due to the deposited silt and organic matter (Sahu et al., 2015). The *haveli* system of cultivation is an excellent example of participatory rainwater management and collective action for the management of available natural resources in Bundelkhand region.

5. Innovation process of AWM interventions in Bundelkhand region

The innovation process to intensify the rainfed dominated production system in Bundelkhand was facilitated by a range of partners focused on knowledge transfer, capacity and awareness building. National, state and local policies have clear ambitions to enhance the rainfed dominated production systems of smallholder farmers in dryland areas, including Bundelkhand region. However, capacity and resources need to be pooled beyond local agricultural extension and advisory services. In addition, a clear strategy with recognition of the time it takes to achieve improved rainfed production to improve social and livelihood conditions, is needed. In the case of the mesoscale watersheds located in Bundelkhand, a partnership was built on the rich understanding of the region's issues by the National Agricultural Research System (NARS), together with international knowledge, based on ICRISAT's experience of over 40 years of watershed development. It took significant effort to generate trust and interest from local communities and village institutions. Investment came from various stakeholders, and agencies such as ICAR, company corporate social responsibility programs and state government. The community invested their time in project planning, and intervention implementation. In terms of extension, farmers in the region were not aware of improved methods of cultivation (new crop varieties, machineries, package of practices). These projects have given them the opportunity to interact with researchers of various disciplines, extension officers of both the public and private sectors, and enabled these farmers to gain first-hand knowledge on improved technologies and methods. Large scale exposure visits to learning sites have generated farmer confidence to adopt these new technologies in order to realize greater benefits. Figure 7 summarises the innovation process of AWM interventions in Bundelkhand, carried out by ICRISAT, ICAR-CAFRI and partners, from 2006 onwards.

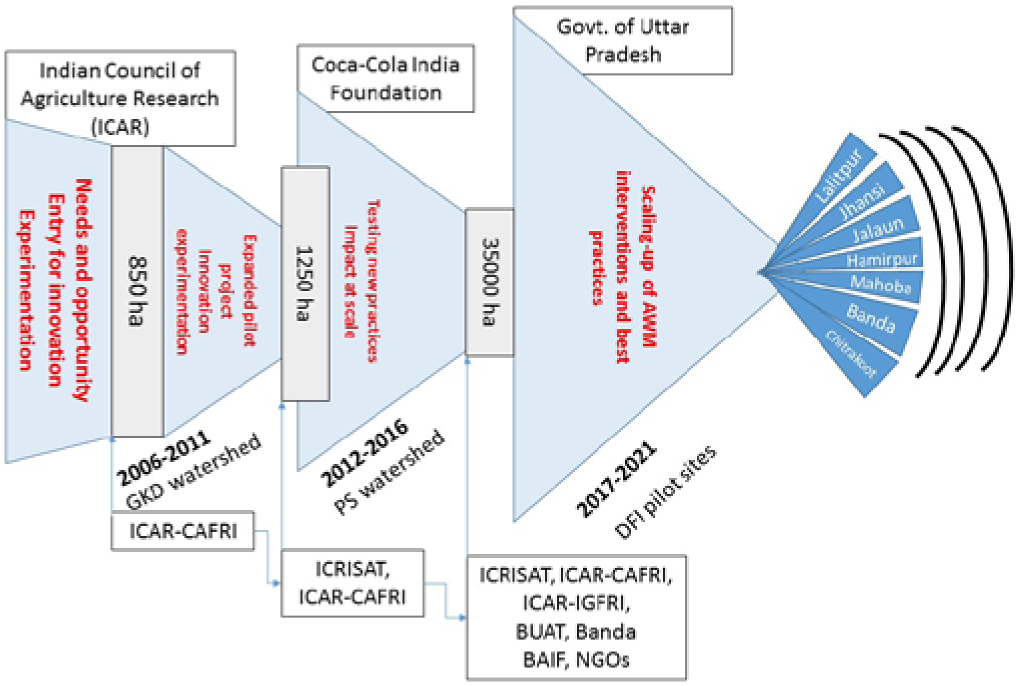

Figure 7: Scaling up pathways of AWM interventions in Bundelkhand region (Source: Authors' own compilation)

Model watersheds in Bundelkhand region

The innovation journey began in 2006 with the ICAR-CAFRI implementing interventions in the GKD watershed. This 850 ha, mesoscale watershed in the Tikamgarh district of Madhya Pradesh state was targeted. Prior to 2006, more than 30% of the area was under degraded forest, 20% was wasteland, and 40-50% was under cultivation with a poor productivity status. ICAR-CAFRI took the lead in conceptualising, designing and implementing new AWM interventions, and regenerating existing AWM solutions. The focus was on developing technically improved rainwater harvesting structures, combined with agroforestry interventions and crop management (see section 4.2), to secure and utilise rainfall better. The project was implemented between 2006 and 2011. ICAR-CAFRI designed low cost (30-40% less compared to normal structures) but robust, water harvesting structures, better suited to the watershed environment and context. Infrastructure developed in the GKD watershed, has been contributing effectively since 2006 with no maintenance. This is due to the superior quality of the structures. We envisage that these structures will continue to serve for more than 50 years. In addition, a number of low cost gully control structures were constructed along the first order streams, at upstream locations, which helped to trap silt and control land degradation. Concurrently it reduced the sedimentation load in middle and downstream check dams. The PS watershed, developed by ICRISAT-ICAR-CAFRI (2012-2016), was different from GKD in terms of land use, land cover and slope. PS has flat terrain, with less than 2-3% slope, and is largely dominated by agriculture (>90%). The major intervention here was the renovation of the defunct, traditional *haveli* system, in addition to the above mentioned structural innovations.

The following innovations were introduced in these pilot watersheds:

- The entire structure of traditional *haveli* were reinforced with new designs informed by both farmers and researchers. The principal aim was to meet rainfall, internal erosion, flood and burrowing challenges, and increase durability (section 4.1.2, Box 1)
- Check dam designs were improved to; stabilise structural strength, enhance the spillway, and prevent piping (due to seepage) around the structure.
- Collective farmer participation was fostered in the *haveli* renovation process, as submerged areas of the *haveli* belong to a number of farming families, and their consent for the renovation was important. Realizing the benefits of the *haveli* system, other farmers came forward to request renovation of other such structures for wider community benefit.

KISAN MITrA in Bundelkhand region under Doubling Farmers' Initiative

Recognising the benefits of AWM interventions, combined with best management practices, the Government of Uttar Pradesh asked ICRISAT to develop sites of learning by scaling these interventions and practices in all seven districts of Bundelkhand region. This program, which took place under the Doubling Farmers' Initiative, was called the Knowledge Intensive Sustainable Network Mission India for Transforming Agriculture (KISAN MITrA).

In May 2017, with the district administration's help (District Magistrate, Chief Development Officer, Joint Director of Agriculture, Deputy Director of Agriculture), pilot sites, covering areas of about 5000 ha area (hydrological boundary), in all seven districts were identified. Two to three villages were selected, for developing as a pilot site, in each district. The project aimed to reach 20,000 households, covering a total population of 100,000. Between May 2017 and June 2018, ICRISAT developed engagement partnerships with each community, with the help of local NGOs. Based on learning from the GKD and PS watersheds, during 2006-2016, scaling efforts were focussed on enabling water management needs to be combined with good agronomic practises in order to intensify rainfed agriculture. The process began with soil sample collection, analysis and a soil fertility management campaign. ICRISAT formed a consortium of national institutes; ICAR- CAFRI, Jhansi; ICAR-Indian Grassland and Fodder Research Institute (IGFRI), Jhansi; Banda University of Agriculture and Technology (BUAT), Banda; Bharatiya Agro Industries Foundation (BAIF) and local Bundelkhand region NGOs.

From June 2018 onwards, four principal interventions were promoted to raise awareness of the tested best prcatsies in waterharvesting and crop managemnt, and improve rainfed cropping areas:

- Water interventions: a plan for implementing AWM interventions (*in situ* and *ex situ*) was developed with the aim of renovating existing structures (*haveli* system) and developing new *in situ* and *ex situ* water harvesting structures. These interventions created about 500,000 m^3 of storage capacity, which would facilitate groundwater recharge in about 2500 acres.

- Soil interventions: a large scale, soil fertility management campaign was undertaken through wall writings and the distribution of soil health cards. 200-250 participatory farmer field demonstrations of balanced soil nutrient management were conducted. The focus was on addressing deficiencies in soil organic matter, and on restricting micro nutrients such as Zinc, Boron and Sulphur.

- Crop and agroforestry interventions were initiated in all seven pilot sites. Nearly 70,000 pits were excavated to plant teak, lemon, guava and other fruit saplings. Local ber trees were rejuvenated through budding in 228 farmers' fields. Improved crop cultivars of sesame, green gram, black gram, wheat, chickpea, field pea, mustard and barley were evaluated every cropping season, in over 2000 farmers' fields.

- Fodder and livestock interventions were initiated in all seven pilot sites. Sorted semen technology, with a higher probability of female calf birth, was introduced. This helped to address the stray cattle menace. Improved quality feed for small ruminants was introduced to ensure better health and reduce mortality rates. Green, leguminous fodder, as a balanced diet, was also promoted.

We anticipate that these best management practices may be scaled up throughout the Bundelkhand region, including Madhya Pradesh, as a number of high level policy makers have been keenly observing and reviewing these innovations. The government further validated the impact of these interventions, through external expert agencies, to verify them and to generate positive awareness of them within state machinery.

6. Data monitoring and impact analysis

Intensive data monitoring

Watersheds GKD and PS were subject to monitoring of various biophysical, hydrological, agronomic and socio-economic parameters, on both spatial and temporal scales, during the project period. This was done to better understand the process of rainfed landscape intensification, and implications for environmental and social sustainability. Water table depth was monitored in 676 dug wells (138 in GKD and 538 in PS - including some control watersheds) on a monthly time scale. This was conducted in order to understand the impact of various AWM interventions implemented during the project period. Surface runoff was monitored at selected locations using automatic gauging stations. Changes in land use, cropping patterns, and the cost of cultivation, were also measured using household surveys and remote sensing technologies.

Data collected from intensive monitoring will be used to; (i) generate evidence in order to understand key monitoring and impact indicators, which can be used by various stakeholders, including policy makers; (ii) understand the hydrological processes, land use changes and ecosystem trade-offs; (iii) refining interventions based on the actual field, and mesoscale, data base for similar agro-ecological regions (Garg et al., 2020, submitted).

Water balance analysis

Rainfall is the only source of water which is partitioned into various water balance components; surface runoff, groundwater recharge, evapotranspiration, and soil moisture changes (Figure 8). A large portion of rainfall is stored as soil moisture, which is utilized by plants and trees, or evaporates from the soil surface. After satisfying the root zone, excess water which infiltrates from surface soils percolates into groundwater aquifers. Various *in situ* and *ex situ* AWM interventions help to enhance soil moisture availability, and facilitate shallow (up to 10-15 meters) groundwater recharge. These interventions harvest a significant amount of surface runoff, both in time and space.

Surface runoff was directly measured from gauging stations in the watersheds. Groundwater recharge was estimated based on the water table fluctuation method (Sharda et al., 2006; Dewandel et al., 2010; Glendenning and Vervoort, 2010; Garg and Wani, 2013; Singh et al., 2014). Evapotranspiration was estimated using the one dimensional water balance model for different land uses (Singh et al., 2014).

Impact of AWM interventions

Impact on water balance components

Various AWM interventions have influenced watershed hydrology and provided the basis for turning this rainfed agro-ecological system into a more productive area, for the improved wellbeing of the communities living in them. Constructed water harvesting structures have harvested surface runoff, infiltrating water for soil moisture and shallow groundwater outtake. Figure 9 compares outflow generated from the GKD watershed, and a nearby control watershed, between 2006 and 2011. Data shows that surface runoff is increasing proportional to rainfall amount. No runoff was generated at 400mm or below. Nearly 80 to 150 mm of runoff is harvested by low cost water harvesting structures from year to year. Outflow was reduced by 50%, compared to a mere 10-20%, during normal and wet years (Figure 9). Figure 10 summarizes the water balance components, and other impact indicators, of the GKD and PS watersheds, along with respective nearby control watersheds. Water balance components, measured from treated and control watersheds in both the GKD and PS watersheds, show that the various *in situ* and *ex situ* water harvesting interventions have changed hydrological processes. A portion

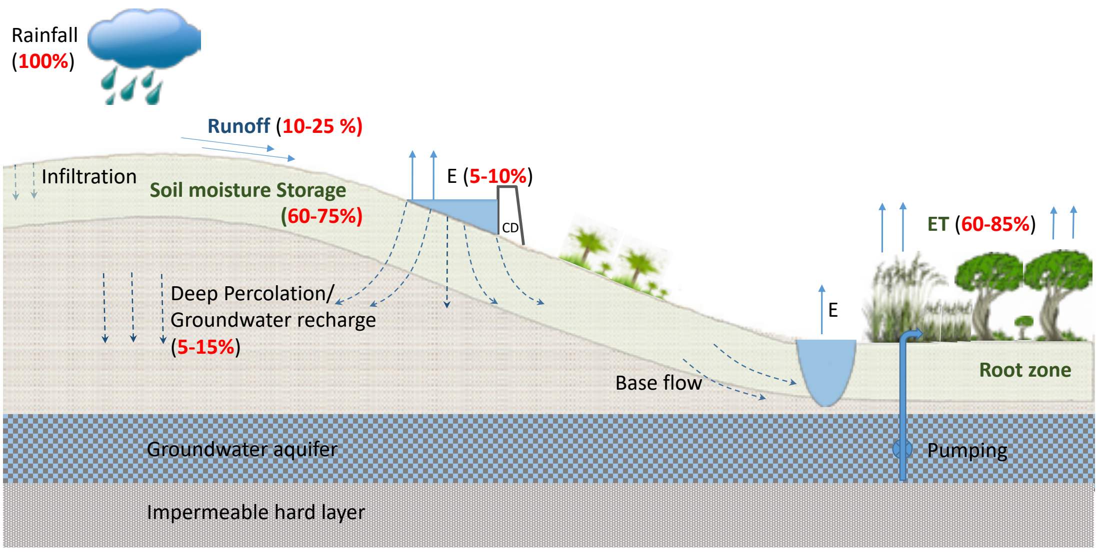

Figure 8: Hydrological processes of a mesoscale watershed in semi-arid tropics of Bundelkhand region (Source: Authors' own compilation based on primary data collection)

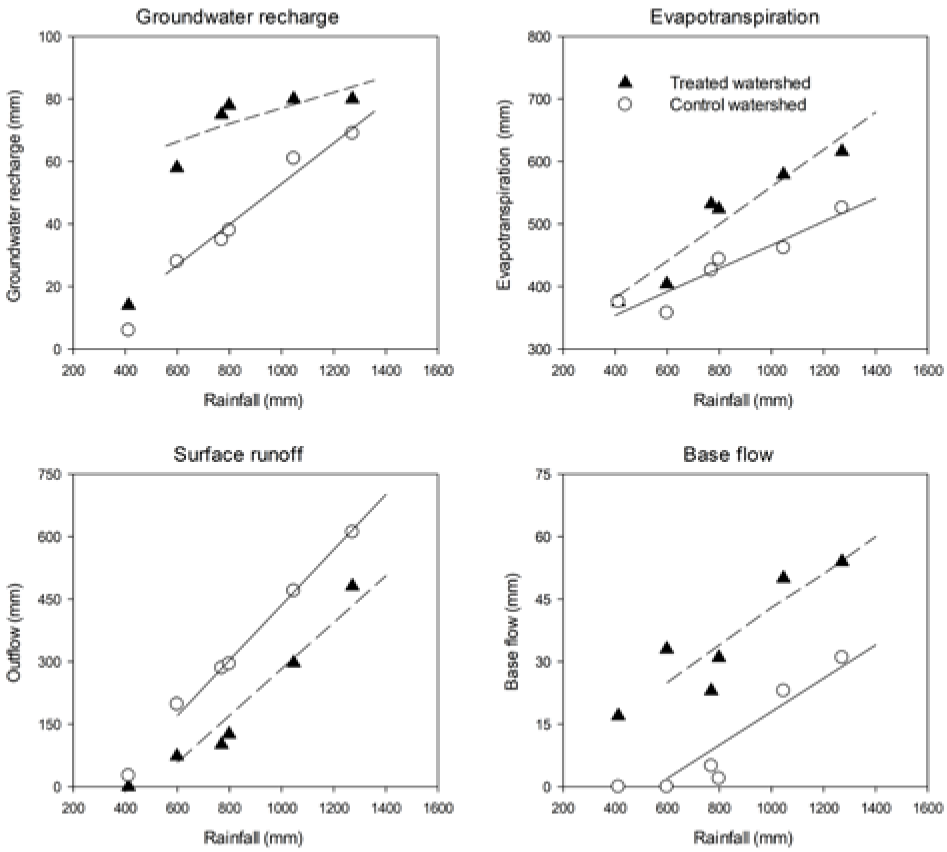

Figure 9: Comparing different water balance components of the GKD (treated), and nearby control, watersheds, between 2006 and 2011, on an annual basis. (Source: Singh et al, 2014)

of runoff, which was previously leaving the watershed, is now harvested as groundwater recharge and soil moisture.

For example, out of 850mm of rainfall in the GKD watershed, 34% (274mm) was generating runoff in the control watershed, whereas only 21% (164mm) generated runoff in the treated watershed. Groundwater recharge in the control watershed was 7% (59mm) vs 12% (96mm) in the treated watershed. Similar results were also found in the PS watershed (Figure 10). Notably, the number of days baseflow received increased from 35-42 days to 110-122 days, between the control and treated watersheds respectively.
The data also shows that the average annual soil loss has significantly reduced (2-3 times) due to various *in situ* and *ex situ* interventions. Increased groundwater availability is reflected not only in an enhanced groundwater table (2-2.5m additional pressure head), but also in the number of pumping hours (from 62-86 to 125-156 hours in the control and treated watersheds respectively). A higher number of wells are now yielding even in May, which is the hottest summer month (max temperature 42-470C) in the Bundelkhand region, improving temporal water security.
A fraction of the harvested runoff contributed to groundwater recharge. AWM interventions have made a significant impact during dry years. For example, recharge estimated in the treated watershed was 55mm, compared to 25mm in the control watershed, under 600mm rainfall conditions. Further, our analysis revealed that achieving 55mm groundwater recharge, under non-intervention conditions, required a minimum of 1000mm rainfall. The probability of receiving 1000mm of rainfall, or above, in this region is less than 30%. However, the probability of receiving 600mm of rainfall, and above, is more than 85%. Thus, AWM interventions have built drought mitigation resilience.

Increased shallow groundwater recharge also contributes to enhanced baseflow. Under control conditions, the amount of baseflow in various

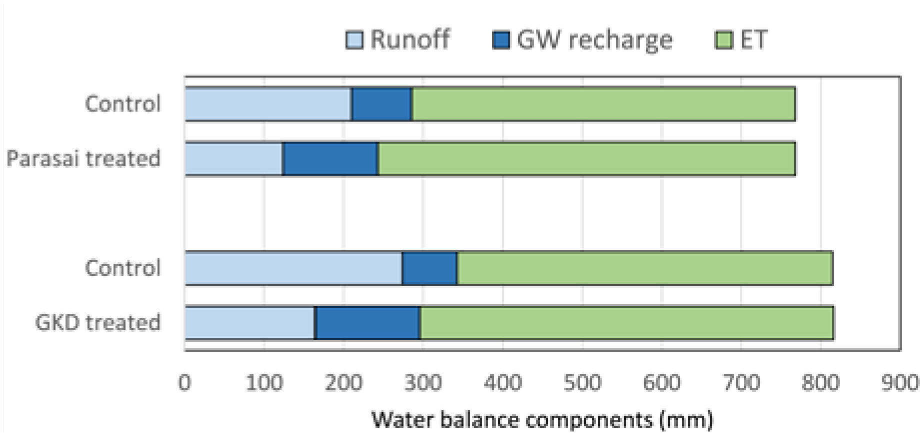

Figure 10: Water balance component of GKD (2006-2011) and PS (2012-2016) watersheds, and nearby control watersheds. (Source: Authors' own compilation based on primary data collection)

years was recorded as up to 30mm a year. Baseflow after AWM interventions increased by a minimum of 15 mm (Figure 9).

Groundwater table data, measured at GKD and a nearby control watershed for a selected year is shown along with received rainfall in Figure 11. The data is presented in terms of hydraulic head. An additional 1m head was found in dug wells of the GKD watershed throughout the year compared to the nearby control watershed, on an average basis (Figure 11). Figure 12 further shows the proportion of dug wells with different head levels in the treated and the control watersheds, before monsoon (mid-June), post monsoon (mid-October) and before the summer (mid-February). 30% of the wells were found to have less than 1m head pressure in the treated watershed, compared to 50% of wells in the control. Head pressures of 1-3m and 3-5m were found in 40% of wells in the treated watershed and 10% of wells in the control. 45% of wells had 1-3m, 20% of wells had 3-5m, and 5% of wells had >5m head pressure in the treated watershed before the onset of monsoon.

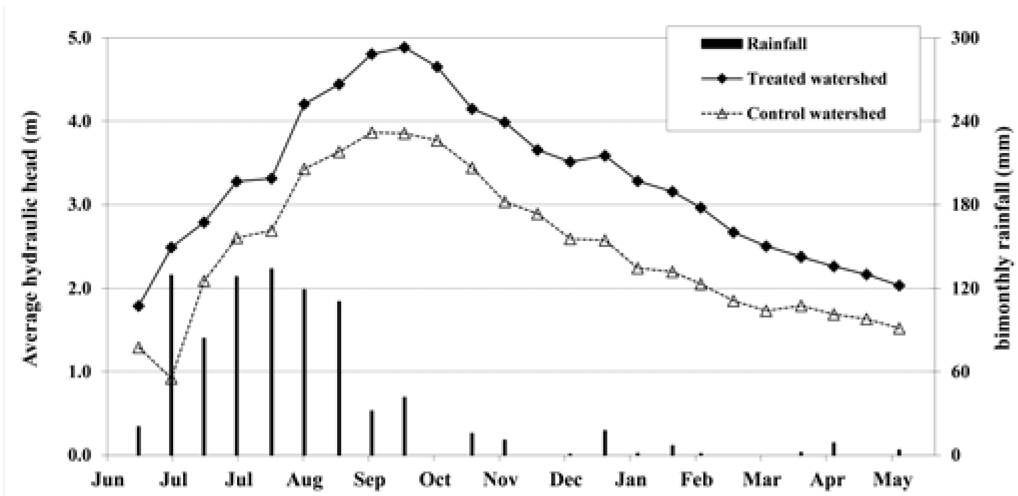

Figure 11: Average hydraulic head measured in dug wells on bimonthly scale in treated and nearby control watershed in GKD watershed ($n_{control}$=42; $n_{treated}$= 96) (Source: Authors' own compilation based on primary data collection)

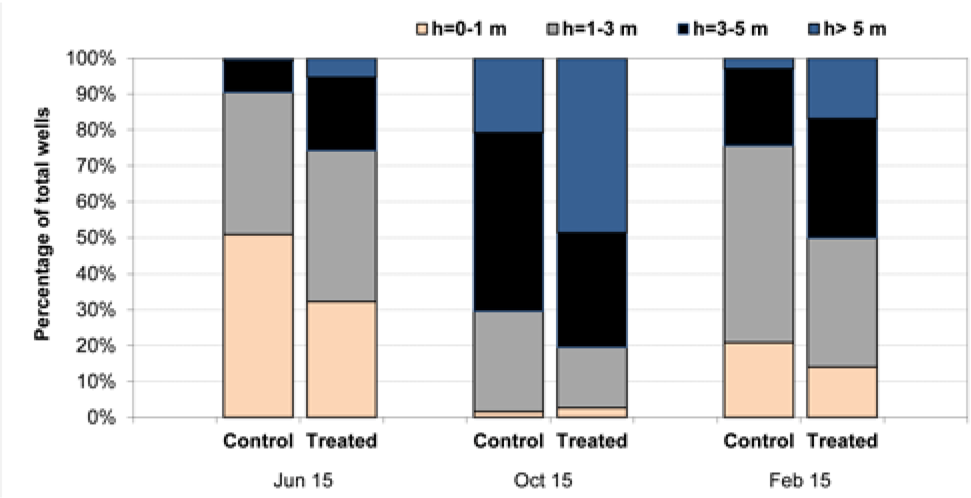

Figure 12: Status of hydraulic head in wells ($n_{control}$=42; $n_{treated}$ = 96) in different seasons, in treated and nearby control, watersheds in the GKD watershed (Source: Authors' own compilation based on primary data collection)

AWM interventions made a significant change in head pressure status in treated watersheds, as 50% of wells were found to have a head pressure of more than 5m, compared to only 20% of wells with a similar status in the control watershed, inthe month of October. Nearly 50% wells were found with head pressure of 3-5m or > 5m in the treated watershed by the end of February, compared to only 25% wells of similar head status in control watershed (Figure 12).

Crop intensification, productivity and income

With increased groundwater availability, a large amount of fallow land was converted to cultivation in the GKD watershed (Figure 13). Before these interventions, farmers left about 30% of agricultural land fallow due to water scarcity. The major of crops cultivated before the

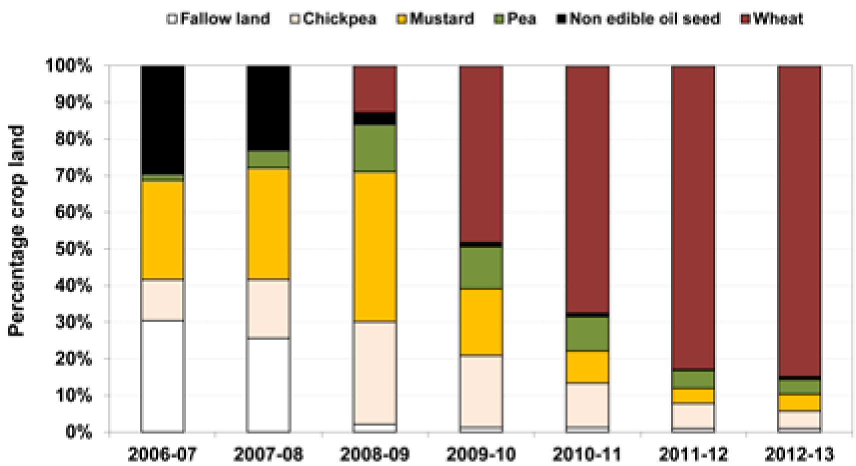

Figure 13: Change in cropping patterns in the GKD watershed, between 2006-07 and 2012-13 (Source: Authors' own compilation based on primary data collection)

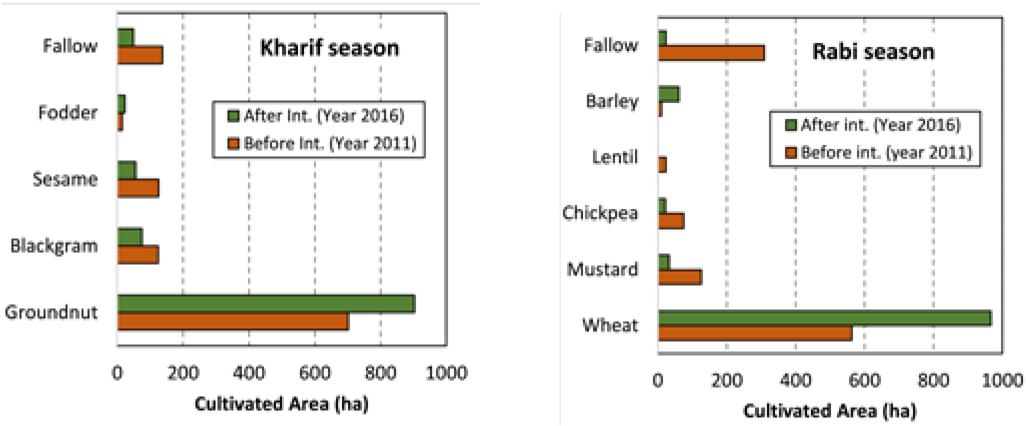

Figure 14: Change in cropped area cultivated before, and after, the watershed interventions in the PS watershed (Source: Authors' own compilation based on primary data collection)

interventions were mustard, field pea, chickpea and other non-edible oilseeds, which were largely grown under rainfed conditions, and one or two with supplemental irrigation. With increased groundwater availability, farmers shifted their crop types from low water consuming to moderately water intensive crops, such as wheat. This requires 3-4 events of supplemental irrigation to support crop development, given this has higher economic returns to the farmer, even when including the labour cost. More than 80% of total cultivable areas shifted to the cultivation of wheat, and the other 20% to other crops. This also increased dry fodder availability, supporting livestock populations.

The water harvesting interventions and productivity enhancement activities implemented in the PS watershed had a significant impact on water resource availability, incomes and farmer livelihoods. Water was no longer a scarce commodity. There was a surplus of both surface and groundwater, even at the end of summer. Hydrological monitoring showed that a minimum of 250,000m^3 of water was harvested in storage structures, which enhanced groundwater levels by 2-5m, with an average of 2.5m compared to the baseline. These rainfed system interventions have significantly changed cropping patterns in both the *Kharif* and *Rabi* seasons (Figure 14).

With increased water availability, the cost of cultivation, especially of wheat and barley, has fallen. Prior to the project interventions, farmers would engage hired or family labour for irrigation due to the poor availability and low levels of

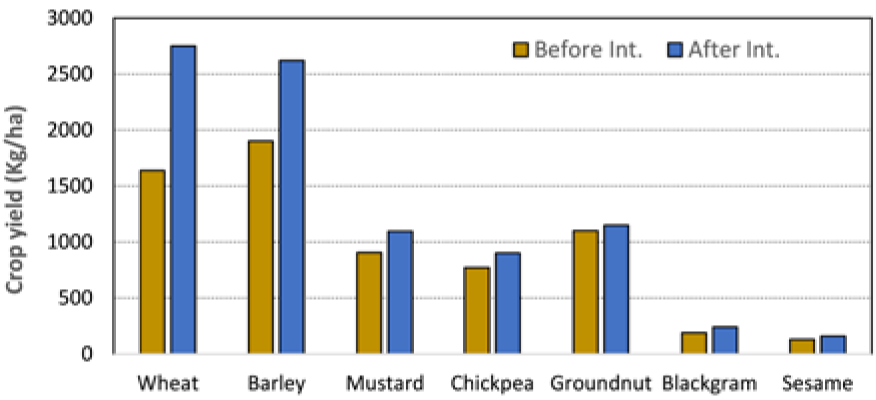

Figure 15: A comparison of the yields of different Kharif and Rabi crops before and after watershed interventions (Source: Authors' own compilation based on primary data collection)

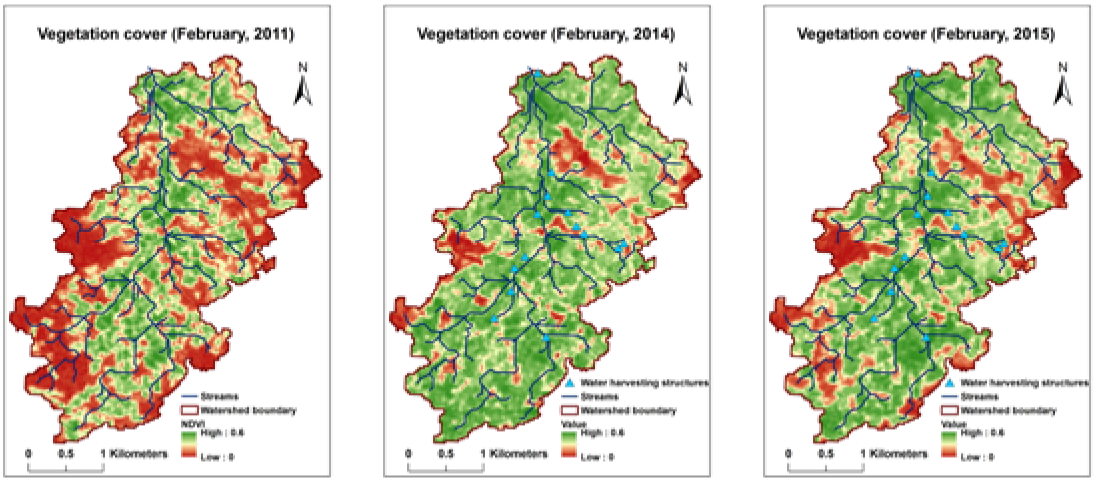

Figure 16: NDVI mapping from remote sensing in February shows Rabi crop areas in the PS watershed before (2011), and after (2014 and 2015), the interventions. Rainfall: 2010-11: 1190 mm; 2013-14: 1270 mm; 2014-15: 520 mm. (Source: Authors' own compilation based on remote sensing analysis)

groundwater needing high labour input. Water in open wells would become depleted within 2-3 hours of pumping. Project interventions saw a 2-5m increase in the water table in open wells, helping farmers complete irrigation quicker as they could pump water for 8-10 hours per day, thereby enhancing labour-use efficiency. By introducing improved cultivars and management practices, wheat yields increased from 1.7 t ha^{-1} to 2.7 t ha^{-1} (Figure 15), compounding net profit from agricultural production significantly. Wheat is a staple food for the majority of the population in Bundelkhand region. Increased wheat production not only enhances net household income, but also addresses household food insecurity. Yield and household data collected from the pilot villages clearly demonstrated that the agriculture sector alone contributed to enhancing net incomes, from 0.41 million USD y^{-1} to 1.14 million USD $year^{-1}$ across the entire watershed (Table 4). This increased net income strengthens the socio-economic and nutritional security status of households.

Table 4: Project impact on average household incomes before and after interventions. (Source: Authors' own compilation based on primary data collection.)

Description	**Before**	**After**
Kharif area under cultivation (ha)	968	1057
Net income generated in *Kharif* (in million USD)	0.26	0.38
Rabi area under cultivation (ha)	797	1083
Net income generated in *Rabi* (in million USD)	**0.0**	**0.35**
Total net income from agriculture (in million USD)	0.26	0.73
Buffalo population	950	1300
Average milk yield (L/day/animal)	6	8.5
Annual income from livestock (in million USD)	**0.19**	**0.40**
Total net income (in million USD $year^{-1}$)	**0.45**	**1.14**
Number of households	417	417
Average household income (USD $year^{-1}$)	**1075**	**2725**

Note: Net income is derived by deducting cost of cultivation from gross income. Cost of cultivation includes input costs, as well as family and hired labour charges.

Normalized Difference Vegetation Index (NDVI) mapping from remote sensing in February shows Rabi crop areas in the PS watershed before (2010-11) and after (2013-14 and 2014-15) the interventions. With increased groundwater availability, a significant amount of fallow land was converted into agricultural use, which made a significant contribution to total production and incomes, by restoring the production capacity of fallow land and increasing crop productivity, (Figure 16).

The AWM interventions also improved fodder and livestock productivity as biomass was enhanced, and fodder became more available. The number of buffaloes in project villages increased from 950 to 1,300, with increased milk productivity of 2-3 l d^{-1} animal $^{-1}$. Livestock-based incomes increased from USD 0.19 million $year^{-1}$ to USD 0.40 million y^{-1}, a gain of USD 0.21 million $year^{-1}$. Altogether, average household income in the PS watershed increased from USD 1075 to USD 2725 hh^{-1} $year^{-1}$, clearly indicating the co-benefits that interventions in Bundelkhand region present (enabling a doubling of farmer incomes) (Table 4). The interventions also enhanced ecosystem services; greater greenery, more tree biomass, reduced soil erosion, and carbon sequestration. Drudgery and migration levels fell significantly in the pilot villages, with increased availability of water for agriculture and livelihood opportunities.

Empowering young professionals

It is important to develop human resources skills, including those of rural youth. This initiative recognized the opportunity to involve local youth, as young professionals working for the project and acting as ambassadors of the best management practices (BMPs) in their respective locations. These young professionals acted as catalysts, ensuring the participation of a large number of beneficiaries. In addition, the BMPs have been demonstrated in a large number of farmer fields, which has addressed two important issues: (i) building the capacity of individual farmers, (ii) dissemination of BMPs to fellow farmers with a view to scaling up. For example, laser land leveling work was initially demonstrated in a few farmer fields, after realizing the benefits (improved irrigation efficiency and reduced labour cost for irrigation application) more farmers came forward to adopt the technology. Further, a few young farmers were willing to offer this intervention as a business opportunity in which they could be service providers. We chose one or two masons from Bundelkhand districts and helped them to work at Jhansi (one of the pilot sites), in order to enhance the skills of masons to expedite scaling up. They were given hands-on training on how to construct check dams: excavation, reducing the width of the foundation, placing iron bars, constructing various components of rainwater harvesting structures, avoiding preferential flow in varied situations, and the quality of materials required. 15 masons were trained in April 2019 at Jhansi and then deputed to their respective districts to undertake water harvesting activities. Regular follow-ups and guidance were provided by the CAFRI and ICRISAT teams.

Bridging yield gaps through best management practices

A stratified soil sampling method (~25-30 ha/sample) was used to collect 1219 geo-referenced soil samples from 20 pilot villages across seven districts during March-May 2018. Analysis of the soil test results shows that farmer fields are degraded in terms of soil organic carbon (SOC) and key nutrients such as nitrogen (N), phosphorous (P), potassium (K), boron, zinc, iron and sulphur as well as pH. Low SOC levels also indicate N deficiency. Deficiencies were observed, in available P mainly in four districts, and of K in two districts. Bearing these results in mind, the cost of phosphatic and potash fertilizers can be optimized. However, there was also widespread deficiency in micro nutrients: sulphur (60-97%), zinc (27-95%), boron (12-76%), and iron (1-59%). Farmers were not aware of micronutrient deficiencies and do not replenish these nutrients. This poses a challenge in terms of realizing productivity potential.

Results from the soil health tests were shared with various stakeholders (farmers and government officers) at formal and informal meetings and

Table 5: Average crop yields (kg ha^{-1}) in various districts during the Rabi season 2018-19. Figures in parentheses are the number of crop cutting experiments undertaken (Source: Authors' own compilation based on primary data collection)

District	Chickpea	Field peas	Mustard	Wheat
Hamirpur	1900 (10)	2475 (09)	1500 (11)	3400 (11)
Banda	1230 (16)	-	1560 (16)	4150 (17)
Jalaun	2745 (8)	3150 (12)	2510 (10)	3400 (12)
Jhansi	2060 (20)	1470 (5)	710 (8)	4100 (19)
Lalitpur	1835 (11)	2100 (9)	1400 (9)	3930 (11)
Mahoba	1260 (10)	2200 (5)	1000 (8)	4400 (25)
Chitrakoot	2020 (20)	-	1400 (6)	3950 (39)

workshops. Soil health cards showing soil nutrient status and new improved, site specific fertilizer recommendations were distributed. Block-specific information on nutrient status, and fertilizer recommendations, were summarized in public displays of wall writings for wider dissemination.

Nearly 1000 farmer participatory field demonstrations were undertaken on balanced fertilizer application and improved crop cultivars of chickpea, field peas, mustard and wheat were undertaken in Bundelkhand districts during the Rabi season of 2018-19. To evaluate both the performance of different crop cultivars and the impact of best management practices, 337 crop cutting experiments were undertaken in seven districts.

Large yield variations were observed among the pilot sites (Table 5). The highest yields were obtained in chickpea (2745 kg ha^{-1}), field peas (3150 kg ha^{-1}) and mustard (2510 kg ha^{-1}) in Jalaun district. Chickpea recorded the lowest yield in Banda (1230 kg ha^{-1}) and Mahoba (1260 kg ha^{-1}). The lowest mustard yields were recorded in Jhansi and Mahoba. Degraded, shallow soils with poor water holding capacity was the main reason for low yields. Wheat is largely cultivated in a groundwater irrigated system, and grain yields

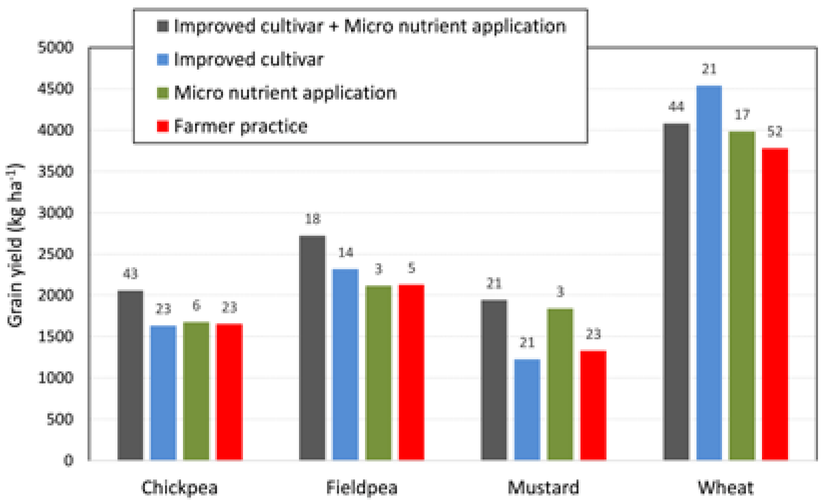

Figure 17: Impact of improved crop cultivars and micronutrient application compared to farmer practices on different Rabi crops (data compiled from all the seven districts of Bundelkhand). Values above the bars denote the number of crop cutting experiments undertaken (Source: Authors' own compilation based on primary data collection)

ranged between 3450 kg ha^{-1} and 4450 kg ha^{-1} (Table 5).

Results of crop cutting experiments were further analyzed to ascertain the performance of different cultivars. A comparison of the performance of improved chickpea cultivars JG-11 and JG-14 and local cultivars showed a superior performance of the former in most districts. JG-14 was found superior, between 250-1000 kg ha^{-1} additional gain was recorded with this cultivar in most of the districts.
Performance of JG-11 was found to be better in Lalitpur, with 500 kg ha^{-1} additional yield compared to the local cultivar. Performance of field peas (Prakash variety) appreciated in all seven districts, with nearly 500 kg ha^{-1} on average additional yield recorded in the pilot sites of Hamirpur and Jalaun districts.

Improved mustard variety Rohani gave the highest yield over local cultivars in Jalaun (>3000 kg ha^{-1} vs 1900 kg ha^{-1}). Performance of Rohani in Hamirpur, Mahoba, Lalitpur and Jhansi was found to be close to the existing cultivar. Whereas in other districts (Jalaun, Banda and Chitrakoot), yield gain from Rohani ranged from 125 kg ha^{-1} to 750 kg ha^{-1}, compared to existing cultivars.

Crop cutting experiment results were further analysed across four categories: (i) improved cultivar and micronutrient application, (ii) only improved cultivar, (iii) only micronutrient application, and (iv) farmer's practice (control) (Figure 17). Grain yields from treated fields were higher than that from the control. The highest yield gain in chickpea, field peas and mustard was obtained with a combination of both improved cultivars and the application of micronutrients.

The KISAN MITrA project has benefited about 15500 households directly so far. We categorized the various AWM interventions and BMPs into eight categories, as shown in Figure 18. In this initiative a comprehensive approach was followed to mitigate risks, build resilience and generate a number of ecosystem services to achieve sustainable livelihoods.

7. Drivers of change and scaling up AWM practices

The government of Uttar Pradesh and Madhya Pradesh have made huge investments in various risk mitigating strategies for rural farming communities to enhance food and water security through a range of schemes and programs. These have helped the region expand areas under irrigation, and crop intensification of rainfed areas, as well as reducing the risk of crop failure. However, a large part of the region is still suffering from water scarcity, land degradation and poverty.

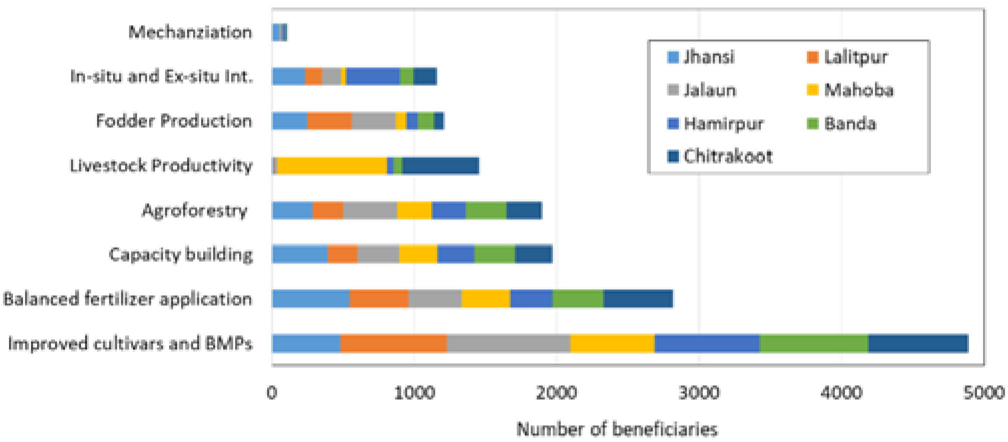

Figure 18: Distribution of beneficiaries by project intervention (May 2017 - December 2019) in KISAN MITrA project, Bundelkhand region (Source: Authors' own compilation based on primary data collection)

This therefore requires holistic, science-led solutions to mitigate risks and ensure scaling up and sustainability. Below are the drivers of change, which indicate pathways to create large-scale, system level impact.

Multi-institutional consortium

As watershed management requires multi-disciplinary expertise, a team of researchers (hydrology, engineers, soil scientists, agronomists, and GIS, socio-economic and gender experts) from ICAR-CAFRI was formed. They were involved in designing and implementing site specific interventions, with the help of local communities, in 2006 in the GKD watershed. Similarly, ICRISAT and ICAR-CAFRI formed a consortium to develop the PS watershed between 2012 and 2016. In the KISAN MITrA initiative, a multi-institutional consortium was formed, led by ICRISAT, to scale up a number of best management practices: rain water harvesting, agroforestry, productivity enhancement, mechanization, fodder production, livestock management and capacity building.

Institutional arrangements

To ensure the sustainability of interventions, community-based organizations such as village committees, self help groups, user groups and environmental clubs have been promoted in all project locations. The beneficiaries of the various interventions have been identified and intervention specific user groups were formed. To ensure effective management, these groups have been trained on the roles and responsibilities relating to maintenance of the intervention assets.

For example, farmers with block plantation of teak on field bunds have formed a user group and collect proportionate user fees for the maintenance of these trees. Similarly, village committees have been formed in all project locations. They decide on the sharing of inputs and also suggest suitable locations for various natural resource management interventions, on a year to year basis.

Promoting accountability, transparency, flexibility in operation and ownership among the community

The concept of a 'measurement book' (MB) is strictly followed. This helps to maintain accountability and transparency in the execution of engineering works. Payments are based on an actual MB, which is verified and vetted by project partners, field staff and venders. There is some flexibility in terms of planning, execution and expenditure. Normally government-led programs have predefined allocations for different components even at minor scale. However, in these projects researchers have had greater flexibility to adjust physical and financial targets as per the needs of the community. In addition, expenditure relating to a specified activity is only processed after completion.

Capacity building

Capacity building is an integral part of all these interventions. The capacity of farmers, project staff, and young professionals (including women), has been strengthened through participatory field demonstrations, field days and exposure visits. For example, both the PS and GKD watersheds have acted as sites of learning. More than 5000 farmers, policy makers and researchers have visited the watershed and learned the nuances of the interventions. During such visits, farmers themselves have shared their experiences and explained the innovation process followed in the watershed. They also highlighted the changes in their lifestyle before and after the interventions.

8. Conclusions

The Bundelkhand region of Central India has a number of challenges, however it holds many opportunities for sustainable crop intensification in the largely rainfed dominated landscape. To address both livelihood and environment goals in agricultural landscapes, this case study shows a successful approach to managing multiple interventions that can be achieved through partnership between farmers, researchers, government and private sector investors.

The traditional rainwater harvesting system was the lifeline of the Bundelkhand region. However, this has become defunct due to the failure of local institutions. Nonetheless this can be rejuvenated by following a hybrid approach, combining traditional knowledge with new innovations. Large areas of the Bundelkhand region are under permanent fallow, is waste land or has been degraded due to ravine formation. This land could be rejuvenated through various *in situ* interventions. Knowledge generating institutes, government agencies and private partners need to come together to harness such opportunities. A large number of farmers in the region are still using old cultivar varieties, which need to be replaced with climate-smart crop cultivars. International, national, state and local institutes and state agricultural universities need to work together with development agencies, policy makers and farming communities to screen and identify suitable crop cultivars specific to each district, and even further at smaller scales. Moreover, the large knowledge gaps that exist among village communities about beneficial approaches and technologies also hold huge opportunity.

The Government of India, and the state government, is placing large emphasis on developing village institutions such as self help groups, user groups and farmer producer organizations. These institutions require technical backstopping from knowledge generating institutes in order to achieve the desired goals. There is large scope for needs-based mechanization in the region. Technologies such as laser levelling, use of zero-tillage and other sowing, intercultural and harvesting instruments, need to be introduced, along with large scale capacity building of local youth for the effective utilization of available machinery. In addition to government agencies, the involvement of private partners and service providers, can bring further synergy towards achieving scaling up targets. Agroforestry is a sustainable solution to ensure long term sustainability, and strengthen ecosystem services (controlling land degradation and carbon sequestration), without compromising the production system. This case study identifies the pathways for adopting best management practices. Significant efforts are now required to scale up these interventions, across a larger area, in order to benefit those in similar agro-ecological regions.

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Acknowledgements

Authors gratefully acknowledges the financial support received from Government of Uttar Pradesh for implementing KISAN MITrA (Knowledge-based Integrated Sustainable Agriculture Network – Mission India for Transforming Agriculture) project in seven districts of Bundelkhand region of Uttar Pradesh state in Central India. Funding support received from CGIAR Research Program on Water Land and Ecosystem for monitoring data in Parasai-Sindh watershed of Jhansi district is highly appreciated. Authors also grateful to Swedish University of Agriculture Sciences (SLU), Uppsala, Sweden for facilitating the development of this case study.

Scaling-up water management interventions for rainfed agriculture in the Ethiopian Highlands: status, issues, and opportunities

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Summary

Ethiopia is the second most populous country in Africa with more than 110 million people. The capacity to feed its rapidly growing population largely depends on rainfed agricultural production systems, in a range of agro climatic regions from arid and semiarid lowlands to temperate highlands. Agriculture is undermined by both severe land degradation and high inter- and intra-seasonal rainfall variability. As a result, the current average productivity of rainfed farming remains low (1.7 t ha^{-1} for pulses and 2.7 t ha^{-1} for cereals). This is despite a slow yield increase (e.g. about 1.5 t ha^{-1} for cereals and 1 t ha^{-1} for pulses) due to the introduction of new crop cultivars, fertilizers and management practices. Recognising the large yield gap in rainfed systems, the Ethiopian government has, since 1970, initiated a number of public welfare programs. These have involved various natural resource management programs with a special focus on agricultural water management (AWM) in Sustainable Land Management Projects (SLMP). SLMPs, centered around rainfed production systems, have been implemented to address land degradation, enhance crop and livestock productivity, and improve household incomes. Integrated resource management approaches have helped local communities obtain tangible benefits from AWM, and strengthened a number of ecosystem services, when compared to a sectoral approach. In the last 15 years, through SLMP 1 and 2, more than 2% of agricultural fields, and communal rainfed land, in Ethiopia, has been subject to AWM and sustainable land management. This has benefitted around 1.4 million households and supported environmental sustainability. Over 430,000 people have also benefited from related income generating activities. However, systematic data on various aspects of AWM is required to obtain a clear understanding of the overall impact of these interventions. This study proposes following a landscape approach, in order to realize the full potential of diverse AWM interventions, and a consortium approach to capacity building to achieve large scale, system level outcomes.

1. Introduction

Food and water insecurity and land degradation are some of the major challenges of the 21st century. Land degradation affects about 30% of total global land area, and around three billion people reside on degraded land (Nkonya et al., 2016). Ethiopia, the second most populous country in Africa with a population of 110 million, is affected by land degradation (Gashaw et al., 2014; Abera et al., 2019). A rapidly growing population, inappropriate land management, rigid land tenure, along with industrialization and urbanization have significantly impacted land use patterns. Endowed with abundant natural resources, Ethiopia has one of the most diverse agro-ecological configurations in the world. With 74.3 million hectares of arable land, spread over 18 major agro-ecological zones at altitudes ranging from 148 meters to 4,620 meters above sea level, the country's diversity makes it suitable for growing a wide range of crops (ATA, 2019). Around 80% of the population of Ethiopia live in rural areas. Agriculture is the dominant economic sector, accounting for 35% of Gross Domestic Product (GDP), 65% of employment, and over 80% of the country's export value (World Bank, 2019; Central Statistics Agency, 2018).

Ethiopia has serious land degradation challenges due to anthropogenic activities. As more forested and protected areas have been converted to crop and grass land, there has been a significant decline in the ecosystem services these provide. Per household land holding size has also been decreasing. The landscape of Ethiopia has been transformed through this land use change (Kassawmar et al., 2018). Soil losses of around 3-85 t ha^{-1} $year^{-1}$, and as high as 300 t ha^{-1} $year^{-1}$, have been reported (Gashaw et al., 2014; GIZ, 2015; Hurni et al., 2015). The annual cost of land degradation, associated with land use and land cover change, is estimated to be around $4.3 billion (Gebreselassie et al., 2016). Cultivated land is more vulnerable to soil losses, ranging from 50-180 t ha^{-1} $year^{-1}$, due to various tillage approaches and the often steep slopes (Shiferaw and Holden, 1999; Adimassu et al., 2002). This has resulted in nutrient losses of 10-120 kg ha^{-1} $year^{-1}$, siltation of downstream reservoirs, and productivity losses in the uplands (Adimassu et al., 2002; Gebrehiwot et al., 2013). For example, heavy soil erosion (380 million tons annually) from upland areas of the Upper Blue Nile basin have caused serious siltation at the Great Ethiopian Renaissance Dam reservoir, reducing its live storage capacity (Hurni et al., 2015). The substantial loss of highly fertile top soil affects rainfed systems, further reducing production capacity, as soil nutrients and organic matter are lost. Rainfall in Ethiopia is characterized by high spatial variability, from 400 mm in the Somali region to 2300 mm in the Benishangul-gumuz region (Gummadi et al., 2017), with large year to year variability (Alhamshry et al., 2020). Except for a tendency towards increased main season rainfall (JJAS) in some parts of north eastern and south western Ethiopia (Gebrechorkos et al., 2019), rainfall analysis does not currently indicate any other significant trend. The large year to year rainfall varaibility may bring more uncertainty in terms of water resource availability, and the frequency of droughts or flood events. Maintaining and increasing rainfed production under changing rainfall patterns is therefore a critical priority, alongside the urgent need to reverse land degradation and rebuild soil health.

Despite rapid economic development in the last two decades, poverty and food insecurity have remained serious challenges. In response, the Government of Ethiopia (GoE) implemented structural transformation through two phases of its Growth and Transformation Plan (GTP). GTP-I (2010-2015) targeted Ethiopia's long-term goal of becoming a middle-income country by 2025. Ethiopia achieved a growth rate goal of 10% per year during this period, which was close to its goal of at least 11%. Achievements and implementation lessons from GTP-I informed the formulation of the Second Growth and Transformation Plan (GTP-II), implemented 2016-2020.

GTP-II priorities for natural resource management capitalized on initiatives in the Climate-Resilient Green Economy (CRGE) Strategy, launched by the GoE in 2011. These seek to concurrently foster economic development and growth, reductions in greenhouse gas emissions, and improved climate change resilience. A major investment area of both GTP-I and GTP-II was

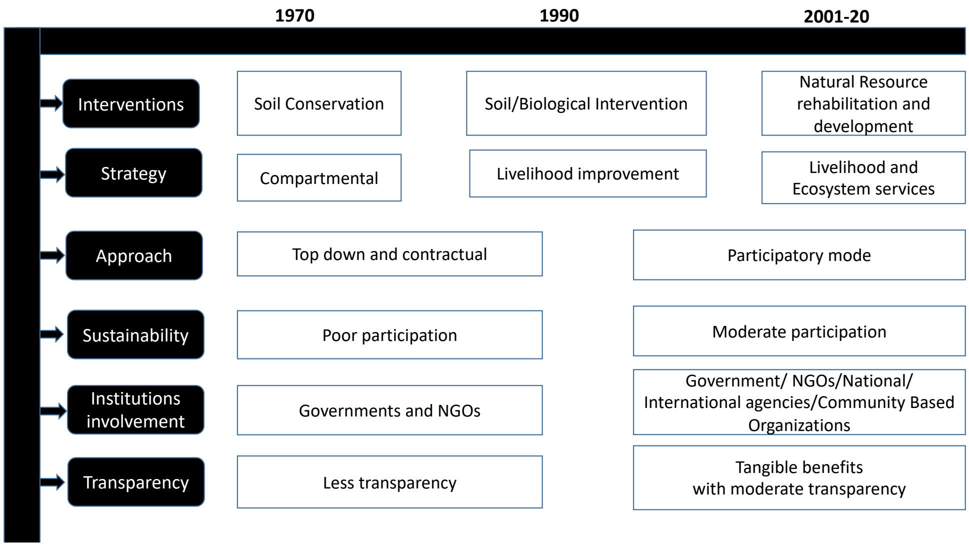

Figure 1: Journey of the Ethiopian land restoration program since 1970s onwards.
Source: Authors' elaborations based on literature review.

in tackling land degradation and the rehabilitation of watersheds and degraded landscapes. The GoE has attempted to address land degradation through various soil and water conservation measures (Figure 1), investing around US$8 billion since the 1970s (Figure 2) (Adimassu et al., 2018; Nedessa and Wickrema, 2010). Ethiopia, and its development partners, have invested more in improving water and land management than any other country in Africa (Merrey and Gebreselasse, 2011).

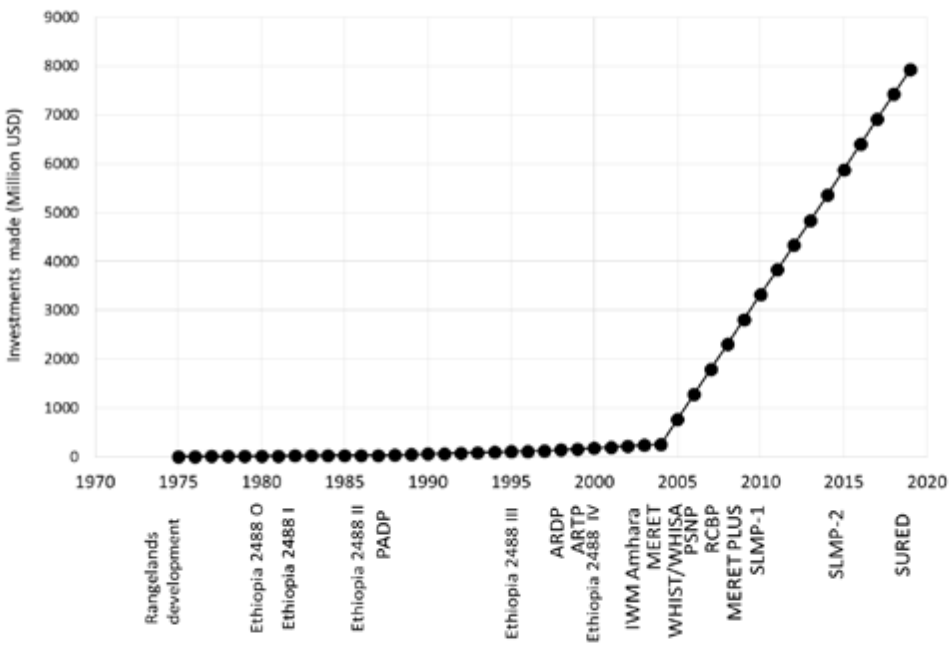

Figure 2: Investment made in key agricultural water management programs in Ethiopia from 1975 to till date. (Adimassu et al., 2018; Nedessa and Wickrema, 2010)
Note: Due to lack of information, small grants from locally operating NGOs and contributions from the community is not included in this calculation of investment.

The Sustainable Land Management Program (SLMP), a flagship program of the Ministry of Agriculture, was designed under the long-term (2009-2023) Ethiopian Strategic Investment Framework (ESIF) for Sustainable Land Management. SLMP was implemented in two phases; SLMP-1 (2009-2013) and SLMP-2 (2014-2019). SLMP-1 focused on sustainable land management (SLM) practices in 45 pilot watersheds, in six regions; Amhara, Tigray, Oromia, SNNP, Gambella, and Benishangul Gumuz. During SLMP-2 this was extended to 135 major watersheds, including the first 45 of SLMP-1 (Center for Development Research, 2019; Water and Land Resource Centre, 2018). The GoE and various development partners including; *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ), the World Food Programme, the African Highlands Initiative, Menschen für Menschen, Save the Children, Catholic Relief Services and many others have invested in watershed management.

This case study focuses on assembling and synthesizing existing information on land and water management for scaling-up AWM interventions in the Ethiopian Highlands. This study describes the national program of SLM, which is the main national initiative to address production capacity in the predominantly rainfed, agricultural production systems of Ethiopia. The main objective is to distil lessons to inform policy. This study also examines the current status of watershed interventions of various initiatives to assess their impact and scope for improvement.

Evolution of approaches in agricultural water management

Ethiopia is a particularly diverse country in terms of agro-ecology, range of elevations, farming systems, landscapes and production systems. All of these aspects affect the natural resources base, in particular the quantity and distribution of agricultural water resources. Land degradation in these diverse systems may require a range of management solutions. Raising awareness and mobilizing communities are the key to rehabilitating degraded landscapes in Ethiopia (Amede, 2003).

During the evolving journey of land restoration in Ethiopia, a number of technologies and practices have been adopted by smallholder farmers. This includes a range of soil and water conservation practices, *in situ* interventions (bunding, terracing, pits, diversion drainage ditches, conservation agriculture practices) and *ex situ* interventions (check dams, cut-off drains, and various gully control structures), together with biological interventions (tree planting, agroforestry, silvi pasture). *In situ* interventions harvest surface runoff locally in the field, enhance soil moisture availability, and control soil erosion. *Ex situ* interventions harvest a significant amount of surface runoff, and control land degradation, mostly in stream networks. Agroforestry interventions strengthen *in situ* interventions and address short and long-term productivity goals.

During the initial phase of the land restoration program, in the 1980s, the Ministry of Agriculture and World Food Program (WFP), with technical support from the Food and Agriculture Organization of the United Nations (FAO), implemented a development project named: Rehabilitation of Forest, Grazing and Agricultural Lands (Project 2488). The predominant focus was on physical soil conservation practices (Table 1). A top-down, contractual approach was followed, which resulted in less planning and execution process transparency. In the 1990s, during the next phase of the land restoration program, the focus was also on agriculture development through the introduction of the Peasant Agricultural Development Program, along with later phases of the Rehabilitation of Forest, Grazing and Agricultural Lands project. The primary objectives of the project were to increase; the production of food grains, soil productivity, and the incomes of rural, smallholder farmers. Over its five phase, 20-year lifespan, efforts made through Project 2488 have been successful in afforestation, addressing feed and fodder availability, soil and water conservation, and agricultural productivity through landscape treatment (Nedessa and Wickrema, 2010). Consequently, it laid the foundation for the Managing Environmental Resources to Enable Transition (MERET) program. From 2000, many more integrated natural resource management programs were initiated to strengthen institutional capacity, address poor productivity, and improve livelihoods, by introducing a holistic approach. This has ensured improved participation and tangible stakeholder benefits. These programs were supported by multiple donor agencies, as well as by national and international agencies (Table 1). Building on initial pilots, GoE and WFP merged farmer priorities with technical specifications for watershed and farm (field) soil management in rainfed production systems. The result was the Local Level Participatory Planning Approach which developed into the MERET program, under the auspices of the Productive Safety Net Program (PSNP) (Tongul and Hobson, 2013). PSNP was implemented by GoE, with assistance from development partners. The program has been widely studied and found to have positively impacted food-insecure households (Weltejii et al., 2017; Rashid et al., 2013). Households that received technology

Table 1: A snapshot of projects and programs related to sustainable land management activities in Ethiopia.

Time period	Program	Donors
1975-1985	Rangelands Development Project	WB
1980-1982	Rehabilitation of Forest, Grazing and Agricultural Lands (Ethiopia 2488 original)	WFP, FAO
1982-1987	Ethiopia 2488/ Phase I	WFP, FAO
1988-1994	Ethiopia 2488/ Phase II	WFP, FAO
1995-1998	Ethiopia 2488/ Phase III	WFP, FAO
1999-2002	Ethiopia 2488/ Phase IV	WFP, FAO
2003-2006	MERET	WFP
2007-2011	MERET plus	WFP
1988-1997	Peasant Agricultural Development Program	WB
1997-2008	Sida-Amhara Rural Development Program	SIDA
1998-2005	Agricultural Research and Training Program (ARTP)	WB
2004-2009	Integrated Watershed Management in the Amhara Regional State	Government of the Netherlands
2005-2020	Productive Safety Net Program (PSNP)	Multilateral
2005-2011	Water Harvesting and Institutional Strengthening in Tigray (WHIST)	CIDA
2005-2011	Water Harvesting and Institutional Strengthening in Amhara (WHISA)	CIDA
2006-2012	Rural Capacity Building Project (RCBP)	WB
2008-2013	Sustainable Land Management Program (SLMP-1)	WB, GEF, GoE, FAO
2014-2019	Sustainable Land Management Program (SLMP-2)	WB, GEF, GoE, FAO, GIZ
2018-2020	Sustainable use of rehabilitated land for economic development (SURED)	GIZ, EU

(Adimassu et al., 2018; Nedessa and Wickrema, 2010)

Note: CIDA: Canadian International Development Agency; WB: The World Bank; GEF: Global Environment Facility; GoE: Government of Ethiopia; FAO: Food and Agriculture Organization of the United Nations; GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit; SIDA: Swedish International Development Cooperation Agency, WFP: World Food Program packages of agricultural support were found to more likely be food secure (Gilligan et al., 2009). In 2008, a major breakthrough came with the formulation of the Ethiopian Strategic Investment Framework for the Sustainable Land Management Program which aimed to guide government and civil society stakeholders towards promoting SLM planning and investments, to address linkages between poverty and land degradation (Merrey and Gebreselassie, 2011; Abera, 2019). Ethiopia's SLMP is designed to address concerns about the production capacity of rainfed cropland, including associated deforestation, with technical support from GIZ. SLMP contributes to mitigation of land degradation and improvement of crop productivity, in selected watersheds, of target regions of Ethiopia.

A large proportion of the population of Ethiopia is landless with limited, or no, participation in adoption of SLM measures. Previously there was little clarity in the land tenure system, whereby all land belongs to the government. Especially common land held unclear tenure arrangements. This hindered the participation of many land users. Recognizing this, GIZ together with the EU, initiated the Sustainable Use of Rehabilitated Land for Economic Development (SURED) project in 2018. The aim was to add value to rehabilitated land under SLMP through increased productivity and market linkages for products and services, from the restored landscapes.

2. National actions for rainfed intensification from farm to landscape

A strong foundation for the SLMP projects has been laid since 1970 through the legacy of good practices from successive projects, including two decades of actions through the Ethiopia 2488 project, and successor projects MERET and MERET PLUS (2003-2011) (Amede et al. 2007). The key common components of these projects have been:

i. selection and prioritization of watersheds;
ii. engaging local officials and negotiating with the community;
iii. inventory assessment and constraint and opportunity analyses;
iv. developing base and development maps;
v. identification and prioritization of innovations;
vi. implementation; and
vii. participatory monitoring and evaluation.

SLMP-1 (2008-2013) introduced SLM practices in selected areas through an integrated approach beyond individual farmers' fields. It helped to rehabilitate degraded land which had previously been stripped of its economic value and was considered unproductive. SLMP-1 supported a comprehensive, strategic approach to improved natural resource management over 190,000 ha, involving 98,000 rural households.

SLMP-2 (2014-2019), was based on the implementation experience and results of SLMP-1. SLMP-2 was implemented through three thematic components: (i) Integrated Watershed and Landscape Management; (ii) Institutional Strengthening, Capacity Development and Knowledge Management; and (iii) Rural Land Administration, Certification, and Land Use. SLMP is currently planning a rapid impact assessment of previous phases before it continues to the next phase, which is expected to be implemented up until 2023 (from personal discussion with project leader). A schematic description of the thematic components, interventions, outputs and impacts is given in Figure 3.

Working with principles of natural resource management for rainfed crop and pasture land

The major entry point in SLMP-2 was supporting farmers within the watershed boundary. It involved the adoption and scaling up of best-fit, sustainable land and water management technologies and practices by smallholder farmers in selected watersheds/woredas, on both private fields and community land. A total of 874,300 ha of land, across 135 watersheds (2.5% of the total crop and pasture land of Ethiopia), was planned to be convert to SLM practices by the end of

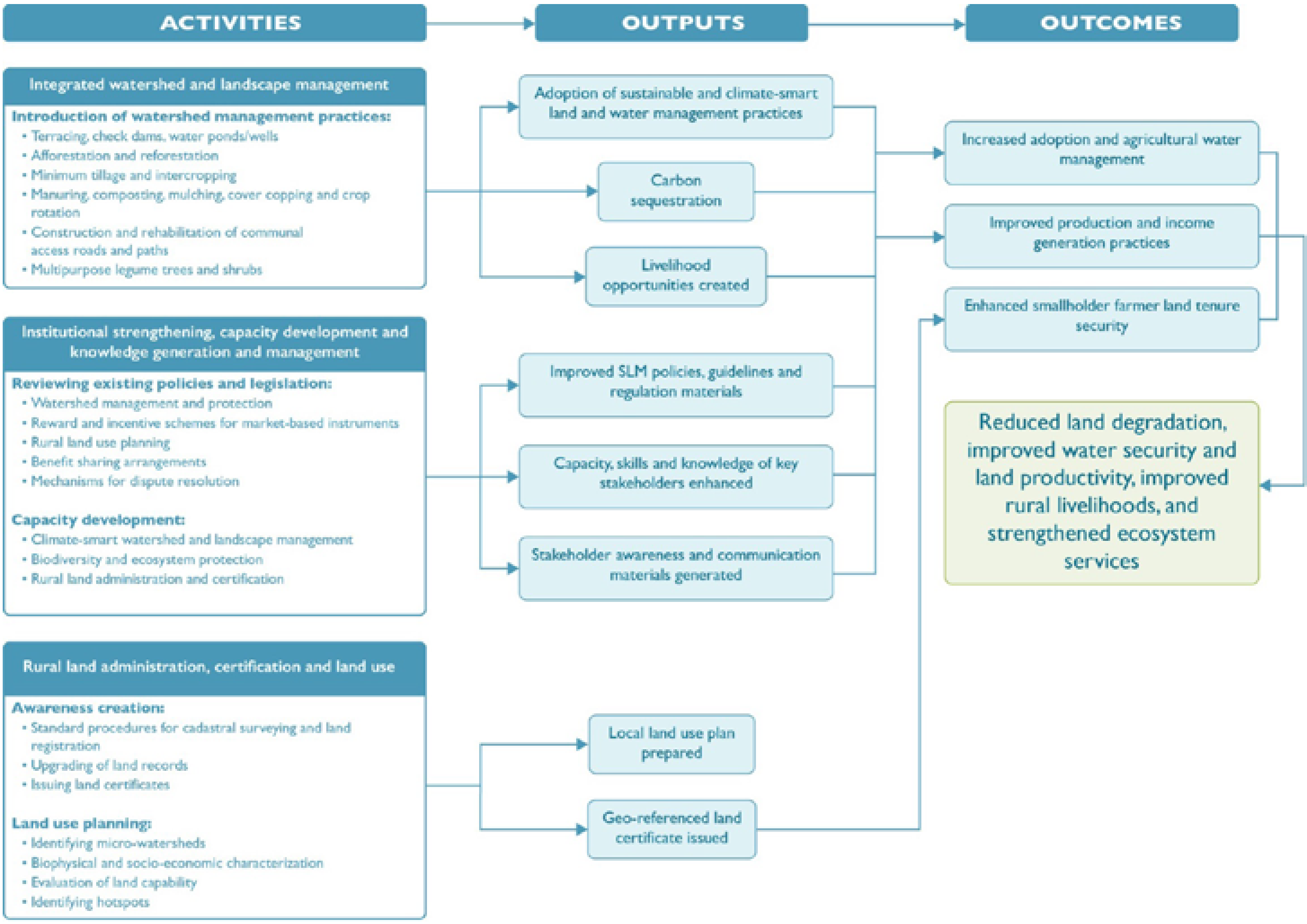

Figure 3: SLMP-1 (2008-2013) and SLMP-2 (2014-2019) theory of change (Source : World Bank, 2019; 2020)

SLMP-2. 98.5% of the plan was achieved through investments made to implement SLM on 861,400 ha. On the communal lands 665,500 ha was treated using various physical structures. Various biological, soil and water conservation (SWC) measures were implemented across 75,000 ha (80%) of hilly areas (Box 1). The project treated about 65% of the total 142,200 ha of degraded land reported in the baseline study of the 135 watersheds. Consequently, about 709,400 households, of which 202,000 (28%) were female headed households, benefited directly from physical and biological structures on communal land.

Landscape and community level interventions

Gully rehabilitation was an important intervention under SLMP. Around 5,500 ha of gully areas were treated using various measures including reshaping and biological re-vegetation. 3,000 ha of gully areas were restored and converted to productive land, equating to 74% of the total planned for. This investment benefited around 43,600 households directly (of which around 8,500 were female headed) by enabling the use of restored gulley areas for fodder and fruit production.

Box 1: Soil-water-biological practices

Soil and water conservation measures are helpful for arresting surface runoff, controlling soil ero-sion and land degradation. SWC along with biological interventions such as afforestation, agrofor-estry and fodder production, brings sustainability to the system. Field bunding, trenches, and ter-racing are important *in situ* interventions, whereas farm ponds and check dams, are important *ex situ* interventions. The photos below represent of some of these measures.

Source: Center for Development Research, 2019. Photo from 2019 trip and documentation.

SLMP-2 implemented community forest management activities based on a communal land use plan. This focused on improving existing forest management practices, promoting afforestation and reforestation activities, and measures to reduce forest degradation.

About 16,000 ha (82% of the target) was delineated as under existing community forest management. Community forest management benefited around 71,600 households through afforestation and reforestation on non-agricultural lands, 131% of the project target. Around 22% of these households were female headed. Nearly, 17,600 ha (99.7% of the target) were covered by bamboo. To support supply of sufficient planting materials, the SLMP invested in the establishment and management of 22,500 ha (99.5% of the planned target) of nursery sites across the SLMP watersheds of the six regional states. Some of the nurseries were managed centrally whereas others were managed individually or by a group. Around 384 million seedlings were grown in these nurseries, equating to 102.63% of the target. Community pastureland management was another landscape level SLMP intervention. From a total pastureland area of 5,600 ha in the project watersheds, 4,500 ha (80%) had been treated with both physical and biological measures as of September 2018. The treated pasture land area served over 345,000 livestock.
SLMP also invested in supporting community infrastructure developments. These included; water-harvesting structures, introduction of water lifting structures, and construction of diversion weirs, potable water supply schemes and community roads. The project developed 803 small-scale irrigation schemes, benefitting around 20,700 households (of which 17% were female headed). Construction of community roads improved access to 603 micro-watersheds, achieving about 98% of planned targets.

Farm/household level interventions

SWC measures on farmland, which can be considered good AWM practices, were a key investment area of SLMP interventions. During the project period, 137,200 ha of farmland was treated using physical SWC measures, of which 83,700 ha was also covered by biological SWC measures. A total of around 363,500 households benefited from this farmland treatment, accounting for 99% of the project target. This equates to 66% of the total number of households in the 135 watersheds. About 26% of beneficiaries were female headed households. The areas and beneficiaries of some selected interventions are presented in Table 2.

This project also implemented climate smart agriculture (CSA) activities, contributing to adaptation, mitigation and food security efforts. These are part of SLM technologies, with the potential to improve soil fertility and promote and

Table 2: Implementation of integrated watershed management interventions on selected land units

Particulars	Area (ha)	No. of households benefited
Communal land area covered by physical structures	95,460	740,800
Communal land area covered by biological measures	79,360	
Forest area demarcated	16000	71,600
Bamboo (natural + plantation)	27600	
Small scale irrigation	4730	20,700
Potable water	137,150	363,500
Conservation agriculture	37,200	150,600
Backyard livestock farming		63,800
Apiculture		10,800

Source: Center for Development Research, 2019

produce high value crops. These practices were implemented on 37,200 ha, benefitting around 150,600 households, 21% of which were female headed. Around 9,500 ha received other CSA measures, such as green manuring and cover crops, 56,600 ha received compost, and 7,300 ha were treated with agroforestry practices.
As part of good practices aimed at promoting the adoption, sustainability and resilience of SLM technologies, open grazing was controlled. To realize this, SLMP-2 invested in fodder/forage production, poultry promotion, as well as fattening and breed improvement activities. Consequently, 63,800 households benefited from improved backyard livestock management, 55,100 households applied a cut and carry feeding system, and 18,100 households were involved in livestock breed improvement. Female headed households benefiting from backyard livestock management accounted for 22.9% of the total. 19% of female headed households benefited from cut and carry feeding systems, and 23% from using improved livestock breeds.

Developing incentive systems, and integrating income generating strategies into natural resource management practices, are necessary to maintain commitment to SLM investments (Amede et al., 2007). Apiculture was promoted as an alternative income generating activity, benefitting several households. This benefited from watershed management interventions involving area closures, afforestation and enrichment plantation, among others. As a result of apiculture promotion in the 135 SLMP-2 watersheds, a total of 210 tons of honey and 12 tons of wax were produced. This benefitted 10,800 households, of which 19.7% were female headed.'

Rural land administration, certification and land use

Rural land administration and certification was implemented to enhance smallholder farmer tenure security in the project area. There is evidence that this 'first-stage' land registration has had a positive effect in terms of increased investment, land productivity and land rental market activities. The government has since initiated another round of land registration and certification that involves technically advanced land survey methods and computer registration (Bezu and Holden, 2014). An important incentive to increase farmer and landowner motivation to adopt sustainable land and water management practices in individual fields was to increase tenure security (Table 3). This increases farmer confidence to invest in long term solutions.

Table 3: Summary of land registration and certification achievements

No	Indicator/activity	Target	Achieved
1	Number of communal lands surveyed and mapped for certification	23,525	39,168
2	Number of certificates issued for communal land	19,996	21,277
3	Parcels of land surveyed and mapped for certification	1,917,325	1,695,636
4	Individual parcels surveyed and mapped for certification	1,893,800	1,656,468
5	Number of households issued with geo-referenced map-based certificate	473,450	410,205
6	Women who received 2nd level certificate Individually or jointly	340,088	287,144
7	Landless youth who have been issued a second level certificate	9,504	11,259
8	Landless female youth received land certificate	1,544	3,264

Source: Center for Development Research, 2019

Local level participatory land use plans were prepared in 545 kebeles[1] to ensure engagement and ownership. This also enabled the design of measures in a collaborative way, helping to ensure context specific implementation directly including the voice of farmers.

Project management and funding

As per the framework agreement for SLMP-2 implementation, the Ethiopian Government was responsible for ensuring that the project achieved its development objectives. The World Bank was required to make arrangements to ensure that loans and credit given were used only for the purposes for which they were intended. SLMP implemented a project management approach, that clearly set coordination, and monitoring and evaluation, processes, to achieve success.

SLMP-2 had a coordination structure, from federal to kebele level, following the structure of the government extension system. At the federal level, a national project coordination unit was established, composed of a multidisciplinary team (specialists in monitoring and evaluation, watershed management, land administration, safeguarding, infrastructure, procurement and finance), led by a national coordinator. A similar coordination setup was implemented, with key specialists, at regional level, and focal persons led coordination at woreda level. SLMP-2 had steering and technical committees at federal, regional, woreda, kebele and community levels, to facilitate and implement interventions.

Community participation was an important element of the design and implementation of SLMP (Amede et al., 2007). A household survey indicated that the majority of the community (69%) had participated in the SLM planning process, enabling them to prioritize their needs and interests (Center for Development Research, 2019). A total of 5,897 formal community-based institutions, self-help groups and associations were established, and made functional, across intervention areas. About 431,300 people participated in income-generating activities under the implementation process. Similarly, 399,735 households are reported to have used at least three SLM technology packages on individual household lands in 2017 and 2018, suggesting a good adoption rate (Center for Development Research, 2019). Various capacity building, training and experience sharing, visits were conducted. These targeted the various components of the project at different levels. These adoption rates, supported by the capacity building, are good indicators of sustainability.

SLMP-2 put in place a web-based monitoring and evaluation (M&E) system for management and documentation of project results, at all levels (community, kebele, woreda, region and federal). The system had a planning and reporting tool, as well as M&E elements. However, a major limitation was that no comprehensive benchmarking was conducted at the start of each phase of the project. Furthermore, most of the assessments and success stories were conducted based on stakeholder feedback, without any triangulation through objective measurement of the changes. Therefore, a critical impact assessment is required to support the M&E findings.

There are also difficulties in assessing the actual investments made in SLMP activities, and associated PSNP programs. Both public and donor funding contributes to several components in each of the different regions. In addition INGOs, and other research institute linked activities, for example CGIAR programs and bilateral initiatives such as the R4D partnership with the Netherlands, benefit (Schmidt and Tadesse, 2019). One estimate suggests that between 2009-2013, the World Bank, the Global Environment Facility, the Government of Ethiopia and FAO funded a total of at least US $37.79 million to implement SLMP-I. Whereas, between 2014 and 2019, a US $94.65 million investment was made in SLMP-2 by these same funders plus GIZ (Adimassu et al., 2018).

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[1] *kebeles: the smallest administrative unit in Ethiopia, that may contain several watersheds.*

3. Impact on agricultural production and various ecosystem services

Improving water security and productivity

SLMP-2 influenced agricultural production systems by enhancing infiltration upstream, and increasing water resource availability downstream, especially through groundwater recharge, and also strengthened various ecosystem services. Kato et al. (2019) studied the impacts of SLMP programs in Amhara regional. Assessment revealed that the program has: (i) helped adoption of various best management practices at the plot level; (ii) significantly increased plot-level adoption of SLM practices, particularly of soil bunds and stone terraces; (iii) contributed to improved water security for both crop and livestock production; (iv) provided households in SLM-supported learning watersheds with more access to groundwater for irrigation; and (v) increased income from livestock products, compared to households in control watersheds. The study attributed the positive impacts of SLM, and complementary interventions on livestock income, to three key factors. These are; improved water security conditions in the learning watersheds, access to better animal forage planted along SLM structures, and animal vaccination and artificial insemination services, which were part of the broader set of interventions.

However, the study only found statistically significant differences in crop yields between SLM supported learning watersheds, and non-SLM supported control watersheds, in three of the ten crops analyzed. Hence, to improve rainfed cropping and pastures, emerging evidence suggests that retaining rainfall and reducing sediment loss is not sufficient to enhance crop yields. Measures to combine rainfall infiltration with; specially improved soil nutrients (through building organic matter or using mineral fertilizers), the use of climate information and other agronomic best practices, are essential. This is supported by Adimassu et al. (2017), and further elaborated by Abera et al. (2019) (Figure 4) who demonstrated that only SWC combined with biological components (i.e. green or organic manure) result in increased yields.

Reducing soil erosion and increasing ecosystem services

A meta-analysis of ecosystem services (yield productivity, soil carbon sequestration, erosion and surface runoff reduction) in Ethiopia, was undertaken by Abera et al. (2019). This included 103 peer reviewed, published studies, representing a wide range of methodologies, approaches and scales. The analysis showed that the various AWM interventions applied in multiple locations under SLMP-1 and 2, reduced average surface runoff by between 40-90% compared to the non-intervention stage. However, large variability was observed due to the diversity of land uses, soil types and slopes. Average soil erosion rate was reduced with 50-70%, depending on type of intervention, compared to the non-intervention stage. Biological interventions, conservation agriculture practices, and controlled grazing helped enhance soil organic carbon from 20 to 140%, compared to the non-intervention stage. The study also showed that there was a slight reduction in crop productivity with the implementation of field bunds, or biological interventions, alone (Figure 4). Importantly, it concluded that so far the major emphasis of SLMP2 interventions had been on SWC structures, with less coverage and success through beneficial combinations of *in situ* SWC and biological interventions, which have the highest agricultural productivity gain. Recent evaluations and impact assessments, show that there is scope to improve efforts to intensify rainfed crop and pasture systems, within SLMP. This may be achieved through better targeted and integrated approaches to rainfall, soil, crop and agronomic management, including soil nutrient management both on farm and at the watershed scale, combined with new knowledge generation and dissemination approaches.

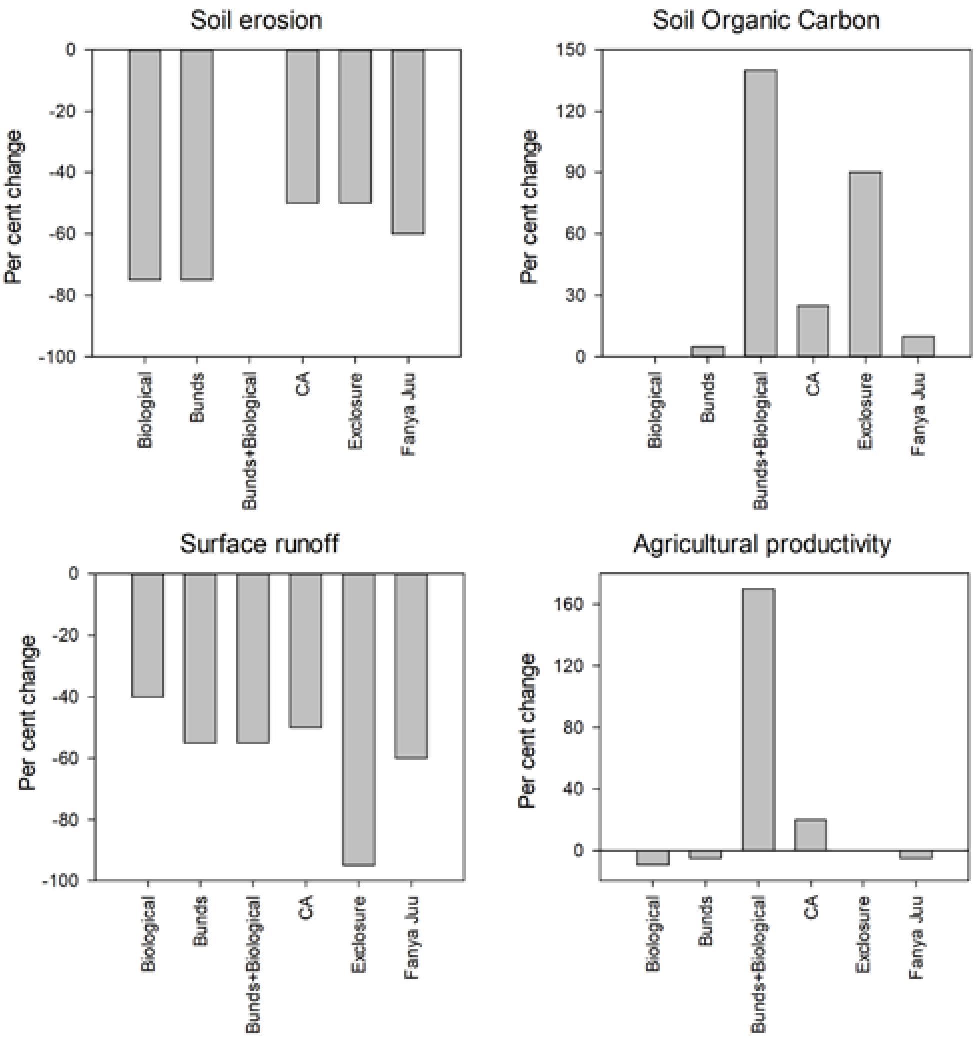

Figure 4: Magnitude of effect of different SLM interventions. The bars show the mean value of impact indicators for major AWM interventions. (Source: Abera et al., 2019)

A study of factors that influenced implementation of SLM practices in Tigray region suggested that the value of agricultural production of users of SLM was on average 77-100% higher than that of non-users (Haftu et al., 2019). Based on the comprehensive meta review, it appears that the benefits of improved land management in rainfed systems is largely related to reductions in sediment loss, and to some extent reduced runoff (i.e. increased infiltration), at the community and watershed levels. Farmers therefore need more support to enhance biological and agronomic aspects in order to realize the full yield opportunity, a key goal of the SLMP interventions.

The long term data, obtained from the GoE Central Statistics Agency, reveal that crop yields in Ethiopia have an increasing trend between 2001-02 and 2015-16. There is a sharp increase in root crops such as sweet potato and Taro (Figure 5). However, yield levels of major rainfed crops are below the potential, resulting in huge yield gaps in the rainfed system. These are estimated, for

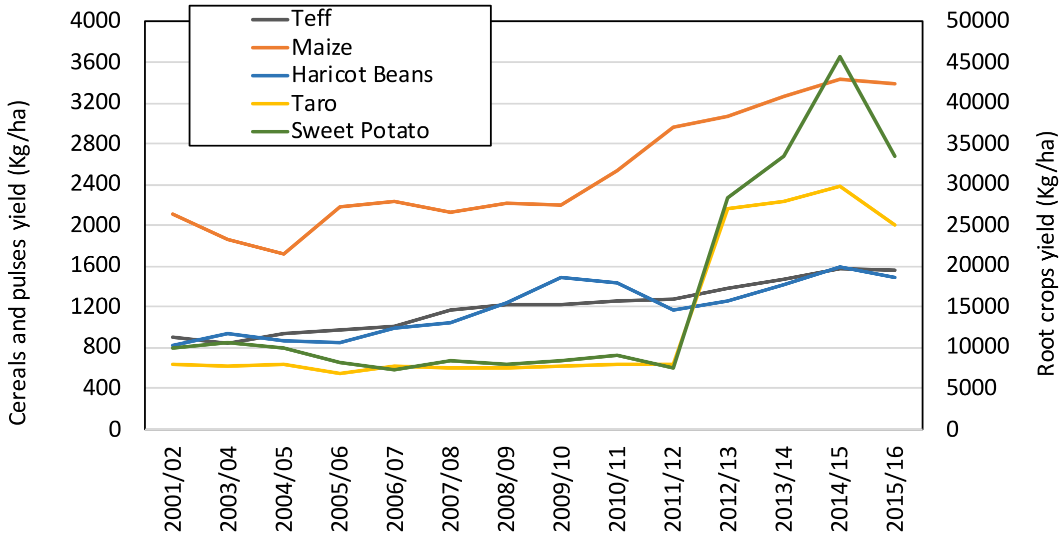

Figure 5: Change in crop yields in Ethiopia between 2001-02 and 2015-16 (Source: Central Statistical Agency, Government of Ethiopia)

example, at 1.3 t ha^{-1} for chickpea, 2.3 t ha^{-1} for common bean, 10 t ha^{-1} for maize, 3.7 t ha^{-1} for millet, 5 t ha^{-1} for sorghum and 6 t ha^{-1} for wheat (GYGA, 2020). This requires the adoption of integrated approaches to enhance rainfed systems yield levels, in order to meet the growing demand for food grains in Ethiopia. There is a strong positive relationship between public investment and supporting policies at the national level, and this needs comprehensive implementation analysis at national and regional levels.

Implementation of SLMP interventions impacted the livelihoods of participating smallholder farmers (Kato et al., 2019). Hillside plantations produced fodder and tree poles, which increased household incomes. Furthermore, land certification has motivated the community to adopt sustainable land and water management practices (Figure 6). This motivated land holders to contribute two months worth of free labor per year, on a voluntary basis, to soil and water conservation practices.

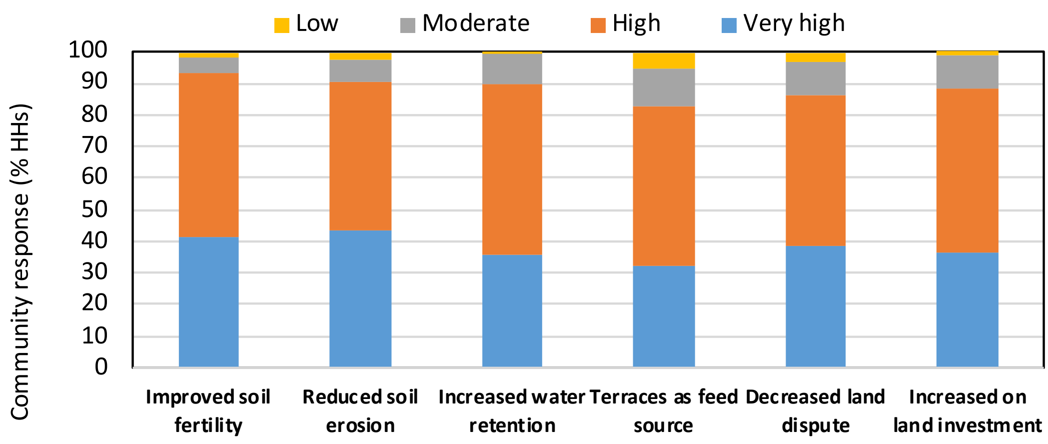

Figure 6: Community perceptions of SLMP interventions (Source: Meaza et al., 2016)

Increasing vegetative cover (feed, energy, soil fertility and reducing competition)

An impact of the long years of SLM has been increased vegetation cover, and biomass, in the exclosure area. This has increased community access to forage for livestock, that made fattening possible, and enabled beekeeping activities. Improved vegetation and biomass increased soil fertility in farm lands and reduced competition for biomass for feed, firewood and other purposes.

Economic benefits from treated areas

Experience from decades of SLM practice shows that unless rural communities gain economic benefit from restored landscapes, long-term sustainability is at risk. The German Government, GIZ and KfW collaborated with the Ethiopian Ministry of Agriculture, and relevant agricultural institutions, to implement the Sustainable Use of Rehabilitated Land for Economic Development (SURED) project (2018-2020). The aim was to add value to rehabilitated land under SLMP by increasing productivity, and improving market linkages for products and services from restored landscapes. Incomes generated from the introduction of high value crops, home gardens, beehives, community forests and grasses not only helped to increase household incomes, but also became an incentive for the implementation of more SLM practices. This is particularly important because the benefits were also distributed to landless youths and women.

4. Opportunities and synergies

Despite considerable efforts and investments by the Ethiopian government, there is still large scope for bridging yield gaps and reaching out to millions of smallholder farmers in the country. A recent study indicated that more than 75% of smallholders depend on traditional cultivars and follow conventional practices, resulting in poor land and water use efficiency (Liniger et al., 2011). There is dire need to implement various best management practices. Below are some of the key aspects to be addressed further for overall development and improved smallholder farmer livelihoods.

Developing SLM activity learning sites

There is a big opportunity to learn from the legacy of cascade projects implemented by the Ethiopian Government on SLM, aimed at increased productivity of dominant rainfed agriculture. SLMP Phase-1 introduced SLM practices to selected areas, and achieved significant progress in rehabilitating previously unproductive, degraded areas, within 45 critical watersheds in six regions. This provided benefits to rural households. SLMP-2 continued tackling poor cropland management practices, rapid depletion of vegetation cover, poor livestock grazing practices and land tenure insecurity by leveraging the successful outcomes of SLMP-1. SLMP-2 expanded its watershed restoration to cover 135 watersheds and integrated new activities targeting land productivity, deforestation, and the reduction of greenhouse gas emissions.

Another point of note is that the SLMPs, and their precursor projects, have been executed in alignment with Ethiopia's existing extension system, which makes learning easier in the process of scaling up effective interventions to all regions and districts. SLMP includes a number of watersheds with good success stories to capitalize on, and these have been used as learning sites where field days and exchange visits have been organized. It is important to further develop these learning sites with new knowledge and improved technologies, including integrated land-water-crop-livestock-tree components at watershed and landscape scales.

A cluster approach will help to achieve more benefits for all stakeholders, including; farmers, researchers, policy makers, development agencies and donors, when compared to a more sectoral approach. According to Abera et al. (2019) individual component interventions seem to be less effective, or ineffective, in creating impact and sustainability. An apropriate combination of *in situ*, *ex situ*, and biological, interventions is critical to achieving full impact potential. A number of management best practices will help to utilize available water resources more effectively. These include; the facilitation and promotion of improved quality seeds, soil quality assessments on farm and at the landscape level, all combined with local fertilizer design and advice (Tamene et al., 2018) and other agricultural inputs.

Learning sites will generate evidence on the various agro-ecological areas and help to optimize the site specific adaptation of diverse technologies, according to topography, soil type, rainfall and management practices. By applying a "seeing is believing" approach, more farmers will be able to realize the benefits of AWM by visiting these learning sites and adopting the management best practices demonstrated there.

Dissemination of the SLM outputs by strengthening extension system

Agriculture extension plays a major role in disseminating technologies and bridging knowledge gaps. In order to reach a large number of farmers with SLM technologies, it is important for the extension system to identify; local 'champion' farmers that have a demonstrated success story, and also extension workers that have shown good skills in facilitating community level implementation. The major challenge to adoption of new practices, or improved technologies, by smallholder farmers is the lack of new, location specific knowledge among farmers or extension service. Moreover, due to socio-economic challenges, lack of infrastructure, and poor communication channels, these technologies are not reaching intended stakeholders in a timely way that would enable adoption. Therefore, greater emphasis should be placed on knowledge generation and dissemination, by involving relevant stakeholders.

Monitoring, data collection and impact evaluation
As Abera et al. (2019), Adimassu et al. (2019) and Kato et al. (2019) concluded, there is a lack of data for impact assessments, and for learning that would improve future efforts. This relates to several key components of impact assessments, including; biophysical, meteorological, hydrological and socio-economic parameters. For example, most of the results on uptake of practices (section 2.2-2.4) are based on field-scale data collection, which is not representative of landscape or regional scales impacts on ecosystem services such as water and sediment flows, or different vegetation cover, due to scale effects. There is no systematic, long-term monitoring of the different water balance components or analysis of upstream and downstream effects. Understanding of enhanced water resource availability, due to AWM interventions and crop intensification, could be improved to better manage water resources in local landscapes and basins. For downstream users. Also, there is poor understanding of the effects of different SLMP-1 and 2 interventions on the temporal weather scenarios of normal, dry and wet years. A systems level analysis is largely missing. It is also important to better understand the technical and economic feasibility of the program, which is necessary for scaling-up good practices. In addition to the tangible benefits generated through implementation of various interventions at the farm and watershed scales, there is also a need to capture the various ecosystem services generated by these interventions. Long-term data monitoring would help to improve understanding of both the sustainability of interventions and their impact, which is critical to informed decision-making by policy makers and donors.

Institutional strengthening and capacity development

Building partnerships between national and international research institutions, universities, non-governmental organizations, and government agencies will help to develop synergy among the various institutions involved in rural development through the programs like SLMP and PSNP. All these institutions share a common goal of achieving system level outcomes to bridge the rainfed yield gap. There is considerable knowledge available, generated by institutions such as research and academic institutes, and state universities, which needs to reach the field level if it is to play a role in achieving large scale outcomes. Non-governmental organizations and government agencies need to work closely with these knowledge generating institutes to facilitate dissemination through the appropriate channels. A strong feedback mechanism also helps knowledge generating institutions to modify technologies and approaches, based on local requirements, and the feasibility of these in different agroecological zones.

5. Way forward

The SLMPs in Ethiopia have had considerable success in contributing to the intensification of rainfed systems for millions of smallholder farmers, over more than 15 years. Efforts through SLMP-1 and 2 have focused on controlling land degradation, contributing to enhanced agriculture and livestock productivity, and strengthening a number of associated field and watershed ecosystem services. Detailed analysis of the benefits and impacts are challenging to quantify, due to the lack of systematic monitoring. Current yield levels of major crops are still far from the full potential of rainfed systems, indicating a substantial opportunity to improve current resource use efficiency. This may offer opportunities to improve the efficacy of future programs. Key aspects to be considered when preparing strategies for future interventions, include:

- the need to use an integrated approach, involving soil-crop-water-tree-livestock components, from field to landscape scales, in order to realize the full benefits of rainfed systems. A thorough analysis of the anticipated impacts of climate change on different agro-ecosystems also needs to be taken into account when designing interventions, to improve sustainability and resilience. The use of climate information (including seasonal and short-range forecasts) and agro-advisories needs to be strengthened by involving competent public and private institutions.

- thorough analysis of the technical, and economic, feasibility of various interventions will help to prioritize interventions, leading to better investment decisions. This could help generate evidence on the scaling-up potential of the best management practices.

- establishing a few, select benchmarks and learning sites, with long-term data monitoring, which capture baseline hydrology, meteorology, agriculture and livestock productivity, change in land use, and socio-economic parameters, at field and landscape levels. This information would help to generate strong evidence for the likely success, or failure, of particular interventions, and also help to inform appropriate corrective measures. Success stories and case studies should be documented to foster awareness among stakeholders of the performance of the best management practices. Similarly, visits to expose diverse stakeholders to these approaches, and their outcomes, should continue to be organized. This would foster awareness, and help them to better understand the usefulness of such initiatives.

- exploring the use of state-of-the-art technologies such as GIS, remote sensing, ICT, and simulation modeling to; identify hotspots in respective regions, inform technology prioritization, map the creation of assets and infrastructures, monitor changes in land use, and to analyze impacts. Emerging and existent ICT tools offer opportunities for large scale knowledge dissemination, feedback analysis, and real time monitoring, which can support accountability and transparency.

- making efforts to reach all regions and districts of Ethiopia, by expanding beyond the project watershed approach to include a larger number of community owned watersheds, while utilizing structural alignment, coordination and M&E experiences from SLMP in the agriculture extension system.

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Acknowledgements

Authors would like to thank the experts of SLM Program Coordination Unit for providing the re-quired information. Authors also gratefully acknowledges Swedish University of Agriculture Sciences (SLU), Uppsala, Sweden for facilitating the development of this case study.

Sustainable land management with conservation agriculture for rainfed production: The case of Paraná III watershed (Itaipu dam) in Brazil

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This chapter is a contribution to the Background Report to the FAO ESA 2020 SOFA Report on Agricultural Water Management, under a contract between the Swedish University of Agricultural Sciences (SLU) and the European Conservation Agriculture Federation (ECAF). June 2020.

Summary

This case study examines measures taken in the Paraná III watershed, that drains into the Itaipu reservoir (Brazil-Paraguay), to establish sustainable land management for agricultural production intensification based on no-till Conservation Agriculture (CA). Prior to initiation of hydropower production from Itaipu, in May 1984, agriculture in the watershed was based on the conventional tillage production system. This caused significant soil erosion and surface runoff, polluting water courses with sediments, agrochemicals and organic waste, resulting in premature filling and eutrophication. The operational lifespan of the Itaipu hydropower complex was initially estimated to be 60 years. Within the framework of Itaipu Binacional's Cultivando Agua Boa (Cultivating Good Water) program, most agricultural land use was then transformed to no-till CA. Later this was improved through participatory support, based on a self-assessment method involving scoring of soil quality and land use parameters. CA-based land use resulted in increased crop productivity, a drastic reduction in runoff and soil erosion, and significant improvement in the quality of water discharging into water courses, Itaipu reservoir, and through the dam. A participatory extension program promoting CA systems was

available to all farmers, from smallholders to large-scale. Currently, 91% of agricultural land area in the watershed is under CA, which supports productivity and incomes, while also contributing to water related ecosystem services. Overall economic, social and environmental development of the Paraná III watershed is based on a socially and economically equitable framework, managed collaboratively by several entities. This calls for the whole watershed population to be engaged in improving quality of life and ensuring the watershed is an area of opportunity and hope. CA-based land use management, and soil and water conservation practices, have increased the operational lifespan of Itaipu hydropower complex by more than five-fold, offering long-term economic security to the population of the watershed. Given the need to ensure equitable development of all relevant economic, social and environmental sectors in the watershed, productive and sustainable agriculture continues to be both a key economic driver of change and an area of opportunity.

1. Introduction

When the Itaipu dam complex began operating in May 1984, on the border between Brazil and Paraguay (Figure 1), its working lifespan was expected to be around 60 years, on a worst case scenario. This was because of the heavy sediment, agrochemical, and animal manure loads of water draining from the Paraná III, and Ivai river, watersheds into Itaipu reservoir. The polluted discharge caused siltation and eutrophication,

Figure 1: Location of Itaipu dam, Paraná III watershed and municipalities involved in the program (data source: IBGE)

which posed a serious threat to power generation infrastructure and the reservoir´s economic, recreational and tourism potential. This case presents one of the measures taken within the Cultivando Agua Boa (CAB) (Cultivating Good Water) strategy, implemented by the Itaipu Binacional (IB) authorities, to improve the quality of water discharging into Itaipu reservoir. IB established a long-term participatory strategy to improve agricultural land management on small to large farms, initially in the Paraná III basin. The aim was to minimize water runoff and erosion, and so reduce the sediment, agrochemical and animal manure load of water draining into the reservoir. The strategy included animal manure bioenergy generation and reductions in agrochemical use. Replacement of conventional tillage agriculture by no-till farming, known as Conservation Agriculture (CA), and an ongoing participatory program to improve the quality of CA at farm level, were at the core of the land use transformation strategy. The overall result has been an increase in the life expectancy of the Itaipu dam complex to 350 years, with co-benefits in the watershed related to increased farm productivity and incomes (Laurent et al., 2011; ANA, 2011; WWAP/UN-Water, 2018).

2. Methods and materials

Agricultural development in CAB deals with the adoption and improvement of land use, based on the no-till CA system. This case study examines the results of the Itaipu land management strategy as documented in several technical reports, and interviews with farmers and other stakeholders involved in participatory extension within the study region. Public data, provided by the county scale agricultural census of the Instituto Brasileiro de Geografia e Estatística (IBGE) (Brazilian Institute of Geography and Statistics) and the MapBiomas database, is also used. MapBiomas provided maps of land use based on automated classifiers developed and operated from a Google Earth Engine platform, to generate an historical series of annual land cover of Brazil, at 30m resolution. Additionally, much has been written about the Itaipu experience in the literature, and this has also been used (Mello and Van Raij, 2006; Laurent et al., 2011; Viviane de Souza et al., 2018; Faia, 2018; Lee et al., 2018; Anderson, 2018).

3. Challenges of rainfed production and livelihood systems in the study area

The west of Paraná State in Brazil was covered with dense sub-tropical forest until the 1950s. From then on, smallholder farmers coming from the south (Rio Grande do Sul and Santa Catarina) and from the east (eastern Paraná and São Paulo) cleared the forest. Farmers cultivated corn and raised pigs in the valleys, and grew soybeans and wheat on the plateaus. During the 1970s, large, mechanized farms expanded across the plateau pushing smallholders in the valleys to the west (Paraguay) or to the north (State of Mato Grosso). Transformation of the region was rapid, supported by state subsidies and bank loans, with the participation of large private groups of agro-suppliers and from the agro-food industry (Bardy et al., 1977; Gregory, 2002). Original forest only remains in the well protected Foz do Iguaçu National Park, in very few, dispersed, remnant patches in the agricultural landscape, on steep or stony areas, and along riverbanks (Figure 2).

In 1973, the presidents of Paraguay and Brazil signed an agreement to build the largest hydroelectric dam in the world, on the Paraná river, which forms the border between the two countries. The Itaipu dam complex was built between 1975 and 1982. The first hydroelectric turbine began operating in May 1984. The power plant is now the second largest in the world in installed capacity (14,000 MW). The reservoir, formed by the dam, is 150 km long, covering an area of 1,350 km^2, (Figure 1). Water from the Paraná III watershed, covering an area of 8,389 km^2 (Figure 2) equal to a fifth of the size of Switzerland, drains into the reservoir. The Itaipu dam is managed by IB, a public enterprise, joint owned by the governments of Paraguay and Brazil. In 1994, the American Society of Civil Engineers named Itaipu dam one of the seven modern wonders of the world (Withers, 2020).

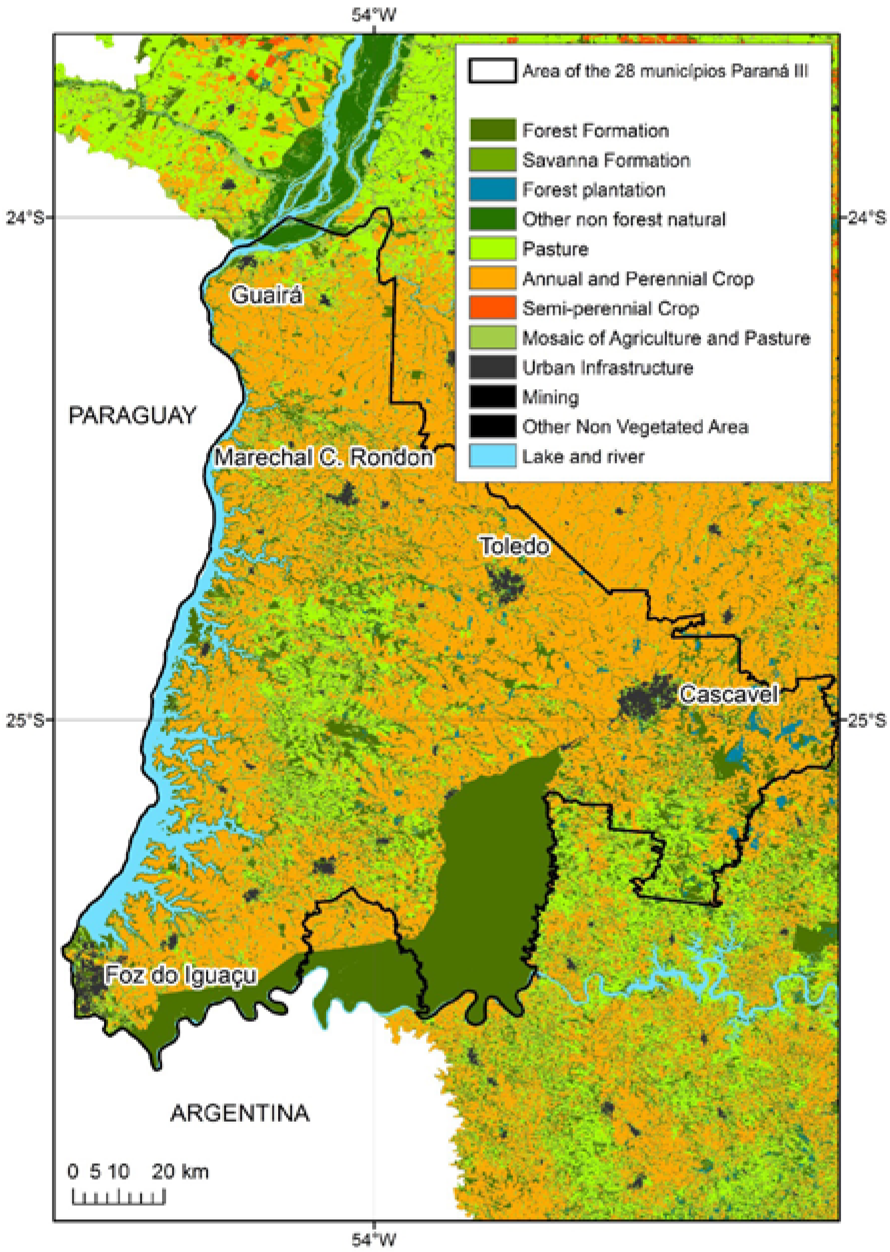

Figure 2: Land use in the Brazilian part of the Itaipu area (MapBiomas, 2017)

The Paraná III watershed, with a population of nearly one million inhabitants, is the main influence on the hydropower reservoir. The watershed has a sub-tropical humid climate without a marked dry season. Temperature seasonality occurs because the area is located away from equator. According to Koppen classification, the southwest region of the State of Paraná has a sub-tropical climate (Cfa), with average temperatures under 18°C and infrequent frost in the coldest month, and above 22°C during the warm summer months. Annual rainfall varies from 1,550 mm in the far north (Guaira region) to 2.125 mm in the south of the watershed (Cascavel region). There are no rainless months. The driest months are in winter (July and August) with around 75 mm of rainfall per month, and the wettest are in the summer (November to March) (Caldana et al., 2019). The soils, mainly Oxisols derived largely from basaltic bedrock, and some from sandstone, are naturally deep, highly weathered and well drained when not disturbed. Topography is mainly rolling hills with long, gentle slopes, with some patches of shorter, steep slopes.

The watershed is home to more than 35,000 local farms, all mechanized. 43% of these cover up to 10 hectares, and many of the rest up to 50 hectares or more. Smallholder farms, of less than 50 hectares, comprise 76.4% of the total (IBGE, 2017). The two main cropping seasons are summer, from October to March, and winter, from April to September, with crop establishment in August-October and March-May respectively. Summer crops are mainly soybean and maize, with other associated crops such as dry beans, sunflower, cotton and cassava. Winter crops are mainly wheat, barley and oats (Muzzili, 2001). Around 1 million dairy and beef cattle, over 1.5 million pigs, and 30 million poultry, are farmed within the watershed, along with multiple agro-industries based on these crop and animal production practices. The intensity of conventional tillage agriculture and animal protein production in the basin area began to impact Itaipu reservoir in the 1980s.

Figure 3: Water course in Paraná III watershed with high sediment load. December 2010 (Francois Laurent)

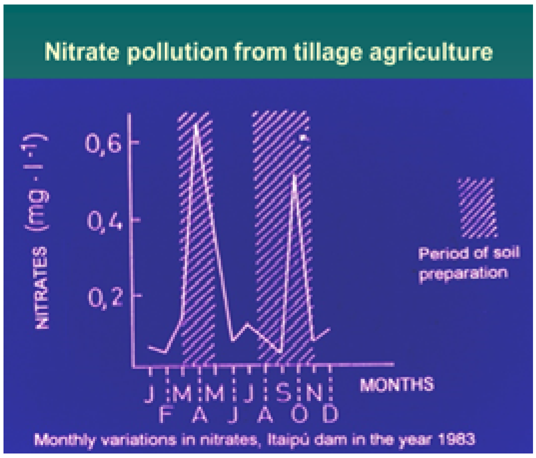

Figure 4: Monthly variations in nitrates in Itaipu reservoir, 1983
(Sorrenson and Montoya, 1984)

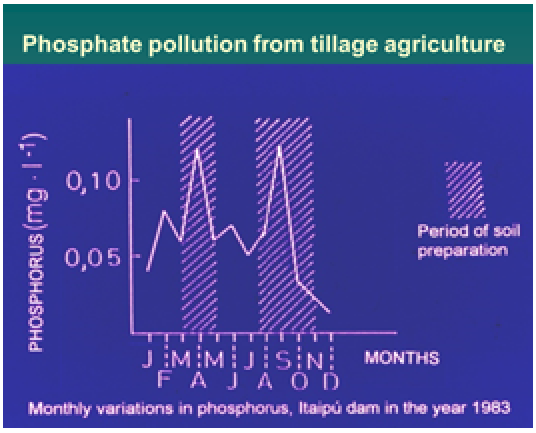

Figure 5: Monthly variations in phosphorus in Itaipu reservoir, 1983
(Sorrenson and Montoya, 1984)

Collectively, deforestation, runoff and intensive soil tillage have affected water quality in water courses and the Itaipu reservoir. These practices led to extremely high rates of soil erosion, reaching 50 t $ha^{-1}yr^{-1}$, and to high sediment loads flowing through water courses (Figure 3), into Itaipu dam, and in downstream water. Nitrogen (Figure 4) and phosphorus (Figure 5) fluxes, from fertilizers and pesticides, increased in the surface water system at the time of tillage due to high rates of runoff and soil erosion.

Figure 6: Eutrophication in Itaipu reservoir (source: Ivo Mello)

This led to severe eutrophication in parts of the reservoir (Figure 6). Since completion of the dam, eutrophication and premature sediment filling (Figure 7) of the reservoir have threatened Itaipu's hydropower production and infrastructure (Ribeiro Filho et al., 2011). Threats that are now compounded by the impacts of climate change.

Consequently, IB financed a large program called "Cultivando Água Boa" (CAB) (Cultivating Good Water), between 2003-15. Since then the "Itaipu Sustentável" (Sustainable Itaipu) program has succeeded CAB. These programs focus on wastewater treatment plants, forest conservation around the reservoir and along riverbanks, slope stabilization and anti-slide management, and development of agricultural practices that produce more positive externalities. Environmental goals are linked to quality of life improvements for local communities, through public and private commitments between IB and the 28 watershed municipalities, cooperatives, associations, NGOs, schools, universities, and farmers. Governance of the program is based on public participation.

The regional agro-ecological conditions make the watershed highly productive, allowing five commercial crops every two years in most of the basin, or two crops a year in higher, colder areas.

Agricultural production is rainfed. Around 47% of the Paraná III basin area is covered in annual crops (MapBiomas, 2017). Productivity is high: in 2018, a mean of 3.5 t ha^{-1} for soybean (up to 5.5 t ha^{-1} in some farms) and 5.6 t ha^{-1} (up to 8.0 t ha^{-1} in some farms) for maize (IBGE data base: Produção Agrícola Municipal). Soybean (Figure 12) and maize (Figure 13) crop productivity have continued to increase in the last decade despite some years of drought (IBGE, 2017).

Figure 7: Sediment deposition and eutrophication, mouth of river São Francisco Verdadeiro where it enters Itaipu reservoir (source: Glaucio Roloff)

4. Driving change in agricultural intensification through soil, water and agronomic management in rainfed production systems

Figure 8: Contour bunds, with terraces in between, constructed across the slope to stop runoff and soil erosion. December 2010 (source: Francois Laurent)

In 2003, recognizing the links between the altered watershed hydrology of the dam, the poverty of the region, and the environmental harm associated with both agriculture and energy production, IB expanded its mission to include social and environmental stewardship of the Paraná III watershed (ITAIPU, 2017). On the Brazilian side of the basin, it initiated the CAB program as a response. CAB focused on 63 initiatives, including conservation of water, protection of farmland and forests, and the adoption of strategies to reduce land and water pollution from agriculture. These included the use of no-till farming, promotion of rural sanitation and wastewater treatment, reduced use of pesticides, and forest and stream protection. Through CAB, which was principally based on civil society's participation in the farming settlements, IB built a model example of a multidimensional framework for local stewardship of land and water resources (ITAIPU, 2017). In 2015, IB received the Best Water Management Practices Award from the United Nations *Water for Life* program. In 2017, Itaipu Binational's effort earned praise from UNESCO, which designated the 1 million ha territory of the Paraná III watershed a Biosphere Reserve. More recently CAB has been replaced by an extended initiative *Itaipu Sustentável* (Sustainable Itaipu)[1].

Land in the Paraná III watershed is protected with anti-erosive contour bunds and terraces, which were constructed and are maintained mechanically (Figure 8). 80% of construction costs were financed by Itaipu´s programs. The bunds were designed with the aim of stopping and retaining runoff water generated by an intensity of rainfall with a 10 year frequency. The high hydraulic conductivity of the Oxisols allows infiltration of water between bunds but with intensive tillage infiltration is impaired, causing water runoff and erosion of topsoil, leading to crop damage. Although most farmers accepted construction of these bunds not all of them are well-maintained. Some farmers have even cut through them when they consider the bunds to be too closely spaced or if they pose a hindrance to the passage of machinery.

However, the main land use practice which helps to maintain high infiltration rates in the terraces, and to minimize runoff and erosion as well as raising productivity, is Conservation Agriculture (CA). CA has been promoted in the watershed since the 1980s, and its effectiveness was further improved during the 1990s.

The Agricultural Research Institute of Paraná State (IAPAR), together with IB, created the concept of a "no-tillage system with quality" (Muzilli, 2006). This clarified to farmers that adopting no-tillage (NT), in conjunction with other conservation practices, would qualify as CA, as well as helping to maintain contour bunds and terraces. IAPAR worked closely with the Technical Assistance and Rural Extension Service of Paraná (EMATER/PR) to develop and transfer suitable no-till technologies to smallholders, including to those using animal traction. They were responsible for the wide-scale adoption of CA in the Paraná III watershed, and throughout

[1] *https://www.itaipu.gov.br/meioambiente/politica-ambiental*

the state of Paraná (Muzilli, 2001, Muzilli, 2006). IB also partnered with FEBRAPDP and EMATER/PR to reduce sediment and nutrient loads being deposited in the reservoir. This involved, amongst other actions, establishing a methodology to improve the quality of CA, at the farm level, in the Paraná III watershed. A national census of soil management, conducted by IBGE in 2017, showed that 81% of farms were managed under NT systems, and 19% under conventional tillage systems. 89% of agricultural cropland was managed with NT systems. We emphasize here that NT alone does not constitute a CA system.

Section (i) describes the concept and practice of CA. Section (ii) describes a self-assessment system introduced to improve the quality of CA systems on individual farms.

Conservation Agriculture systems

FAO defines CA as "an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment" (FAO, 2020). CA is characterized, along with other complementary good agricultural practices of crop and production management, by the practical application of three linked principles, namely (Kassam, 2020):

- **Principle 1:** Continuous no, or minimal, mechanical soil disturbance, implemented by the practice of no-till seeding or broadcasting of crop seeds, and direct placing of planting material into untilled soil; and causing minimum soil disturbance from any cultural operation, harvest operation or farm traffic;

- **Principle 2:** Maintenance of a permanent biomass soil mulch cover on the ground surface, implemented by retaining crop biomass, root stocks and stubbles and cover crops and other sources of *ex situ* biomass; and

- **Principle 3:** Diversification of crop species, implemented by adopting a cropping system with crops in rotations, and/or sequences and/or associations involving annuals and perennial crops, including a balanced mix of legume and non-legume crops.

CA enhances biodiversity and natural biological processes above and below ground surface. Soil interventions such as mechanical tillage are reduced to an absolute minimum or avoided, and external inputs such as agrochemicals and plant nutrients, of mineral or organic origin, are applied optimally and in ways and quantities that do not interfere with, or disrupt, the biological processes (FAO, 2020).

In this way CA facilitates good agronomy, such as timely operations, and improves overall land husbandry for rain-fed and irrigated production. Complemented by other known good practices, including the use of quality seeds, and integrated pest, nutrient, weed and water management, CA is a base for sustainable agricultural production intensification (Kassam et al., 2009, 2013; Jat et al., 2014; Farooq and Siddique, 2014; Friedrich, 2013). Overall crop and biomass production within a season increases over time under CA management, compared to tillage-based management, since unproductive times used for tillage and land preparation are eliminated, and soil moisture and carbon are conserved. Simultaneously, CA complies with generally accepted ideas on ecological sustainability because the three principles, when implemented, act similarly to land with natural vegetation (Kassam et al., 2009, 2013, 2014; Dumanski et al., 2014; Shaxson et al., 2008; Basch et al., 2012; Kassam, 2020).

Increased cropping system diversity, also involving cover crops, and stimulation of biological processes in the soil and above soil surface, combined with reduced erosion and leaching, can lead to increased retention and use of water and nutrients. This can also result in a decline in the application of mineral fertilizers, pesticides and herbicides, in the longer term (Sorrenson, 1997). Groundwater resources are replenished through improved water infiltration, reduced surface runoff, and greater water retention in the soil (Pan et al., 2018). All this improves the return flow of soil water and groundwater into streams and rivers in a more regulated manner. Water quality is improved because of reduced agrochemical and soil nutrient contamination levels, through a decline in leaching and soil erosion (Bassi, 2000).

CA has been proven to: (i) sequester organic carbon in the soil at a rate ranging from about 0.1–0.5 t ha^{-1} $year^{-1}$, or more, depending on; the amount of biomass being returned, prevailing soil organic carbon content, thermal and moisture climate, length of growing season, soil type and fertility, and cropping systems and management practices (Amado et al., 2006; Gonzales-Sanchez et al., 2012; Sá et al., 2013; Corsi et al., 2014); (ii) reduce labour requirements, generally by about 50%, which allows farmers to save time and machinery costs (Saturnino and Landers, 2002; Baker et al., 2007; Lindwall and Sonntag, 2010; Baig and Gamache, 2009; Crabtree, 2010); and (iii) save around 60%, or more, on fuel (Sorrenson and Montoya, 1984, 1991; Friedrich et al., 2009). Overall, CA has been shown to contribute to both climate change adaptability and mitigation (Gonzalez-Sanchez et al., 2012, 2017, 2019, 2020; Sá et al., 2013, 2020a, 2020b).

In Brazil, NT was first introduced in the early 1970s, through the initiative of pioneer farmers of Paraná State and extension agronomists. Initially the aim was to control water runoff and soil erosion (Telles et al., 2013; Calegari et al., 2014). Later the objective expanded to include improving soil health and productivity by integrating other complementary practices to form CA systems. Introduction of NT was a response to the use of intensive tillage systems in grain production areas. In the 1970s and 1980s these were causing severe soil erosion losses and soil degradation, which in turn was affecting productive capacity and crop yields (Bolliger et al., 2006).

Paraná was, in the early 1970s, also one of the states that pioneered NT research and development at the national level (Ekboir, 2003; Freitas and Landers, 2014). Between 1977 and 1991, agricultural research conducted by IAPAR, in partnership with the then Gesellschaft für Technische Zusammenarbeit (GTZ), proved that production systems based on NT and soil mulch cover, involving cover crops in the cropping system, are efficient in controlling water erosion (Derpsch et al., 1986). Research efforts supported the technical and scientific base. Later, this led to technology development and transfer, consolidating NT cropping with mulch cover as a reference management system for soil conservation. Throughout the 1990s the NT system expanded rapidly across Paraná and the other Brazilian states (Calegari et al., 2014). Now the term 'NT system' is often used synonymously with CA.

In Brazil, official data on the number of farms using, and areas under, NT were first collected and disseminated by the Agricultural Census 2006, of the Brazilian Institute of Geography and Statistics (IBGE) (Fuentes-Llanillo et al., 2013). This enabled a more detailed understanding of the magnitude of NT practices and NT systems. A first comparison has been made possible with the Agricultural Census of 2017, which enabled an accurate assessment of the change in spread of the practice of NT in NT systems.

According to IBGE (2017), NT in Paraná State is practiced in around 4.9 M ha (82%) of agricultural land, an increase of 29% from 3.8 M ha (76.5%) in 2006. Soybean, as a summer crop, has been driving the expansion of the NT-based cropping area when used for intensive grain production of both soybean and maize. Yet a true CA cropping system involves, in addition to NT, the use of several other crops. Mixtures of cover crops, including for example, under sowing maize crop with cover crops such as brachiaria, black oats or hairy vetch, can be used. This aims to produce extra biomass, add atmospheric nitrogen to the soil, maintain soil cover before the next main crop, and promote plant nutrient recycling. The use of this approach has generally been used in all agricultural land in Brazil in which CA has been promoted, since the early 1970s. In 2018, the total rainfed cropland area under CA was about 33 M ha, having started in 1972, expanded to 25.5. M ha by 2008/09, and then further increased by around 30% since then. This now accounts for 81% of total cropland in Brazil. Additionally, there is a significant amount of land under CA with trees and livestock.

A self-assessment system to improve the quality of CA

In the 1980s and 1990s, farmers in the Paraná III watershed, as elsewhere in Brazil, largely adopted NT practices. However, in order to develop good quality CA involving soil biomass cover and diversified cropping, solutions adapted to the needs and constraints of farmers in the local context must be found (Scopel et al., 2004). Strategies proven to be effective in promoting change in farming communities, in Brazil, including in the Paraná III watershed, share two important characteristics:

- Community mobilization and participation as the backbone of the change strategy. This can occur with the establishment of trained groups in the communities, so that participants themselves can improve social and economic conditions through collective action. Such capacities must be built in a participatory way, through ideas, initiatives and actions of group members themselves. In the specific case of Paraná III watershed, IB invested in land stabilization by constructing contour bunds, or banks and terraces, at landscape and farm levels. This benefits farmers and serves as an incentive to participate in conservation practices through common actions.

  Community participation is one of the pillars of CAB. The CAB program provided an umbrella for various actions taken to enhance the sustainability of hydroelectric power generation. It was subsidized economically by IB, always in a systemic way, aiming to integrate all sub-programs. Resource contributions from IB subsidize actions such as terracing at farm level, provided that the farmer participates (even if through representation) in the municipal management committee. The Municipal Steering Committee decides priorities for application of resources, according to sub-sectorial plans, in a participatory manner.

- Conducting group evaluations of; small, medium and large farms through a self-evaluation process to improve understanding of the agronomic and environmental effects of adopting CA systems; and of the interactive mechanisms involved in improving the quality of CA practices. Most farms had already adopted the practice of NT before the CAB program. The program was not structured to convince the farmer to simply adopt the three pillars of CA. The objective was to demonstrate to a farmer, within the physical-social scope of his/her microwatershed, that attitudes and actions in relation to the management of the soils of his/her farm property can add value to the productive process (more profit with less resources). That it can offer externalities that the regional population was interested in, for example, the quality of water that their production process delivers to the hydrological cycle of the Paraná III watershed. This can be viewed as an ecosystem or environmental service provided by farmers to generate sustainable, renewable energy. The CAB program then delivers value back to farmers by improving facilities, such as contour bunding or banks and terraces.

IB is a two-country state company, hence its resources are public. The CA improvement part of this program was financed by IB through FEBRAPDP, a non-profit, non-governmental organization. The main aims of FEBRAPDP were to promote and coordinate the adoption of no-till cropping and to assist farmers to develop the practice into a good quality CA system. FEBRAPDP enabled the program to assemble a core team of professionals and consultants to meet mutually established objectives. One main result was the establishment of a participatory, self-assessment methodology used to evaluate the adherence of individual farming practices to the three interlinked principles of CA. Importantly, there was also participation, mainly in the form of non-financial assets, by local municipalities, EMATER (Parana State Extension Agency), and farmer´s cooperatives, a mainstay of local agribusiness.

IB partnered with FEBRAPDP, in the Paraná III watershed, to carry out land use improvements involving both the adoption, and enhancement, of CA at the farm level. The goal was to reduce soil erosion and improve farm economic performance. IB, in partnership with, FEBRAPDP, worked to strengthen the ability of farmers to adopt CA and to formulate their own solutions based on a diagnostic system of self-assessment of their CA practices (Bartz et al., 2011). The project, begun in 2009, was built on a participatory approach, involving farmers in meetings and field visits across six sub-watersheds. The entire process was voluntarily, validated by external agents and indicators, and comprised the following steps (Bartz et al., 2011):

i. In December 2009, a two-day meeting was held, involving agronomists, environmental scientists and engineers, and agricultural leaders from each community, to exchange knowledge on soil conservation, fertilization and water resources.

ii. A survey was then carried out in February 2010 through a questionnaire conducted with 237 farmers. Most were smallholders (77% cultivating less than 30 ha). Data collected included: size of area under no-till, time of adoption of no-till, type of no-till, duration of soil exposure without cover, level of satisfaction with the production system, difficulties and problems encountered, and conservation related operations used such as terracing and contour bunding.

iii. In April 2010, validation meetings were conducted to present the results of farmer interviews in each of the six sub-watersheds. Discussions were conducted to obtain the maximum number of opinions on the results, and to generate a participatory environment. From the set of indicators thus identified, some were chosen by farmers to form the axis of the multi-criteria analysis, namely: no-till effectiveness, crop rotation, soil and water conservation, crop fertilization, and farmer's involvement in no-till. The indicators required neither costly measures nor external engineering and were based on farmer observations and knowledge. These are either quantitatively or qualitatively assessed, compared to a local benchmark (Table 1).

iv. 25 farmers representing the six sub-watersheds were selected as candidates to apply the self-assessment system on their farm properties. The survey provided a register of comparable data between farmers and even between different plots on the same farm. The aggregation, by weighted sum, of indicators results in a No-Till System Quality Index (NTSQI). Details of the conceptual framework underlying the derivation of NTSQI and its trial application in Western Paraná is give in Roloff et al. (2011), summarized below.

The NTSQI is built upon indicators that reflect four key land use system components, directly or indirectly, namely: no-till, soil mulch cover, diversified crop rotation and runoff management. Crop rotation and, partially, soil mulch cover permanence are evaluated through rotation intensity (RI), rotation diversity (RD) and crop residue persistence (RP). Soil cover permanence, also partially, and absence of tillage are assessed by tillage frequency (TF). Runoff is addressed by terrace adequacy (TA), based on runoff over-topping frequency (runoff water overflowing the contour bunds), and conservation evaluation (CE), based on the absence of signs of erosive runoff. Plant nutrition, indirectly linked to soil cover permanence by its affect on crop growth, is evaluated through balanced nutrition (BN). Farmer commitment to no-till, an indirect indicator of the combined components, is evaluated through its adoption time (AT).

The NTSQI is calculated by the sum of indicators multiplied by respective weights, in order to generate easy to understand values of quality parameters, from 0 to 10. Farmer self-assessment generates a score for each quality indicator, and a total score for the adopted production system, at various scales: plot, farm, sub-watershed and Paraná III watershed. After saving the self-assessment, the system generates a report for each farm. This summarizes information computed through the diagnosis, providing a scoring matrix of the program indicators. Based on this, and suggestions from field technicians, the report concludes with an assessment of strengths, items for improvement and a set of actions to improve the quality of the farm's no-till system, called the "Attitudes Agreement". This is very relevant as it enables farmers to assess their farms, and it generates a quality management system indicating a cycle of planning, action, verification and feedback for continuous improvement. Optionally, farmers can participate in comparative ranking within the same sub-watershed or entire Paraná III watershed.

The results of NTSQI at farm scale, for 25 farms in the six sub-watersheds, are presented in Roloff et al. (2011). The NTSQI varies from a low value of 4.8, for a farm in the Sanga Mineira sub-watershed, to a high value of 9.7, for a farm in the Aquiles Orlando sub-watershed, indicating that

Table 1: No-Till System Quality Index (NTSQI) indicators (Itaipu Binacional, 2011)

Axis	Indicator	Justification	Assessment	Weight
Crop rotation	Crop rotation intensity (RI). Crop rotation and level of soil cover during a time step.	- Soil protection by active crop - Mulch production - Maintaining macroporosity - Nutrient recycling	Ratio number of crops maximum number possible during 3 year period.	1.5
	Rotation diversity (RD)	- Diseases, weed control - Diversity of depth explored by roots for nutrients recycling	Ratio of effective number of species used/ideal number (4) during 3 year period.	1.5
	Mulch persistence (RP)	- Resulting from C/N ratio - Erosion reduction - Evaporation reduction - Biological	Ratio of number of crops that are gramin-eous/ideal number (6) during 3 year period.	1.5
No-till	Tillage frequency (TF). Absence of tillage and soil cover (permanent / partial), assessed.	- Organic matter oxidation - Vertical macroporosity destruction	Ratio of years without tilling/ considered time to reach an equilibri-um in no-till (6 years).	1.5
Soil and water conservation	Terrace adequacy (TA), to assess runoff based on runoff over-flowing frequency.	- Superficial runoff limitation by increasing infiltration time	Terrace overflow frequency	1.0
	Conservation evalua-tion (CE) based on the absence of signs of erosive runoff	- Infiltration process - Erosion process	Presence of com-paction and erosion marks	1.0
Crop fertilization	Balanced plant nutri-tion (BN) based on fertilization balance and soil analysis.	- Avoid nutrient excess (main-ly Phosphorus, responsible for freshwater eutrophication)	Use of fertilization bal-ance or soil analysis	1.0
Farmer's history of no-till	Duration of no-till adoption time (AT)	- More time means farmers should be more experienced	Number of years in no-till/ideal number (22 yrs)	1.0

NTSQI is capable of clearly differentiating the quality of CA and soil and water conservation practices at the farm level. The indicator with the highest frequency of critical cases was Terracing adequacy (TA), with 52%. This suggests issues related to terracing with contour bunding should be prioritized in sub-watershed projects. Rotation diversity (RD) and Mulch persistence (RP) appear critical in 32% of cases, demonstrating they need improvement. This suggests that actions aimed at improving the quality of the CA system for those farmers must focus on Terracing adequacy (with contour bunding) and on increasing the number of cover crops in the rotation, by using winter cover crops such as black oats. This is useful for defining priorities to improve overall environmental externalities of no-till systems in the area.

CA systems are known to improve soil organic matter which enhances soil functions and health, and crop performance. As expected, the NTSQI showed a close relationship to soil organic matter of the first layer (0-10 cm depth), with an R^2 of 0.60 (n=23, 2 farms were erased for not consistent values). Thus, the index has a valuable ability to reflect soil organic matter differences, improvement and conservation.

Farmers were also trained to count earthworms and classify the numbers (Table 2, Figure 9, Figure 10), applying the method defined by Anderson et al. (1993). Earthworms are very sensitive to conservation practices and they are fundamental to improving soil health and function, and to the environment. Where there are more earthworms, there is greater biological macroporosity, more organic matter cycling, and enhanced levels of bioavailable plant nutrients. From the no-till assessment viewpoint, the earthworm indicator is complementary to NTQI. Earthworm density is a general indicator of the impacts of the farming system on soil biology, while NTQI is an indicator of the means necessary to achieve good biological and physical soil functioning. Two earthworm counts were conducted by the FEBRAPDP team (December 2010 and February 2011), in 49 plots of the 25 participant farms. The results show an uneven variation between farms in soil biological activities, ranging from poor to excellent (Figure 10).

Figure 9: Earthworm counting to assess the quality of the no-till system at plot scale (Francois Laurent, December 2010)

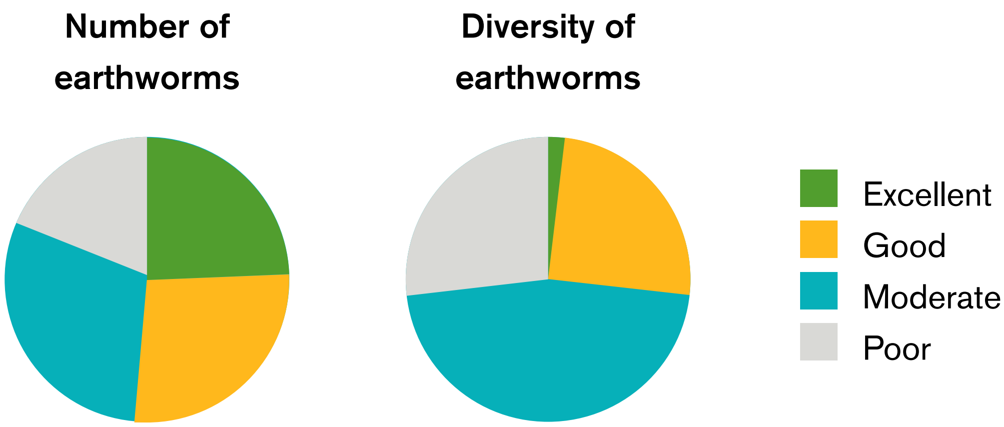

Figure 10: Earthworm ranking results in the 25 participant farms (Bartz, 2011)

Since 2011, through the SoloVivo network, led by Embrapa (Brazilian National Research Entreprise on Agriculture), and funded by IB, the no-till system scoring method and the NTSQI farm level assessment for improving CA quality has been disseminated in other regions of Brazil, including Goiás, Mato Grosso do Sul, São Paulo, and Paraná e Rio Grande do Sul (Martins et al., 2018). The concept and structure of NTSQI allows for regional customization through stakeholder contributions.

5. Economic and environmental benefits of no-till CA system

Adoption of CA systems and economic benefits

According to Telles et al. (2019), some form of CA is practiced in 89% of the Paraná III watershed. Figure 11 shows that 14 of the 29 Paraná III watershed municipalities use CA in more than 91% of areas dedicated to temporary crops. These municipalities are mainly located in the central region of the watershed. The area dedicated to annual crops managed through CA ranges from 71-90% in 10 municipalities, from 51-70% in 3 and from 38-50% in 2. The quality of CA varies across different areas and there is also variation in the adoption of other conservation practices such as contour bunding and terracing. However, as a result of the watershed-scale adoption of CA, the Paraná III watershed has become known for its high agricultural productivity with small-scale and large-scale farmers using modern, mechanized, intensive and highly technical systems. Small-scale farmers have access to affordable no-till seeding and spraying services. The watershed is also known for its equitable community-based rural and agricultural development which has benefitted participating farmers, small and large-scale, as well as the watershed's non-agricultural population.

Through the adoption of CA, crop yields have shown continued increases. Figures 12 and 13 show soybean and maize yields from 1996 to 2018. Since 1996, there have been increases in soybean yields of around 40%, and 70% in maize yields. There has also been a 30-50% decrease in fertilizer use for both crops, as biological forms of nutrient pools increase in the soil as a result of more soil organic matter.

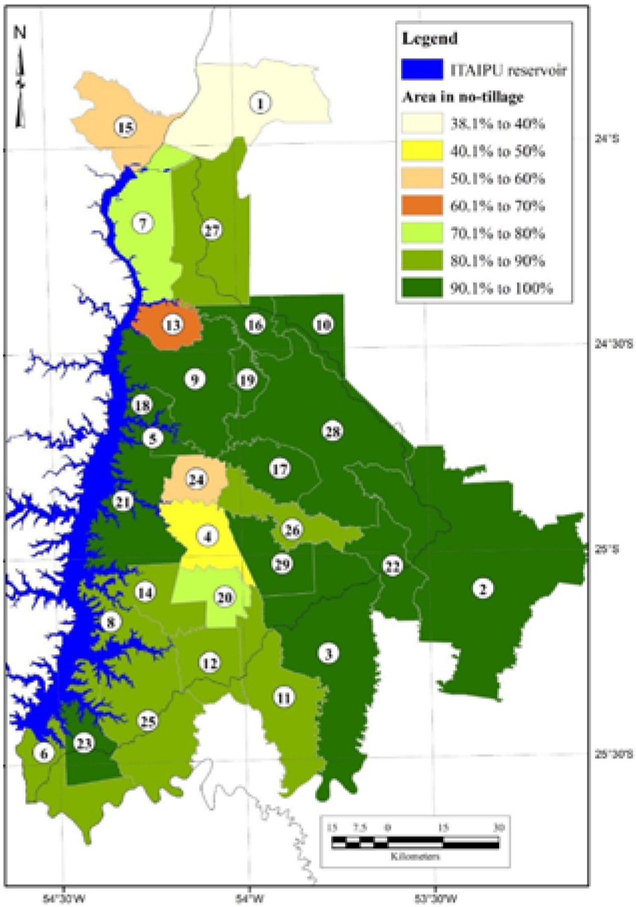

Figure 11: Adoption of CA system in the Paraná III watershed. (Telles et al., 2019)

The economic impact of CA adoption can be best described through the example of two farms (small and large). The small farm is situated in the Paraná III watershed. The large farm is in the Itapua region, on the Paraguay side of the Itaipu reservoir, where similar CA-based land use development was followed. CA systems were applied on farms of all sizes. The adoption and improvement of CA systems was a grand scale, technological revolution in Brazil, including in the state of Paraná. A break though was achieved by FEBRAPDP when it partnered with the seeding equipment industry and encouraged the manufacture of no-till seeders for all farm sizes, including smallholders using animal traction, at costs compatible with their realities.

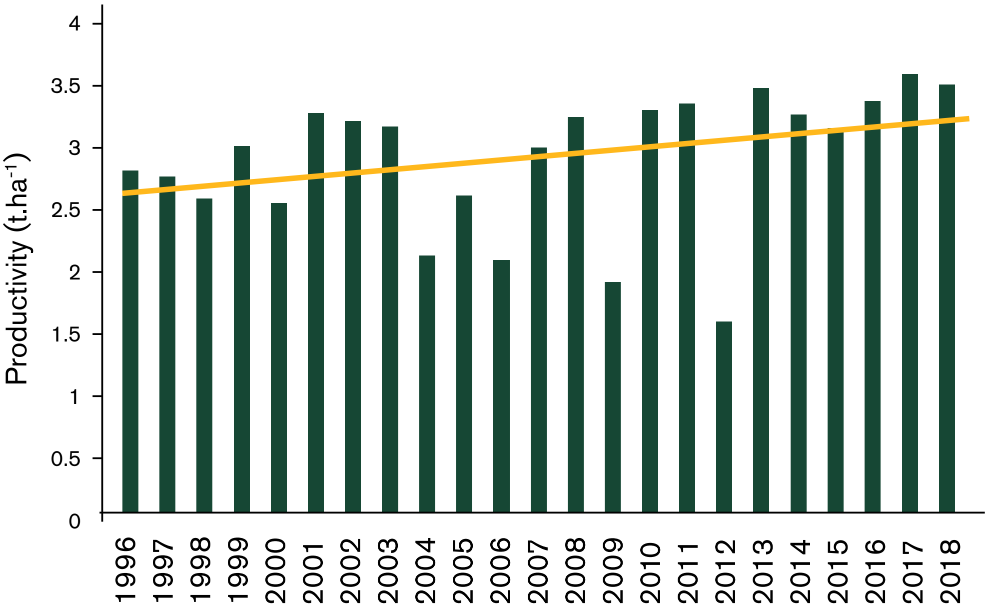

Figure 12: Mean soybean productivity in the Paraná III watershed (IBGE - Produção Agrícola Municipal)

The case of a smallholder farmer, Itaipulandia, Buriti sub-watershed, Paraná III watershed

Ilario Holzwending is a smallholder farmer who owns 8 ha of land, and rents another 13 ha. He is married with three grown up children. He remembers that when he first moved into the area with his father, as a small boy, in the 1960s, mud and erosion were everywhere because of intensive tillage farming. Adoption of good quality CA brought the erosion under control, allowed the land to regenerate and remain protected as a highly productive asset in the soybean-maize-cover crop based cropping system (Figure 14). The NTSQI score of his farm was above 8.4 in 2011, meaning that the CA quality rating of his farm was Class 1, or excellent.

Ilario rents another 13 ha and developed a 15 cow dairy operation on it, which his wife

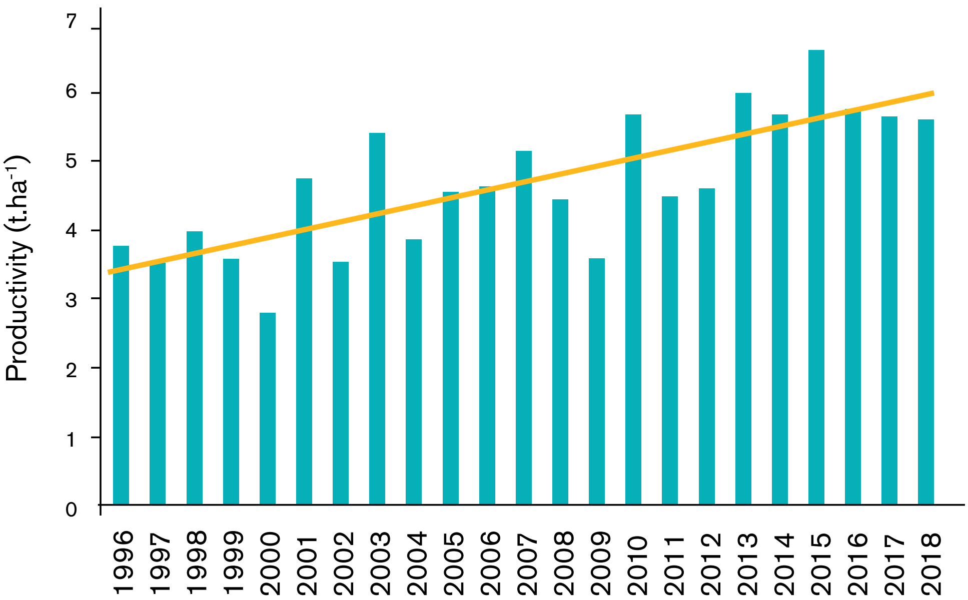

Figure 13: Mean maize productivity in the Paraná III watershed (IBGE - Produção Agrícola Municipal)

Figure 14: Farmer Ilario Holzwendling's CA cropping system maize field after harvest, August 2011. Left to right: Theodor Friedrich (FAO, Rome), Amir Kassam (FAO, Rome), Ivo Mello (no-till agronomist), farmer Ilario Holzwendling and his son. (Amir Kassam)

manages. Ilario also purchased a second-hand, 2 m wide no-till disk seeder (Figure 15) and further supplements his income by offering no-till seeding services and extension advice on CA-based land management, to smallholder farmers in his area.

From their farm income, the Ilario family have been able to build a bungalow on their land and educate their children. All three now work as agronomists in the governmental extension service, earning a good living and are keen to remain in the agricultural sector.

The case of a large farm on the Paraguay side of the Itaipu reservoir

The financial impacts of good quality CA were analysed in detail by Sorrenson et al. (1997) in the watershed on the opposite side of the Itaipu reservoir, in Paraguay, where a similar CA-based land improvement program was implemented. The financial performance of a typical large-sized farm (135 ha), in the Itapua region, were traced over a 10 year period from the late 1980s while the quality of the CA system was being

Figure 15: No-till seeder belonging to farmer Ilario Holzwendling, who provides no-till seeding service to smallholders to supplement his income. (Amir Kassam)

improved. Farm model results for the overall farm, as well as separately for each crop and for each crop rotation, were produced. The farm model was based on thorough analysis of data from the case study farm (and others) spanning a number of years. Therefore the results can be confidently considered indicative of what was actually being realised in practice by farmers on both sides of the Itaipu reservoir, as a result of practicing good quality CA systems.

Results are shown in Figure 16. The changes in farm income and costs are also based on actual farmer experience in the region. Farm costs (both variable and fixed costs, the latter exclusive of the cost of NT equipment) increased under the CA system, compared to conventional tillage (CT), but these increases were less than the corresponding increases in gross farm income. Net farm income increased considerably under CA, from US$ 9,770 in year 1 to US$ 33,700 in year 10. Under CT it decreased from US$ 7,300 to US$ 1,100. In each of these years, net farm income was higher under CA than CT. A similar study of a medium-sized farm (45 ha) showed that in year six, the CT farm was making an annual loss of US$ 158 compared to a profit of US$ 20,043 in the CA farm. By year 10 the CT farm was losing US$ 3,013 annually compared to an annual profit of US$ 31,142 in the CA farm (Sorrenson et al.,1997).

Risks, defined as the probability of net farm income falling below zero in any given year, were also analysed by Sorrenson et al. (1997), who concluded that farm risks decreased considerably following the adoption of a CA system, compared to CT. The main reasons for this were: (1) higher and more stable yields in CA, due to improved soil structure, higher water infiltration and soil moisture retention, and reduced pests and diseases; (2) the impact of lowering farm income when soybean and wheat prices fall is less under NT, because it is possible to diversify into other cash crops; (3) reduced fuel use under NT, lowering the impact of any increase in the price of fuel; (4) over time, lower fertiliser and herbicide costs per crop under NT, as the impact of green manure crops, and reduced fallow periods between crops, take effect. Sorrenson et al. (1997) concluded that a situation such as the one presented here, whereby highly attractive financial returns are accompanied by a lowering of risk, is rarely encountered in agricultural technology development. Generally,

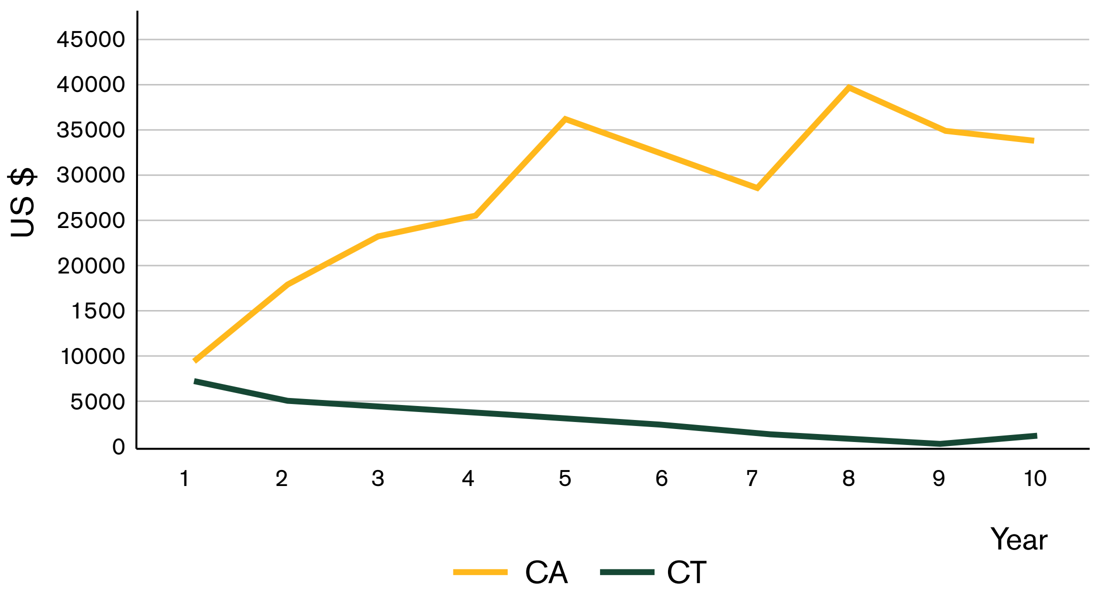

Figure 16: Net farm income for CA system compared with conventional tillage (CT). (Sorrenson et al., 1997)

Figure 17: Spillway of Itaipu dam showing water with low sediment load, December 2010 (Francois Laurent)

more profitable technologies carry with them concomitantly higher risks which necessitate farmers to weigh-up accepting these in exchange for higher profits, as opposed to operating at lower average profit but with lower risk.

Erosion and water quality

Water quality is affected by sediment and agrochemical loads. Many studies in Brazil have shown that CA-based land use in the Paraná III watershed have resulted in drastically reduced soil erosion. In some cases, erosion is reduced to negligible levels (Derpsch et al., 1986;Venialgo, 1996; ISTRO, 1997; Sorrenson, 1997; Sorrenson et al., 1997; Sorrenson and Montoya, 1984, 1991; Ribeiro Filho et al., 2011; Faia et al., 2018). This can be seen from the colour of water; in water courses, the Paraná river, the Itaipu reservoir, and passing through the dam (Figure 17). Most studies, including longitudinal studies, show that water draining into Itaipu reservoir is; less polluted with agrochemicals, carries much less sediment, and has a greater transparency (Ribeiro Filho et al., 2011; Faia et al., 2018). An extension of the working life of Itaipu dam, from the original 60 years to 350 years now (WWAP/UN-Water, 2018), is a major result of this. However, studies also show that much needs to be done in terms of maintaining the various soil and water conservation practices to continue keep water pollution, from various sources, to a minimum (Anderson, 2018). This is a key objective of IB, and their wide range of cross-sectoral programs.

6. Discussion of findings and system sustainability

The success of CA in the Paraná III watershed been has achieved by increasing crop and farm productivity, and incomes, while also improving the sustainability of the soil resource base.

This required a full, integrative approach involving no-till, soil mulch cover and a diversified rotation with cover crops. These are the fundamental practices of CA systems. The methodology developed within Itaipu´s programs, to improve the quality of CA, produces farmers who are more knowledgeable and confident about their CA practices. The quality improvement, self-assessment scheme, based on field observations and cost-effective measurements, enabled them to keep production costs low while improving their long-term productivity. Society benefits from the positive externalities of CA systems through reductions in sedimentation and eutrophication of Itaipu reservoir. This in turn reduces power generating costs and increases the operating lifespan of the Itaipu hydropower complex. Water resources, and aquatic ecosystems, in the Paraná III watershed are also better protected through cleaner, less contaminated water because of sustainable, CA-based, agricultural land use. The experience of introducing CA, and land water conservation practices, in the Paraná III watershed is summarised in the theory of change in Figure 18.

Managing the productivity and sustainably of the whole Paraná III watershed is a massive responsibility, requiring multi-sectoral, and socially inclusive, management of continuity and change. Although the Itaipu project had a controversial beginning, the community development framework within which IB manages its affairs has much to do with its enviable economic, social and environmental achievements. Promotion of best practices in the management of agricultural soils, water resources, and ecosystem conservation, are part of the framework. This includes the adoption, and practice, of good quality CA-based land use systems, animal manure management, forest and biodiversity enhancement, and riparian vegetation maintenance (Anderson, 2018). There is an ongoing need for a participatory approach to the technical and management training of farmers, land managers, civil society groups and institutions, in order to observe best practices. This can minimize negative externalities from agricultural land use, and optimize productivity and ecosystem services. It can also help in minimizing, or reversing, deforestation and biodiversity loss, thus creating more opportunities for ecosystem services and tourism development.

The Paraná III watershed experience shows that overcoming water quality problems, requires the involvement of all stakeholders, through an integrated approach, in order to act on both accidental and historical, point and non-point pollution, from agricultural and urban origins. This was possible in the Paraná III watershed

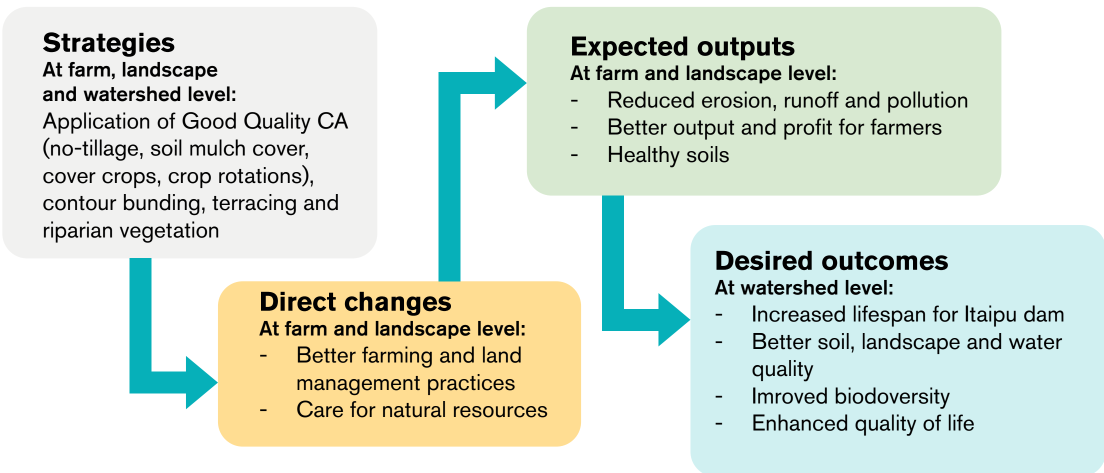

Figure 18: Theory of change for Conservation Agriculture, and soil and water conservation, in the Paraná III watershed: strategies, changes, outputs and outcomes

due to IB and a profound paradigm shift from centralized and curative management to participative and preventive management. Strong investment of human and financial capital, to support a transition to more ecological systems was possible through technical advice, and facilitation of farmer groups. This was all achievable due to the financial means generated by the hydroelectric power plant.

Stakeholders wanted to link conservation of water resources with agricultural production, not consider them mutually opposed. Under CA, recommended solutions, based on soil ecosystem services, did not reduce agricultural productivity to protect the environment but instead reinforced long term productivity. Permanent soil cover, with no-till, limits erosion and regulates runoff over time by increasing infiltration resulting in aquifer recharge. It also increases soil biological activity, enriches fertility, and makes crops more resilient to drought through better rooting and water infiltration. Diversification of crop rotations reduces pressure on soil and crop health and reduces the need for pesticides, which is good for water resources and saves farmers money. It also leads to better exploration of soil fertility, in particular by associating cereals with legumes, like soybeans.

CA takes into account the multifunctionality of agriculture by linking ecosystem services with productivity. It generates more positive externalities (carbon sequestration, water infiltration, biodiversity, reduction in erosion), while improving crop resilience and enabling producers to reduce inputs. As can be seen from graphs of the region, productivity of soybeans and corn increased (Figures 12 and 13). The consensus is that this is due in large part to the spread of CA.

This experience shows the value of participatory approaches aimed at ensuring that technical choices are made with producers. Participation enabled them to assess for themselves the quality of their system with simple, visible indicators that do not require external technologies. Farmers who better understand interactions between their techniques, soil life and crop growth, can constantly improve and best adapt CA to the specifics of their land. They gain autonomy, know-how, and knowledge of environmental processes and so become the best agents of improved water quality.

However, further progress remains to be made. Firstly, in the diversification of crop rotations. Soybeans are a very profitable crop and it is difficult to replace them with other crops in order to lengthen rotations. Soybean has a low C:N ratio, which leads to rapid mineralization of organic matter. Enrichment by straw cereals in rotation would increase organic matter content, but this remains difficult because they offer lower returns than soybean. Another challenge is to reduce pesticide use, which is high in the region. Persistent pollutants are dangerous to health and the environment, and although banned in other countries, some are authorized for use in Brazil. The development of practices that limit pest pressure, and so the use of these types of pesticides, is a priority.

There are indications that climate, and land use, change is leading to increased water discharge into the Paraná River, and that peak discharge is shifting from February to March/April. Climate change may also modify watershed hydrology, resulting in more extreme events such as droughts and floods, which may damage public infrastructure. In Brazil, including in Paraná state, few studies have evaluated the impacts of climate change on hydropower reservoirs. Some studies have more generally evaluated the impact on river basins, not directly evaluating hydroelectric reservoirs. Given the all-pervasive nature of climate change impacts, studies examining Itaipu watershed development and climate change are essential for forward planning and in order to make adjustments in all the sectors, as well as for emergency readiness. CA is a core element of climate smart agriculture. This is because it is productive, has good resilience to biotic and abiotic stresses, and is a good mitigator of climate change impacts. However, it is important to assess how adaptable all the other value chain linkages and institutions are to climate change across different sectors.

The Itaipu hydropower project, and Paraná III watershed development programs, are based on equitable, social and economic goals, which demand that everyone living and working in the watershed becomes fully and responsibly engaged in the joint effort. Thus, the potential sustainability of overall economic, social and environmental development of the watershed and the Itaipu dam remains high.

7. Conclusions with lessons related to policy and new knowledge

This case describes the actions taken by IB to establish sustainable agricultural land use in the Paraná III watershed. Over 90% of the agricultural land was able to be converted from the degrading tillage agriculture system to a CA system, albeit with varying quality. This enabled farmers to manage their rainfed farms productively and sustainably while also delivering water related ecosystem services at farm, landscape and watershed levels. The multi-institutional research and development, and extension, efforts, relating to the adoption of CA were based on locally formulated practices and technologies, and also on a participatory support program aimed at improving the quality of CA systems.

As a result of adopting CA production systems, farmers have been able to minimize soil erosion and runoff, increase water infiltration into the soil, and maximize water retention for production. At the same time, CA-based land use has led to more productive agriculture for farmers and has been a major driving force for economic and rural development.

In terms of new, transferable knowledge about efficient water management for rainfed production and system sustainability, the Paraná III watershed development offers several policy and technical lessons:

1. Tillage agriculture is not suitable for sustainable land management. Only good quality no-till CA systems can offer higher productivity and incomes, while mobilizing the ecosystem services needed by society, resulting in the effective functioning and maintenance of the Itaipu hydroelectric complex.

2. Sustainable agricultural production intensification and protection of ecosystem functions and services are not mutually exclusive. They are two sides of the same coin, feeding into one another. With any form of tillage agriculture, this is simply not possible, because soil-mediated functions and processes are debilitated.

3. Community-based soil and water conservation programs can be developed in a socially equitable manner so that both smallholders and larger-scale farmers, as well as civil society, can work and live in a mutually reinforcing and self-empowering manner.

4. The achievements of the Itaipu project have been dependent upon the goodwill, investments and cooperation of several ministries (energy, water, agriculture, environment, social development, health and education), all of whom worked constructively together for the benefit of all. Their inputs included construction of bunds and terraces, riparian vegetation, safe pesticide disposal sites, farm-based biodigesters and payment for biogas, research and extension. This emphasizes the importance of intersectoral approaches.

5. Land and water related developments on the Brazilian side of Itaipu reservoir also took place in Paraguay, a country dominated by smallholder farmers at that time, many of them relying on animal farm power. Yet, like farmers on the Brazilian side, they transformed their agricultural approach, based on good quality CA, to become the 4th

largest exporter of soybeans in the world by 2020[2] Brazil being the top global exporter. Both Brazil and Paraguay have gained much from Itaipu hydropower and watershed development cooperation on both sides of the Paraná river and the Itaipu reservoir.

Effectively achieving a multi-sectoral approach to economic, social and environmental development at all levels in the Paraná III watershed, given its size and 1 million inhabitants, is in essence equivalent to managing a small nation. A large proportion of the watershed population rely on agriculture, and related sectors, for their livelihoods. Productive and sustainable agriculture is not only a key driver for economic and social change, it is also a necessary foundation for both a good quality of life and for delivering soil and land mediated ecosystem services to society. The agriculture and rural development achievements in the Paraná III watershed, and those of the Itaipu hydropower complex, have been nationally and internationally recognized. Increasing the working lifespan of the complex by more than five-fold bodes well for the future, and gives hope to its population that the Paraná III watershed has the potential to remain an area of opportunity for the foreseeable future.

[2] *http://www.worldstopexports.com/soya-beans-exports-country/ (accessed May 30, 2020)*

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Endnote

All five co-authors have followed developments in Paraná III for many years (e.g. see Photos 1, 2 and 3) and two of the co-authors (Ivo Mello and Glaucio Roloff) participated in the agricultural extension process to improve CA systems in the watershed within the Cultivando Agua Boa (CAB) strategy implemented by the IB authorities. During that period, Ivo Mello was the chairman of the Confederation of American Associations for the Production of Sustainable Agriculture (CAPAAS) and general secretary of the Brazilian No-Till Federation, or Federação Brasileira de Plantio Direto na Palha (FEBRAPDP), with Herbert Bartz as its President. Glaucio Roloff was professor at the University for Latin American Integration at Iguassu Falls, a government supported project initiated in 2007. The university doesn't aim to offer traditional careers, but instead new, integrative curricula with crosscutting issues related to environmental, economic and social development. Both he and Ivo Mello were physically co-located at the IB complex during the time when the strategy for land use improvement was being formulated and tested within the CAB program, and Amir Kassam (based at FAO, Rome, at that time), Francois Laurent (based at Le Mans University in France), and Emilio Gonzalez-Sanchez (based at Cordoba University) were visiting collaborators.
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