Water Smart Agriculture for Productivity and Resilience of Rainfed Smallholder Farms in Mesoamerica: EVIDENCE FROM THE FIELD

POVERTY, LAND DEGRADATION, AND CLIMATE CHANGE ARE CREATING A GROWING HUMANITARIAN CRISIS IN RURAL CENTRAL AMERICA AND SOUTHERN MEXICO

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 Central America and southern Mexico.[1,2] Current trends, including increasingly irregular rainfall, more frequent and intense drought, and intermittent extreme precipitation events and storms are predicted to continue to worsen over the next decades as the region becomes significantly hotter and drier.[3] These changes are felt most acutely in the Dry Corridor, a sub-region of dry, tropical forest where millions of smallholder farmers produce staple crops like maize and beans. 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.[4]

Large areas of Central America experienced moderate to severe drought conditions in six of the eleven years from 2009 through 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.[4,5] These predominantly rainfed systems produce 92% of the region's basic food crops[6] and more than half of these farmers are highly vulnerable and poor.[7] As climate variability intensifies the already existing challenges for smallholders in Central America and southern Mexico, building the resilience of smallholder farming systems through sustainable climate-adaptive approaches has become an essential humanitarian issue that crosses the nexus from emergency response and disaster risk reduction to economic development.

WATER SMART AGRICULTURE INCREASES AGRICULTURAL PRODUCTIVITY AND RESILIENCE THROUGH THE RESTORATION OF SOIL AND WATER RESOURCES

Water Smart Agriculture (WSA) is an approach to simultaneously confront the challenges of land degradation, drought and erratic rainfall, low agricultural productivity, and poverty in Central America and southern Mexico. Over the last 5 years, the Water Smart Agriculture Program for Mesoamerica (WSA) has 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 in the region.

WSA focuses primarily on "green water", which refers to infiltrated rainfall, stored as soil moisture and available for plant uptake[8] (Figure 1). In the Dry Corridor, where the poor distribution of rainfall rather than the overall amount is the biggest limiting factor, improved soil and water management combined with timely management of crops offers potential for substantial yield and resilience gains and provides significant opportunities for producing more food with the same amount of water.[8,9] 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 – the volume of crop produced per the amount of rainfall. Plant health has an indirect effect on water use efficiency in that a well-fertilized and pest and disease-free plant will produce more biomass per unit of water used. The relatively simple and low-cost WSA practices improve nutrient management to increase biomass inputs, minimize soil disturbance, and maintain continuous soil cover with residue or cover crops. Crop residue retention has proven especially effective for increasing soil moisture retention and improving soil health.[10]

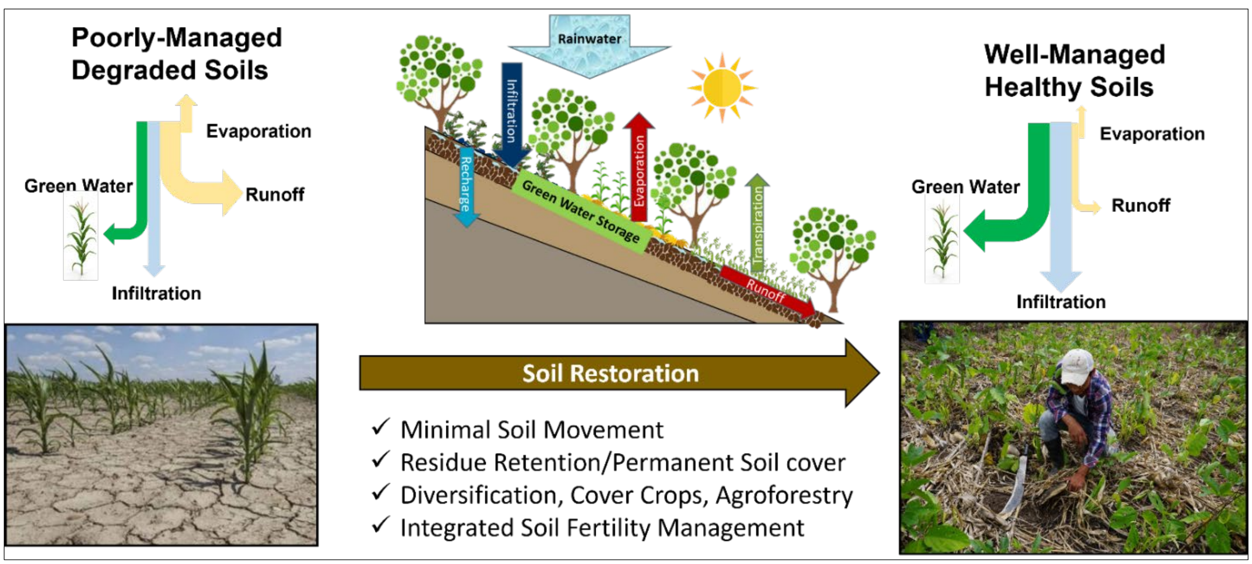

Figure 1: The green water potential of soils. WSA practices restore the soil's ability to capture and retain rainwater making production systems more drought resilient.

EVIDENCE GENERATED BY SMALLHOLDER FARMERS

The WSA program used 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 refined field recommendations for nutrient management, cover cropping, residue management, diversification, and agroforestry options. This contrasts with the conventional practices like tillage, burning, removing residues, or complete grazing of crop residues, that leave the soil bare (Figure 1, left photo). WSA agronomic practices are tailored to available resources that improve system management and increase productivity, profitability, and resilience. Participatory on-farm demonstrations provide proof of concept from the farmer perspective and serve as living classrooms for capacity building and outreach activities.

From 2016-2021, over 3,000 partner farmers planted side-by-side demonstrations in the main Mesoamerican agricultural systems, including maize-bean basic grains systems, coffee agroforestry and pastures. Working with local WSA trained technicians, farmers established water-smart practices on an innovation plot immediately next to a comparison plot farmed with their current practices (Photo left). Innovation 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, WSA first addressed soil fertility limitations and improved nutrient management, providing immediate yield benefits. Over the following two years, farmers then transitioned into crop residue management, cover cropping and agroforestry.

MORE CROP PER DROP WITH WSA

Rainwater productivity (RWP) is the volume of crop produced per amount of rainfall, or crop per drop, and is an indicator of how efficiently an agricultural system uses rainwater. In WSA innovation plots improvements in soil health and fertility have led to consistently higher yields, soil water retention and RWP over farmer conventional practice comparisons. The maize growing seasons in 2016, 2018 and 2019 were all relatively dry, with average precipitation of 702 mm during the rainy season from May to August, while 2017 was a relatively good year for rainfall quantity and distribution. 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). This initial increase in RWP can be attributed to improved crop nutrition and demonstrates the opportunity to improve the productivity of rainfed systems with integrated nutrient management practices. In the following "good year," the majority of WSA farms incorporated conservation agriculture practices (residue retention and cover crops) and further surpassed the comparison in RWP. Even though seasonal rainfall was well below average 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 results from WSA practices, such as residue retention 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/mm of rainfall, 1.5 kg/ha/mm more than the comparison. These RWP values are comparable to improvements observed in other tropical smallholder conservation agriculture maize systems around the world.[11] Although significant improvements in yields and RWP have been achieved, average WSA yields still fall below the estimated 4.5 ton/ha yield potential for the region[12] indicating potential to further improve RWP through improved agronomic management.

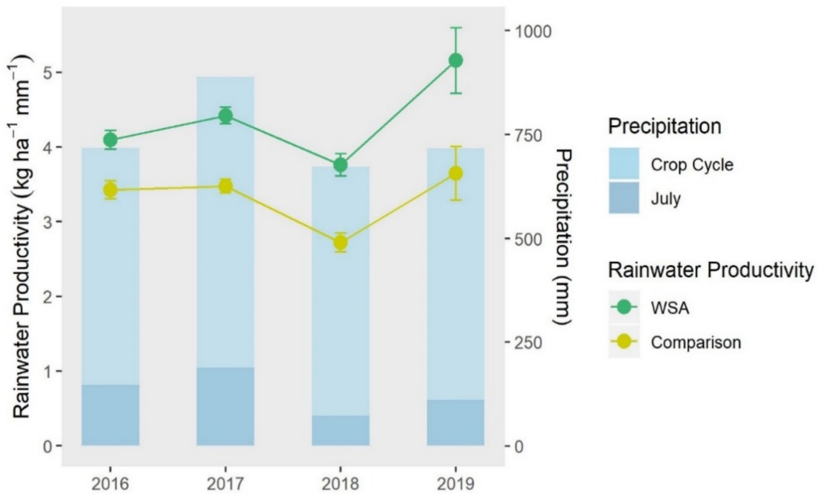

Figure 2: Rainwater productivity of maize in WSA and comparison plots in the Dry Corridor over the past four years: 2016-2019 (N=1291 farmers). Precipitation during the maize season (May-August) and July (when the *canicula* dry spell typically occurs) is shown (CRS 2019).

WSA SYSTEM RESILIENCE 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* (mid-season dry spell) 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.[5] July rainfall was only 80 mm, less than half the average July rainfall of 222 mm[13] (*Figure 3*). Some areas where WSA demonstration plots were located went 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.

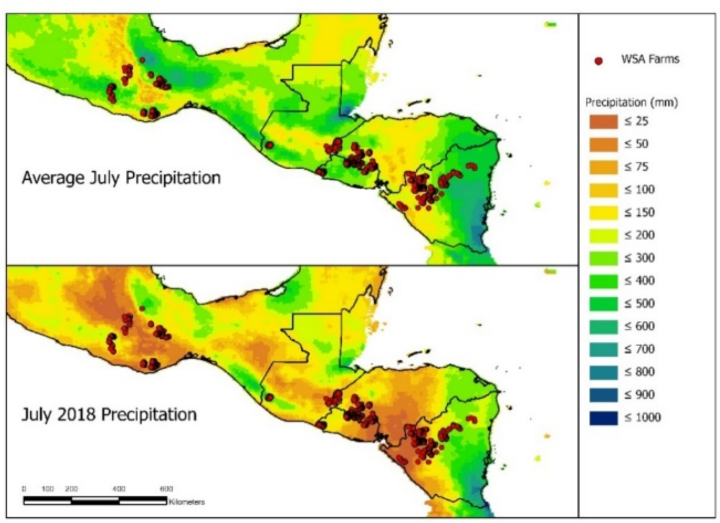

Figure 3: July average precipitation vs. July 2018 precipitation (mm), location of the WSA plots identified by red points (Map prepared by M.-S. Turmel; Map data source, Funk *et al.*, 2014 U.S. Geological Survey Data Series 832).

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 regardless of the 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 (*Figure 4*). WSA maize yields were on average 41% higher, and 80% of all 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 Central

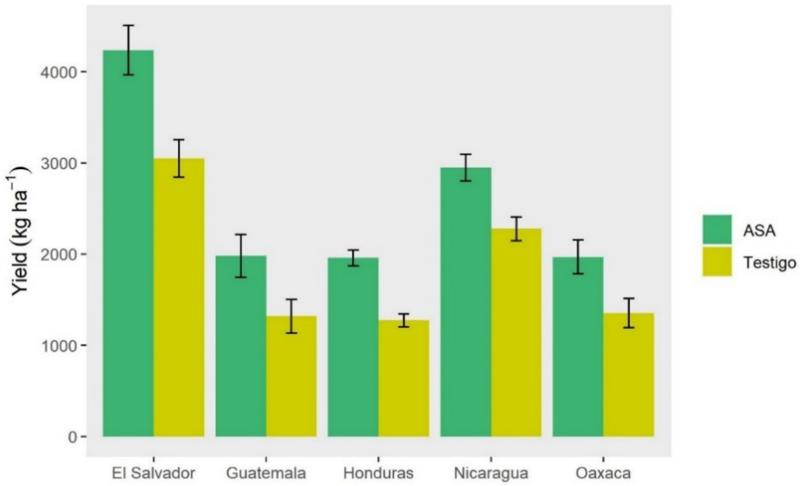

Figure 4: Average maize yield in 2018 from 1065 on-farm WSA vs. comparison plots (CRS 2018)

Americans were affected by yield loss and 1.4 million were left food insecure.[14] Based on 2018 data, at least 33% more farmers in the Dry Corridor will meet their basic maize production needs in a severe drought year if they implement WSA management practices.

During the drought, WSA farms with at least 3 years of permanent vegetative cover on the soil (cover crop and/or crop residue retention) demonstrated the associated benefits of increased soil moisture vis a vis their comparison plots during the *canícula* period of the *primera* season (*Figure 5*). Under the drought conditions of the extended *canícula* period of 2018, WSA plots had on average 7.6% more volumetric soil water during the key maize reproductive stage. With each additional year of WSA practices, WSA farmers increased soil cover with maize and bean crop residues and cover crops, further improving soil health and optimizing the capacity of the soil to infiltrate and retain moisture.

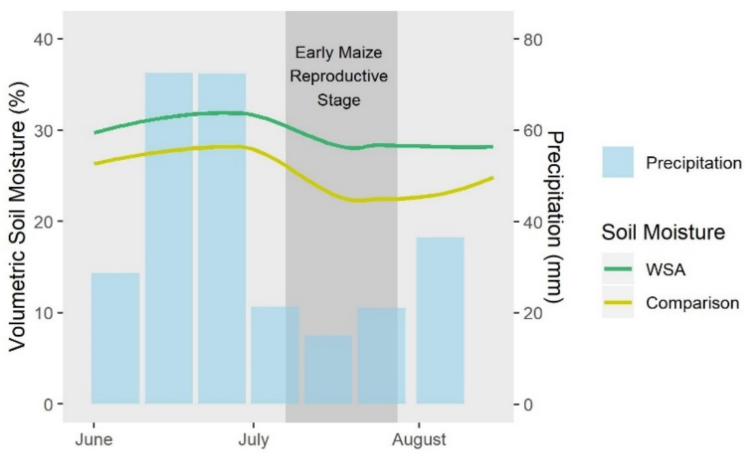

Figure 5: Average increase in soil moisture (%) in WSA plots vs. comparison plots, during the 2018 *primera* season in Nicaragua (N=44 farms). Average 2018 precipitation in the plots is show by the blue bars, and the early reproductive stage is indicated (CRS 2018).

SOIL FERTILITY MANAGEMENT IS FUNDAMENTAL TO RESILIENCE

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 WSA plots, 66% of farmers had at least one severely limiting soil fertility problem: soil acidity, low soil organic matter, low cation exchange capacity or low nutrient concentration. 37% of farms had very low phosphorus (P) content, 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. When left as residue, the plant biomass 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 6*). 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% in soils with moderate P fertility. The average family in Central America needs 1000 kg of maize per year to meet their consumption requirements. The average farm area for basic grains is one hectare thus a yield of 1000 kg/ha is the minimum production required to be maize food secure. For farmers with less than one hectare to farm, the challenge is even greater. Results from the 2018 drought showed that farmers limited by both water (<600 mm of rainfall) and soil fertility conditions (low phosphorus) could not meet this minimum production level with their current production practices. When WSA practices were used, however, on average yields were above this critical threshold in a severe drought year.

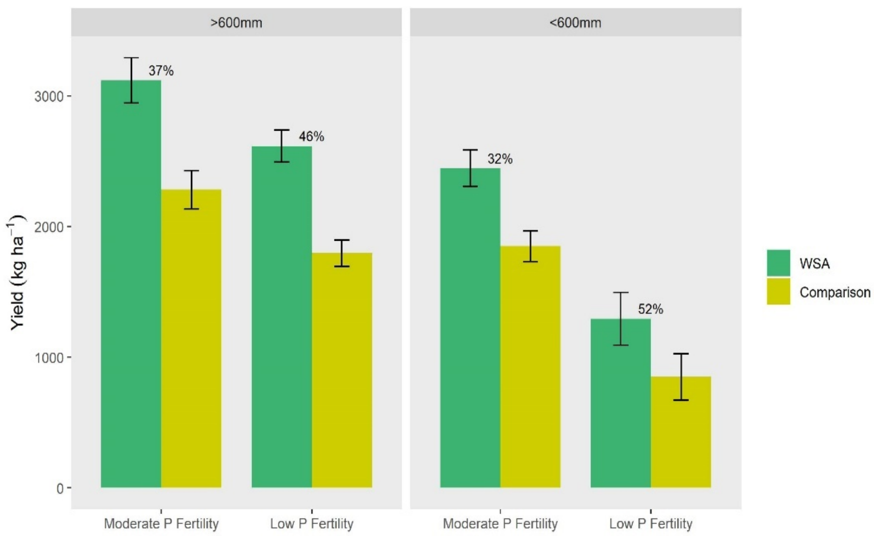

Figure 6: Maize yield in soil fertility (phosphorus) limiting, and water limiting, sites in 2018 (N=973 farms. The percent increase with WSA above the comparison is show above each pair of bars (CRS 2018).

BUILDING A MOVMENT FOR RESILIENT RURAL PROSPERITY

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. 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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