Agroecology and Climate Change Resilience

In Smallholder Coffee Agroecosystems of Central America

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KEY FINDINGS

1. Climate change represents a growing threat to smallholder coffee producers, in addition to the ongoing challenge of fluctuating coffee and food prices;

2. The impacts of climate change predicted to have the greatest effects on coffee farms in Central America are: 2-2.5°C higher temperatures, 5-10% lower rainfall, more extreme weather events, increased pest and disease prevalence, and 40% or more decreased suitability of production areas. Thus the goals of building resilience involve implementing practices that minimize these impacts;

3. Data on coffee production and resilience show that agroforestry and incorporation of shade trees deliver benefits for the greatest number of agronomic and livelihood resilience indicators;

4. For farmers and support agencies interested in implementing adaptation measures with greatest payoff (in terms of delivering on multiple indicators of resilience), incorporating /maintaining shade trees to achieve between 30-45% shade cover and maintaining ground cover of leaf litter are recommended.

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OVERVIEW

Arabica coffee production provides the principal source of monetary income for many smallholder households throughout the mountainous regions of Central America. Coffee agroecosystems serve several functions, which can include supporting livelihoods, and providing ecosystem services (e.g. carbon sequestration), and conserving biodiversity (De Beenhouwer et al., 2013; Valencia et al., 2014). For these reasons, coffee farming plays a key synergistic role in socioeconomic and ecological resilience. Despite these synergies, the livelihoods of Central American smallholder coffee farmers are in a precarious state due to their exposure and sensitivity to common stressors and shocks, including the seasonality of incomes, volatile commodity prices and natural disasters (Jha et al., 2014). This vulnerability makes it extremely difficult for growers to maintain (let alone build) their assets and capabilities, and to embark on pathways out of poverty.

Today, coffee farmers face the added threat of climate change, including higher temperatures and alternating extreme weather events, such as erratic rainfall and drought. Marginalized people, including women, the poor, and the elderly, have unequal access to resources and often suffer the worst impacts of changing environmental conditions from climate change (Tompkins & Adger, 2004). This points to a need for immediate and sustained support for adaptation to climate change-specific threats and integrated resilience-building strategies. It also merits a focus on climate change adaptation rather than mitigation, in order to highlight farmer-centered challenges and solutions to climate vulnerability for smallholder coffee producers. We define adaptation as the actions taken to prepare a system for long-term change, and adaptive capacity is the ability of a system to cope with disturbance and adjust to change (Cutter et al., 2008)

The literature lacks a concise, evidence-based evaluation of the ability of specific practices and interventions to build coffee agroecosystem resilience. To address this shortcoming, we undertook a comprehensive review seeking evidence on the potential of agroecological practices to support the resilience of smallholder coffee agroecosystems and livelihoods in the face of climate change.

Agroecology is an approach that integrates ecological science with other scientific disciplines and knowledge systems, including local and traditional knowledge, to guide the sustainable transformation of our current agrifood system (Mendez et al., 2013).

Some critics argue that most literature on the benefits of agroecology is either anecdotal or so context-specific that broader application is difficult. Taking this into account, we specifically focused on studies that provided evidence on how agroecological practices build resilience and contribute to climate change adaptation for smallholder coffee production. The biophysical indicators of interest included soil water holding capacity, soil erodibility, farm microclimate, nutrient-use efficiency and yield. We also included evidence related to social and economic indicators (such as income stability, food security and empowerment) that could reflect the health and resilience of the household.

While there is no single factor that increases resilience across all domains, we found that incorporation or maintenance of shade trees (i.e. coffee agroforestry), delivers benefits on the greatest number of agronomic and livelihood resilience indicators. With proper management, incorporating/maintaining shade trees can be an effective, low-cost way for smallholder coffee farmers to build farm resilience to climate threats, while simultaneously supporting food security and providing income. Although the management of shade trees with coffee is a classic recommendation, our analysis reinforces this by uniquely demonstrating shade's effect on climate change resilience indicators.

By bringing together and highlighting existing research and gaps in the literature, we seek to inspire future scholarship, inform policy and help direct development interventions. Although this paper primarily focuses on Central American coffee production, many of the examples and lessons are broadly applicable to smallholder coffee producers worldwide. We hope this research brief will benefit multiple stakeholders including coffee cooperatives, development practitioners, industry agents, researchers and policy-makers.

BACKGROUND

Over the past two decades, coffee farmers, the specialty coffee industry, and international development agencies have collaborated to address coffee market price fluctuations, which lead to periodic price crises. These actors responded to the 1999-2002 coffee price crisis with multiple responses, such as promoting price floors and premiums (including certified Fair Trade and organic channels, as well as direct trade relationships); social programs including cooperatives and capacity building; and crop and livelihood diversification efforts. More recently, conversations and resources have shifted toward building coffee farm and livelihood resilience, particularly in response to predicted climate change impacts and in the context of severe crop losses due to an outbreak of coffee leaf rust disease ('la Roya'), beginning in 2012.

Climate change threatens coffee production in Mesoamerica through increased temperatures, greater seasonal extremes (drier dry seasons, warmer and wetter rainy seasons), lower and more erratic rainfall, more extreme and damaging weather events, and increased incidence of pest and disease outbreaks. In many cases, this amounts to a decrease in suitability of production areas. It is estimated that 40% or more of current coffee areas in Nicaragua, Costa Rica, and El Salvador will be affected if no adaptation measures are implemented (Läderach et al., 2010). Other climate scenarios show a loss of 56% of the area currently suitable for Arabica coffee production by 2050, with a gain of only 9% (Magrach & Ghazoul, 2015). Arabica coffee is especially sensitive to agroclimatic conditions related to temperature and moisture (Magrach & Ghazoul, 2015). Once temperature thresholds are reached, crop cycles are affected and critical phases are triggered, with negative impacts on flowering, fruit set, and pollen count. Above 20-24°C, the net photosynthesis of coffee decreases, and above 23°C, fruit ripening accelerates and quality decreases (Lin, 2007). Maximum and mean temperatures are expected to increase by 2°C in Mesoamerica, which would shift the suitable Arabica coffee altitude range from 400-2000 masl to 800-2500 masl. In countries without high mountains, including Nicaragua and El Salvador, it will not be possible to shift coffee farms up the altitudinal gradient (Ovalle-Rivera et al., 2015). Altitudinal migration of coffee farms is also not feasible in many areas, due to lack of land and competing needs for food production on arable land. Even where land is available at higher elevations, soil conditions may not be suited to Arabica coffee production (Jaramillo et al., 2011). Extreme weather also presents problems for farmers through its impact on soils and physical damage to coffee plants. Heavy rainfall during Hurricane Stan caused fruit drop, damage to infrastructure, and landslides (Philpott et al., 2008). Coffee farms in Chiapas, Mexico that were closest to riverbeds, and coffee farmers with most of their land in coffee production, rather than diversified crops, were most vulnerable to losses from Hurricane Stan (Eakin et al., 2012).

Shaded coffee production

Figure 1: Key climate-related threats to coffee production

Climate-related threats to coffee production:

- Increased temperatures
  - Reduced suitability of Arabica production areas
- Increased frequency and intensity of extreme weather events
  - Flooding, soil erosion
- More erratic rainfall, 5-10% lower rainfall overall
- Increased pest and disease prevalence

The coffee berry borer (Hypothenemus hampei), an insect pest, and a substantial biotic constraint for coffee production, was not found in coffee above 1500 meters until 2001. With increasing temperatures, the coffee berry borer is found at higher elevations, including above 1800 masl in East Africa. Climate models predict that by 2050 the coffee berry borer will be particularly damaging to high quality Arabica coffee at 1200-1800 masl in East Africa, and that the number of generations of coffee berry borer per season could double to 5-10 (Jaramillo et al., 2013). In turn, these agronomic pressures weigh on decisions about land use; for instance, smallholders might be compelled to convert part of their holding to crops that do not provide the same benefits as coffee agroforestry systems, or they might be compelled to abandon coffee altogether. In the worst cases, smallholders might be forced to sell their land to cover short-term needs, undermining their asset base and jeopardizing future well-being.

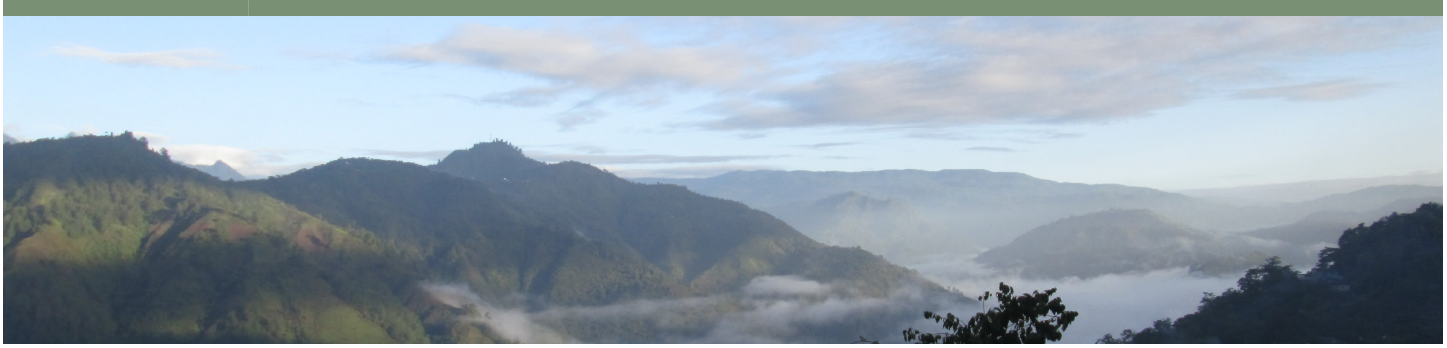
Many of the same interventions that have been applied in the past to cushion coffee farmers from price fluctuations can also function to build climate change resilience and adaptive capacity. Existing adaptation strategies include irrigation, agroforestry and shade management, as well as diversification into crops that are less sensitive to increased temperatures, such as cocoa and mango (Eitzinger, 2013). An important question to examine is what the evidence shows, in terms of what specific practices and interventions have been most successful at building resilience to climate impacts. Here we present a review of data that quantifies the benefits of agroecological practices on coffee farms in building agroecosystem and livelihood resilience to climate change impacts. A table summarizing the evidence is presented below, followed by further description of each resilience indicator. The majority of cases included are from Latin America; however, several examples from other regions are included for their applicability to this topic. The evidence is summarized below (Table 1).

Table 1: Selected results showing the resilience-building capacity of agroecological practices.

Indicator of resilience	Agroecological Practice	Source	Key Results
Microclimate control	Incorporation of shade	a. Camargo 2010	a. 60-70 shade trees/ha decreased air temp. fluctuations by 2-3°C (Brazil)
		b. Siles et al. 2010	b. Coffee leaf temperatures in agroforestry plot (with 25-50% Inga shade) 1-7°C lower than in coffee monoculture (Costa Rica)
		c. Lin 2007	c. Level of shade correlated with smaller fluctuations in temperature, humidity, solar radiation (Mexico)
		d. Barradas and Fanjul 1986	d. Level of shade correlated with smaller fluctuations in temperature and 40% lower evaporation compared to coffee monoculture (Mexico)
Soil moisture retention and water infiltration	Incorporation of shade and leaf litter	a. Tumwebaze et al. 2016	a. Arabica coffee agroforestry plots had 2.6 t C/ha more soil organic Carbon and significantly higher bulk density than coffee monoculture (Uganda)
		b. Cannavo et al. 2010	b. Agroforestry coffee with Inga had less water runoff, higher ground cover, higher water infiltration rates than coffee monocultures (Costa Rica)
		c. Camargo 2010	c. Incorporation of crop residue allowed better root system distribution, reduced soil temperature, increased soil organic matter and soil water retention capacity (Brazil)

Indicator of resilience	Agroecological Practice	Source	Key Results
Minimization of erosion and landslide damage	Incorporation of shade trees, vegetative complexity, and leaf litter	a. Blanco-Sepulveda 2015 b. Philpott et al. 2008	a. Coffee agroforests with 65%+ of ground covered by leaf litter (Inga and Musa) had significantly less erosion (Nicaragua) b. Higher vegetative complexity was correlated with fewer landslides (Mexico)
Nutrient use efficiency	Incorporation of shade	a. Tully et al 2012 b. Avelino et al. 2011	a. Nitrogen losses were three times lower in coffee agroforests with Musa and Erythrina than in coffee monoculture (Costa Rica) b. Litter and pruned branches from legumes on coffee farms contained up to 340 kg/ha/yr of Nitrogen (Neotropics)
Maximization of coffee yields	Shade management	Soto-Pinto et al. 2000	Shade cover had a positive effect on coffee yields between 30-45% shade cover (Mexico)
Pest and disease control	Agroecosystem complexity and shade; Coffee breeding for disease resistance; Biological controls	a.Avelino et al. 2011 b. Jaramillo et al. 2011 c. Avelino et al. 2006 d.Silva et al. 2006 e.Camargo 2010	a. Leaf litter from shade trees is a physical barrier to prevent or delay spread of soil borne disease. Shade cover attracts birds, which can contribute up to 80% of arthropod removal from coffee agroecosystems (Neotropics) b. Lower coffee berry borer densities in shade coffee systems, which harbor beneficial arthropods (East Africa) c. Higher incidence of leaf rust in coffee with more than 230 fruiting nodes per tree (Honduras) d.Hybrid crosses of Hibrido de Timor (HDT) and Caturras and Catuais displayed resistance to most coffee rust races in past e. Obata IAC 1669-20 cultivar is resistant to leaf rust, high yielding, suitable for high planting densities (Brazil)

Indicator of resilience	Agroecological Practice	Source	Key Results
Income stability/security	Crop insurance; Crop diversification; Participation in cooperatives/ support networks; Participation in alternative certifications/ high value markets	a.Borkhataria 2012 b. Rahn et al. 2012 c. Van Asten et al. 2015 d. Ruiz Meza 2014 e.Barham et al. 2012	a.70% of farmers in the study willing to plant shade trees if the practice were supported with insurance, financing (Puerto Rico) b. Farmer vulnerability was reduced through crop and income diversification (honey production, livestock), access to insurance and financing, irrigation infrastructure (Nicaragua) c. Intercropped coffee-banana can increase revenues more than 50% per unit area over either individual crop d. Long-term support of an NGO was critical for climate adaptation project success (Mexico) e. Coffee yields were more important than certified price premiums for increasing net cash returns for smallholder coffee producers (Mexico and Peru)
Food security	Crop diversification; Food production; Livelihood and income diversification	a. Mendez et al. 2010 b. Caswell et al. 2013 c. Chappell and LaValle 2011	a. On-farm biodiversity supports economic and social resilience through food crops, medicinal plants, income, cookstove fuel source, and timber (El Salvador, Nicaragua) b. Coffee farming households experienced 25% fewer 'thin months' after diversifying crops and income (Nicaragua, Mexico, Guatemala) c. Higher crop diversity provides ecosystem services and supports more consistent yields from year to year
Empowerment/ strengthening of social capital	Participation in cooperatives, networks, and higher value markets Participation in farmer field schools	a. Tompkins and Adger 2004 b. Bacon 2010	a. Community resilience increases with expanding networks of support and spaces of engagement b. Members of certified organic and Fair Trade cooperatives felt more empowered and less vulnerable than conventional cooperative counterparts (Nicaragua)



BIOPHYSICAL RESILIENCE FOR CLIMATE CHANGE ADAPTATION:
INDICATORS OF COFFEE FARM RESILIENCE

Shade as microclimate control

Shade trees in coffee agroforestry systems can buffer coffee against temperature spikes and regulate microclimatic temperatures more effectively than in full-sun coffee. Mean daily maximum temperatures in the Atlantic Rainforest biome were 5.4° C lower in agroforestry coffee plots, than in sun coffee plots, on average, across 12 months (Souza et al., 2012). Also in Brazil, shade trees at a density of 60-70 shade trees per hectare were found to decrease air temperature fluctuations by 2-3° C, reduce the risk of frost damage, decrease wind speeds, and increase air relative humidity (Camargo, 2010).

A 15-year experiment of side-by-side Caturra coffee plots at the Coffee Institute of Costa Rica (ICAFE) showed a strong influence of shade canopy on microclimate (Siles et al., 2010). Coffee leaf temperatures were between 1-7° C lower in the shaded agroforestry system (coffee with Inga densiflora shade trees, with percentage shade cover between 25 and 50) than in the coffee monoculture. This is significant, since the optimal temperature for Arabica coffee photosynthesis is 18-24 degrees C, and mean annual temperatures are increasing with climate change. Coffee yields were comparable for the two plots when shade cover was below 50%. There was no evidence of competition for nutrients or water in the agroforestry system. The combined aerial biomass of coffee and shade trees was nearly three times higher in the agroforestry plot than the monoculture, which represents an additional benefit of carbon sequestration potential.

In Chiapas, Mexico, shade cover in coffee agroforests was important in protecting coffee from microclimate extremes and retaining soil moisture, thus representing a viable smallholder climate change adaptation strategy (Lin, 2007). In the study, there was an inverse correlation between the level of shade on the coffee farm and the degree of fluctuations in temperature, humidity, and solar radiation. Shade trees also had the effect of mitigating microclimate extremes and buffering coffee plants from microclimate variability in Brazil, leading to less crop damage from water and heat stress. Maximum leaf temperatures were 4°C lower; Maximum air temperatures were 4.5°C lower; Difference between daily max and min temps 2.1°C lower (Morais et al., 2006).

Shade and leaf litter affects water runoff, soil erosion and water infiltration. Farmers can incorporate shade trees and vegetative complexity to reduce vulnerability to erosion from extreme weather. A study of 10 shade coffee farms in Chiapas, Mexico assessed the influence of various factors on agroecosystem vulnerability to hurricane damage (Philpott et al., 2008). At the landscape scale, higher vegetative complexity was correlated with fewer landslides (the vegetative complexity index accounted for tree species richness, number of trees per m², number of coffee plants per m², stand basal area, and canopy cover) (Philpott et al., 2008).

Perhaps most important for soil protection, especially during heavy rains, is the leaf litter from shade trees, which can also reduce soil temperature, allow for better root system distribution, build soil organic matter and increase soil water retention capacity (Camargo, 2010). A Nicaraguan study on six medium-large coffee agroforests with *Inga* spp and *Musa* spp shade showed that the most significant predictor variable for erosion was the percentage ground cover by leaf litter, followed by slope gradient (Blanco Sepúlveda & Aguilar Carrillo, 2015). Even in slopes with gradients of 50-70%, the presence of a substantial leaf litter layer reduced the influence of slope gradient on soil erodibility (benefit was maximized at 60-65% or more of ground covered by leaf litter). A three-year study comparing Costa Rican coffee agroforestry systems with coffee monocultures showed higher ground cover in agroforestry systems of coffee intercropped with Inga densiflora than coffee monocultures, which resulted in less water runoff (Cannavo et al., 2011). All plots had minimal slope (3-5%).

Agroforestry systems also had higher water infiltration rates than coffee monocultures, a fact that is immediately relevant to regions currently recovering from severe droughts. Deep soil layers had significantly lower water content in the agroforestry systems than monoculture, suggesting that shade trees drew water from deep horizons. In Mexico, coffee farms with a greater percentage shade cover experienced less evapotranspiration water loss from the farm, and soil moisture was maintained more consistently in the high shade sites (30-80% shade cover) than low shade sites (10-30% shade cover) (Lin, 2007).

Shade and leaf litter effects on nutrient cycling and yields

Nutrient-use efficiency and coffee yield stability reflect one aspect of resilience of both the agroecosystem and coffee household socioeconomics. Full-sun coffee monocultures have been promoted by some (Fournier, 1986) for their ability to maximize coffee yields per unit area of land. Farmers may choose sun coffee production under optimal environmental conditions and/or high external inputs, and full sun coffee systems may require fertilizer inputs to maintain yields over time. Shade may decrease Arabica coffee yields due to higher stimulus to vegetative growth rather than flowering and node development (DaMatta, 2004). Full sun stimulates coffee plants to overbear fruit one year, which results in exhaustion of the coffee tree the following year, leading to high variability in coffee yields in a biennial cycle. Shade manages flowering, buffers against overbearing and stabilizes productivity (DaMatta, 2004).

A long-term study in Turrialba, Costa Rica comparing four organic and four conventional coffee agroforests (Caturra coffee variety intercropped with *Erythrina poeppigiana* and *Musa acuminata*) showed that shade trees had a greater effect on soil nutrients than the type or quantity of fertilizer used (Tully et al., 2012). Greater aboveground biomass of shade trees resulted in higher soil nitrogen, whereas nitrogen losses were not significantly different between coffee agroforests fertilized with mineral fertilizers and those fertilized with organic amendments over the 20-year period. Nitrogen losses were three times higher in a nearby coffee monoculture than in the coffee agroforests, suggesting that shade trees help reduce nutrient leaching and maximize nutrient use efficiency (Tully et al., 2012). Long-term experiments in Costa Rica and Nicaragua showed that *Erythrina* shade trees had a positive effect on coffee productivity under moderate organic management, and higher nitrogen use efficiency in terms of coffee yield per kg of Nitrogen applied (Haggar et al., 2011). With similar levels of nutrient inputs, organic and conventional coffee production yielded similar levels of coffee production. Also in this study, comparisons of different levels of nutrient inputs, shade species, and pruning practices showed that leguminous shade trees can benefit coffee production through increased nitrogen availability, but that the benefits are greatest for low or moderate input and organic management than for high input production (Haggar et al., 2011). Under certain circumstances, including sufficient pruning, shade can contribute to coffee yields being maintained or enhanced while minimizing the need for farmers to use fertilizer. Coffee agroforestry plots have also been shown to have significantly higher bulk density and soil organic carbon than coffee monocrop plots (Tumwebaze & Byakagaba, 2016). This shows the carbon sequestration potential of agroforestry, while simultaneously supporting adaptation (Richards and Mendez, 2014).

Shade and pest/disease resistance

The presence of shade trees can result in lower coffee berry borer densities; shade coffee systems can harbor beneficial arthropods that provide biological control of the coffee berry borer (Avelino et al., 2011). Shade cover attracts birds, which can contribute close to 80% of arthropod removal from coffee agroecosystems. Stomach analysis of three arthropod predators, black-throated blue warbler, American redstart, and prairie warbler show approximately half of the stomach content comprised of coffee berry borer. Ants are also important predators of coffee berry borer, and are more abundant in shaded coffee plantations (Avelino et al., 2011).

Coffee leaf rust, caused by the fungi Heileia vastatrix, is another major threat to coffee production, as traditional Typica and Bourbon cultivars are characterized by high susceptibility to almost all known races of coffee leaf rust (Silva et al., 2006). In some cases, higher percentages of shade have been associated with greater incidence of coffee leaf rust (Avelino et al., 2006; Lopez-Bravo et al., 2012), which led coffee agencies such as Mexico's INMECAFE to encourage shade simplification and intensification (Eakin et al., 2012). However, disease pressures only increased beyond the yield threshold of 230 fruiting nodes per tree, as coffee tree yield was the most significant variable in coffee leaf rust incidence (Avelino et al., 2006). Other diseases, such as Rosellinia root rot and American leaf spot disease (Mycena citricolor), may also spread more readily in coffee farms with high planting density of coffee, where dispersal distance is low (Avelino et al., 2011).

Scientific research and technological solutions to the coffee leaf rust challenge have included breeding for resistant varieties, such as the work of World Coffee Research, and chemical control, although these may not be accessible to smallholder coffee farmers due to higher cost (McCook & Vandermeer, 2015). Agroecological management can be a low-cost, labor intensive way for farmers to prevent leaf rust outbreaks (McCook & Vandermeer, 2015). Incorporation of shade trees can reduce wind speeds on coffee farms and minimize the spread of wind-borne pathogens including coffee leaf rust (Avelino et al., 2011; McCook & Vandermeer, 2015). Intercropping with non-host plants, and lining plots with windbreaks and woody borders can also intercept pests and diseases. Reducing wind speeds also benefits coffee by protecting coffee plants from physical damage. Leaf litter from shade trees can also act as a physical barrier to prevent or delay the spread of soil borne diseases (Avelino et al., 2011). Optimal management of the coffee farm, including sufficient pruning, fertilization, and replacement of aging coffee trees, can increase the resilience of plants to diseases and pests (Avelino et al., 2015). There are trade-offs associated with any approach to leaf rust prevention and treatment; what may make agroforestry and shade trees particularly appealing for smallholder farmers is that, coupled with the provision of other ecosystem services and foods and forest products, the benefits may outweigh the potential drawbacks.

Shade to support livelihoods and food security

In addition to the ecosystem services shade trees provide as part of the coffee agroforestry system, their products also contribute to food security and sources of income for farming families. Shade trees are used by farmers for food, firewood, construction, medicine, and other domestic uses (Soto-Pinto et al., 2000). In Nicaragua, number of fruit trees on coffee farms was correlated with fewer months of food insecurity for coffee households (Bacon et al., 2014). In some cases, diversification within and outside of the coffee plot enhanced livelihood security, which in turn could help to preserve coffee agroecosystems through on-farm investment or tolerance of sub-optimal yields. However, there are trade-offs inherent in these strategies, particularly in the conversion of coffee to alternative land uses and in the re-allocation of labor to alternative activities.

A common concern is that shade will reduce coffee yields. Reviewing the literature on coffee production under full sun and regulated shade (approximately 25% shade), Fournier et al. (1988) determined that full-sun coffee yields were 10 to 20 percent higher than those under regulated shade. However, a more recent study of 36 small-scale shaded coffee farms (less than 3 ha, between 600-1100 masl) in Chiapas, Mexico showed a positive effect of shade trees on coffee yields (Soto-Pinto et al., 2000). In this study, shade cover appeared to have a positive effect on coffee yields between 30-45% shade, whereas yields began to decrease above 50% shade cover. The relationship between shade cover and coffee yield is not linear; there is likely a threshold beyond which shade cover has a negative effect on yield (Perfecto et al., 2005).

Furthermore, the economic gains from higher yields under full sun could be partially offset by the costs of more frequent plot renovation as a result of the effect of full sun on the length of the coffee plant's life cycle and on soil characteristics. Gains from higher yields might also be partially offset by the foregone nutrients that shade trees (particularly leguminous trees) could provide (Fournier et al., 1988).

To truly weigh the costs of foregoing higher yields under full sun, researchers and producers must incorporate into their equations the additional benefits that shade trees offer both to the extended life of the coffee plant as a results of optimal microclimatic conditions, as well as to the grower in additional forest products.

Implementing projects for improvements to shade coverage and management implies capital investments, which can be subsidized externally, through on-farm investments, or both. Micro-loans can be used to increase production or to cope with natural disasters and crop loss in the short term (Quiroga et al., 2015). Access to credit has been shown improve food security among Guatemalan coffee farmers, likely due to increasing their investment and land in food production (Caswell et al., 2014). However, in most cases in Central America, financing conditions are unfavourable for small-scale producers (i.e., high interest rates) and households are at-risk of falling into debt (Caswell et al., 2014). The situation can be improved by microfinance opportunities that are tailored to rural agricultural producers with limited collateral (Llanto, 2007).

Coffee cooperatives and other farmer organizations can play key roles in adoption of agricultural best management practices by providing technical assistance to producers, serving both as conduits or collaborators in agronomic research, as well as performing agricultural research internally. They also offer a central body for pooling resources, attracting investments and acquiring credit, from external sources (buyers, investors, NGOs, etc.). Because land use and livelihoods are deeply integrated, it is also interesting to examine how previous development interventions have impacted livelihoods in Central America, given that these factors are tied to the current resilience of coffee agroecosystems.

ACCESS TO SPECIALTY COFFEE MARKETS

Price premiums from alternative certifications, usually in conjunction with producer organizations, deliver economic benefits at both the household (including farm investment and expansion and sustainable management practices), (Bacon et al., 2008; Donovan & Poole, 2014) and community levels, through development projects, health, and education programs (Gingrich & King, 2012). In terms of income, recent research on Fair Trade and Organic certifications showed that it can deliver income increases toward a coffee farmer's income of between 5% (Barham & Weber, 2012) and 15% (Gingrich & King, 2012).

However, the impact of access to specialty markets on coffee-based livelihoods resilience is limited, particularly for smallholder farmers with low yields and high vulnerability (Mendez et al., 2010b), and coffee yields could be more important than price premiums for increasing net cash returns for coffee producers (Barham & Weber, 2012). In addition, real prices for certified coffee often do not keep pace with the rising costs of sustainable production (new adaptive practices could exacerbate this cost-price squeeze). Furthermore, recent changes within the governance structure of alternative trade schemes have reduced smallholders' influence, calling into question alternative trade's commitment to farmer empowerment. Nevertheless, going forward, livelihood resilience is likely to depend on a balanced approach toward international trade and local modes of resistance (Bacon, 2015).

Community focus group in Guatemala, 2015

COOPERATIVE MEMBERSHIP

Mill outside of San Juan Del Sur, Nicaragua, 2015

In addition to their roles of providing access to markets, technical information and, in some cases, credit, cooperatives and other collective associations have also been instrumental in food security and food sovereignty by managing direct interventions for food access (such as organizing communal grain storage co-ops and distributing food donations), as well as representing smallholders in broader agricultural, environmental and food policy debates (Bacon, 2015). Increasing adaptive capacity for smallholder farmers in the Biosphere Reserve region of Mexico has been aided by the formation of strong producer groups (cooperatives), along with diversification of land use types and crops. This has been supported by 'co-management', which entails shifting land rights and responsibilities from government to local resource users. In this particular case, the long-term support of an NGO and a highly motivated local community were essential in allowing for effective increases in adaptation, in combination with favorable biophysical attributes (Ruiz Meza, 2014).

Capacity building and financing, including earning carbon offsets that can be traded to fund adaptation practices, can reduce farmer vulnerability (Rahn et al., 2014), and support networks and institutions help build social resilience to environmental hazards (Tompkins & Adger, 2004). Similar to distinctions in type and quality of shade coffee, cooperatives vary widely by function (e.g., production or marketing cooperative) and stages of development. Cooperatives are also poised within unique historical contexts. These intricacies make it difficult to conclude whether the cooperative model, in abstract, provides (and will continue to provide) benefits in terms of the socioeconomic indicators here. For instance, benefits from membership in Central American coffee cooperatives have had to be qualified by the concurrent advantages accruing from political movements and agrarian reforms (Bacon, 2015). In the future, if coffee cooperatives are able to further consolidate to increase their profits and power, questions emerge around the impact of consolidation on smallholder empowerment and co-optation by local and regional elites. And while cooperatives can have a positive impact on empowerment, special efforts have been necessary to ensure that they empower all genders equitably (Bacon, 2010).

Assertions around the positive contributions of farmer organizations should include other forms of association among farmers (e.g., learning exchanges such as Campesino a Campesino and Farmer Field Schools, international movements such as La Via Campesina, and crop-specific associations). In addition to promoting self-organization among farmers, these bodies can contribute to farmer resilience through improved connection with service providers and more consistent access to markets, including specialty markets and markets for multiple commodities when relevant (Irwin and Campbell, 2015). Those seeking to leverage these strengths through investments should be guided toward developing interventions that are in line with the strategic plans of these farmer groups (including the implementation of context-specific food security interventions, such as grain storage facilities and seed banks), building democratic, operational and gender equity capacities, and forming strategic alliances with social agrarian movements (Bacon, 2015).

DISCUSSION & CONCLUSION

A recurring theme in the literature is that, in many cases, coffee farmers perceive climate risks as inevitable. Farmers might not explicitly cite climate change as a priority concern, expressing more concern about market volatility and low prices (Eakin et al., 2006. Tucker et al., 2010). In our own research with coffee farmers, we have witnessed the importance of a place-based perspective and cultural sensitivity when working with coffee farmers on climate change. Farmers were more motivated to discuss and act on climate change when it was framed in their own terms, including climate 'chaos' (Caswell, personal communication), underlining the continuing relevance of farmers' knowledge to larger scale adaptation strategies (Castellanos et al., 2013).

A review of the evidence shows that the practices of shade management and coffee agroforestry build farm resilience to the greatest number and variety of climate-related threats. Increasing plant diversity, and managing density, in coffee agroecosystems can affect the microclimate of the understory, including buffering air and soil temperatures, reducing wind speed and solar radiation, and increasing soil humidity and relative humidity (Avelino et al., 2011). Shade trees can also stabilize soils, contribute soil nutrients, minimize coffee pest and disease pressure, and provide additional income, food, medicinal plants, firewood and timber. (Méndez et al., 2010: Toledo & Moguel, 2012). There are additional benefits of incorporating a greater number and diversity of shade trees on coffee farms, from the perspective of carbon sequestration (mitigation) and biodiversity conservation of certain species (Jha et al., 2011).

Despite the assumption that coffee produced under a shade canopy is less productive (Magrach & Ghazoul, 2015), shade has both direct and indirect effects on coffee yields, most of which can be positive. The optimal species, diversity and densities of shade trees can vary, depending on the primary goal (stabilizing soils, decreasing on-farm temperatures, and/or supporting farmer livelihoods through additional products).

Considering the complexity of research on shade coffee and the urgency of the situation, we recommend approaches that work closely with growers and rural communities to develop on-farm methods for measuring shade levels, choosing between different types of shade cover according to local needs and interests, and identifying indicators and parameters relevant to growers in order to evaluate the impact of shaded agroforestry systems. This approach integrates rigor and participation without postponing action.

At least part of the reason that shade was highlighted during our literature review was that it has received the most scholarly attention; other agroecological practices might fit within a climate change adaptation program, but the analysis of their impact on resilience indicators has been sparse. The use of resistant coffee varieties is an additional adaptation strategy (Camargo, 2010; Silva et al., 2006), including the use of Robusta coffee. However, genetic selection must be carefully used as a solution and may not be appropriate for smallholders with limited financial resources, in particular where it replaces geographically-specific varieties that have been selected by farmers. If disease resistant hybrids are promoted, farmers and cooperatives should be included throughout the process to ensure that their knowledge is taken into account and to increase the likelihood of acceptance. Furthermore, a number of articles have focused on the impact of development interventions on assets and food security, but few have attempted to evaluate their impact on less easily quantifiable indicators, such as empowerment. We consider this a shortcoming for a more complete understanding of resilience and vulnerability.

The resilience of coffee agroecosystems and livelihoods will rely on more than household-level assets and strategies. In order to reduce the vulnerability of smallholder coffee farmers, inequalities need to be minimized through initiatives that strengthen social and political equity and empowerment (Ruiz Meza, 2014).

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