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Climate change adaptation, mitigation and livelihood benefits in coffee production: where are the synergies?

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Abstract There are worldwide approximately 4.3 million coffee (*Coffea arabica*) producing smallholders generating a large share of tropical developing countries' gross domestic product, notably in Central America. Their livelihoods and coffee production are facing

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major challenges due to projected climate change, requiring adaptation decisions that may range from changes in management practices to changes in crops or migration. Since management practices such as shade use and reforestation influence both climate vulnerability and carbon stocks in coffee, there may be synergies between climate change adaptation and mitigation that could make it advantageous to jointly pursue both objectives. In some cases, carbon accounting for mitigation actions might even be used to incentivize and subsidize adaptation actions. To assess potential synergies between climate change mitigation and adaptation in smallholder coffee production systems, we quantified (i) the potential of changes in coffee production and processing practices as well as other livelihood activities to reduce net greenhouse gas emissions, (ii) coffee farmers' climate change vulnerability and need for adaptation, including the possibility of carbon markets subsidizing adaptation. We worked with smallholder organic coffee farmers in Northern Nicaragua, using workshops, interviews, farm visits and the Cool Farm Tool software to calculate greenhouse gas balances of coffee farms. From the 12 activities found to be relevant for adaptation, two showed strong and five showed modest synergies with mitigation. Afforestation of degraded areas with coffee agroforestry systems and boundary tree plantings resulted in the highest synergies between adaptation and mitigation. Financing possibilities for joint adaptation-mitigation activities could arise through carbon offsetting, carbon insetting, and carbon footprint reductions. Non-monetary benefits such as technical assistance and capacity building could be effective in promoting such synergies at low transaction costs.

Keywords Exposure to climate change · Sensitivity to climate change · Adaptive capacity · Carbon footprint · Carbon insetting · Carbon offsetting · Nicaragua

1 Introduction

There are worldwide approximately 4.3 million coffee producing smallholders generating a major share of several countries' gross domestic product (Jha et al. 2011). In Central America, Arabica coffee (*Coffea arabica*) sustains around 300′000 farmers and provides 1′700′000 seasonal jobs (Castro et al. 2004). Due to their vast extension (nearly 1′000′000 ha in Central America), coffee plantations have large-scale environmental impacts (Jha et al. 2011). Traditional coffee agroforests can make a significant contribution to biodiversity conservation and carbon sequestration (Tscharntke et al. 2011; Albrecht & Kandji 2003), although this role is increasingly threatened by the intensification of coffee production systems (Somarriba et al. 2004; Vaast et al. 2005).

Coffee producers face major challenges to meet livelihood needs due to their small value shares in the coffee supply chain and volatile market prices, now compounded by climate change (Bacon 2005; Schroth et al. 2009; Läderach et al. 2011b). The coffee plant is highly sensitive to climate with respect to productivity and quality (DaMatta 2004; Vaast et al. 2006; Läderach et al. 2011a). Unpredictable rainfall, extended drought periods and extreme weather events are becoming more common in a number of coffee producing areas throughout the world (Schroth et al. 2009; Ericksen et al. 2011). Future climate change will also result in shifts in the incidence of pests and diseases that could be detrimental to coffee yields (Jaramillo et al. 2009; 2011).

The agricultural sector accounts directly and indirectly for 1/3 of global greenhouse gas (GHG) emissions with 74 % originating in low-and middle-income countries, where smallholders predominate (Smith et al. 2007). This raises the prospect of using climate change mitigation as a vehicle for incentivizing and perhaps funding climate change adaptation if courses of action can be identified that simultaneously reduce net GHG emissions from coffee production and increase the resilience of coffee farmers to climate change (Matocha et al. 2012). This could include increasing carbon sequestration in shade trees or soils or reducing carbon emissions through agronomic or post-harvest measures, which can be significant in coffee (Tchibo 2008). Several previous studies have pointed out potential synergies between mitigation and adaptation in coffee agroforestry systems and landscapes while simultaneously improving farmers' livelihoods (Lin 2011; Matocha et al. 2012; Schroth et al. 2009).

The objective of this paper is to analyze the potential for triple wins for climate change mitigation, adaptation and farmer livelihoods for smallholder organic coffee production systems in northern Nicaragua. We assess the vulnerability of coffee farmers to climate change through climate modeling and identify agronomic and other measures that would allow farmers to reduce their net carbon emissions while increasing their resilience to climate change. For those measures that show the highest potential synergies between climate change mitigation and adaptation, we discuss whether carbon trading based on mitigation measures would be a viable way to subsidize adaptation and livelihood improvement. We also discuss alternative ways to capitalize on synergies between climate change mitigation and adaptation. We propose that the methodology and conclusions are applicable to coffee producers elsewhere and, with some modifications, to other smallholder tree crop production systems such as cocoa (*Theobroma cacao*).

2 Methods

2.1 Study region

The study region is San Juan del Río Coco, department of Madriz in the northern central region of Nicaragua. It is a rural area with the majority of the 21′000 (INIDE 2008) inhabitants making their living from agriculture, with coffee as their main crop. Staple crops such as maize (*Zea mays*), beans (*Phaseolus vulgaris*) and sorghum (*Sorghum spp.*) are most important for subsistence and are cultivated in fallow rotations. Additionally, some farmers practice livestock farming and forestry (Table 1). As a consequence of their high tree cover, the coffee farms of San Juan del Río Coco form green islands with a unique microclimate in the landscape that is otherwise dominated by cattle ranches. There was a general trend that the smaller the farm size, the higher the shade tree cover and the lower the educational background of the household head.

2.2 Data collection

The approach to identifying practices with potential for synergies between adaptation, mitigation and livelihood improvement is illustrated in Fig. 1. Field data were collected in April 2012. We worked with four organic coffee cooperatives whose combined membership was 1,500. To obtain a representative sample of coffee farms we included farms at different altitudes and with different sizes. For the baseline assessment of GHG emissions we interviewed 60 farmers and visited 21 farms and 4 centralized post-harvest infrastructures. Additionally, we interviewed 4 local agricultural extensionists, one of each cooperative. For the vulnerability assessment we interviewed the same 60 farmers as for the GHG baseline assessment plus 36 additional farmers. Coffee production systems were classified according to their vegetational and structural complexity as either traditional or commercial

Table 1 Farmer and land use characteristics in San Juan del Río Coco Nicaragua[a]

Age of the farmers	%	Distribution of land uses	%	Coffee area per farm	%
<30 years	5	Maize-beans	7	<2 ha	46
>30 to 50 years	58	Pasture	6	2–4 ha	28
>50 years	37	Fallow land	12	4–6 ha	16
		Forest	15	>6 ha	8
		Coffee	60		

[a] Data are from 96 farmers from four cooperatives that had a total membership of 1,500

polycultures according to Moguel and Toledo (1999). In the more complex traditional polyculture systems, coffee is grown alongside numerous native and introduced plant species including remnant forest trees and canopy height is 20–30 m. The commercial polyculture systems, on the other hand, are characterized by complete removal of the original forest canopy trees and the introduction of specific shade trees that are particularly appropriate for coffee cultivation, often nitrogen-fixing legumes, and canopy height is less than 15 m.

2.3 Assessment of climate change mitigation potential

The main activities related to coffee production were assessed considering their potential to mitigating climate change (Table 2). This included activities on the farm as well as in the supply chain. In addition to coffee production we evaluated different mitigation options related to other livelihood activities of the coffee farms, specifically cooking and water purification. We also evaluated the planting of trees in- or outside the coffee plots, forest protection, and management of the bean-maize and livestock systems that are part of typical smallholder coffee farms of the region.

2.3.1 Quantification of the product carbon footprint

The GHG emissions of coffee production and its different components were estimated using the Cool Farm Tool (CFT) software (Hillier et al. 2011), version 2.0 beta 2. It uses a combination of Tier II methodology of the United Nations Intergovernmental Panel on Climate Change (IPCC) and empirical GHG quantification models built from peer-reviewed studies. The system boundaries for estimating GHG emissions of the coffee supply chain included cultivation, processing of the coffee cherries and their transportation to the warehouses in the port(s) of export (Fig. 2). Information about yields, water, energy and fertilizer use, compost production, number of shade tree

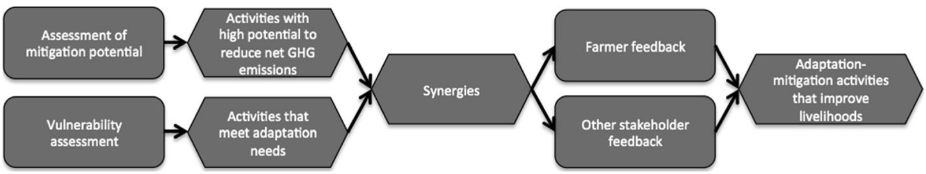


Fig. 1 Methodological framework for assessing "triple benefits" (climate change adaptation, mitigation and livelihood improvement) for coffee farmers in Nicaragua. GHG refers to greenhouse gas

Table 2 Activities assessed regarding their potential to mitigate climate change in coffee systems

System	Activities	Assessment Method
Coffee	Cultivation	Cool Farm Tool
	Post-harvest processing	Cool Farm Tool
	Drying and selection	Cool Farm Tool
	Transportation	Cool Farm Tool
Forest	A/reforestation	Survey & literature
	Forest protection	Survey & literature
Bean-Maize	Slash-&-Burn	Survey & literature
Livestock	Extensive cattle ranching	Survey & literature
Household	Cooking	Survey & literature
	Water purification	Survey & literature

species, etc. were collected through farmers interviews and verified with the help of local agricultural extensionists and through field visits. Average values for yields, fertilizers and other inputs and related GHG emissions were calculated for each of the two system types and average GHG emissions per system type were calculated with the CFT software. Tree densities were calculated from the numbers of trees per species provided by the farmers and total coffee area and were cross-checked in one representative 10×10 m plot per farm, resulting in a total inventoried area of 1,000 m^2 for traditional polycultures and 1,100 m^2 for commercial polycultures. The diameter at breast height of all trees was measured in these plots. Average carbon stocks for each system type were estimated with allometric relationships provided by the CFT software based on published literature.

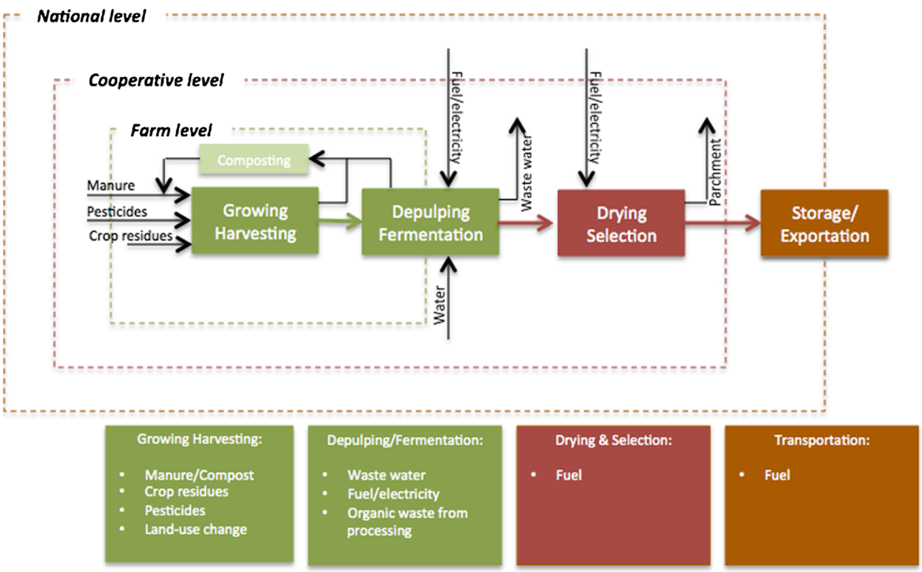


Fig. 2 System boundaries with emission sources for the carbon footprint assessment

2.4 Assessment of vulnerability to climate change

An indicator-based vulnerability index was used to identify and prioritize adaptation needs (Baca et al. 2011; Eitzinger et al. 2012). The approach is based on the IPCC definition of vulnerability (Carter et al. 2007) taking into account exposure of crops, and sensitivity and adaptive capacity of coffee producing families to climate change.

2.4.1 Exposure

Exposure of coffee to climate change was modeled using the crop niche model Maxent (Phillips et al. 2006) with 3,500 coffee farm locations covering the entire coffee production areas of Nicaragua. Climatic suitability of coffee growing was mapped using current climate data from the WorldClim database (Hijmans et al. 2005). Future (2050 time-slice representing 2040–2069) climatic suitability was modeled using statistically down-scaled climate data from 20 Global Circulation Models recommended by the IPCC (Intergovernmental Panel on Climate Change) (2007) for Emissions Scenario A2a (regionally-oriented economic development). The used downscaling method is based on the sum of interpolated anomalies to a 30 arc-seconds resolution of the monthly climate surfaces from WorldClim (Ramirez-Villegas & Jarvis 2010). The suitability change was classified into three groups as low, medium, and high.

2.4.2 Sensitivity and adaptive capacity

The indicators representing sensitivity and adaptive capacity were identified through participatory workshops with farmers and validated by experts (Baca et al. 2011). The participatory workshops with farmers aimed at identifying their perceptions regarding impacts of past climatic events on coffee production and their livelihoods. Based on this information, 20 indicators were developed (Table 3). Data for each indicator on a scale from 0 (no impact) to 5 (strong impact) were collected through the 96 farmer interviews. To classify the 96 families into groups of low, medium, and high sensitivity and adaptive capacity, a cluster analysis (Ward's method) was conducted. Statistical significance of the groupings was tested with multivariate analysis of variance (Hotelling, Bonferroni adjusted). Each of the three components of the vulnerability index—exposure, sensitivity, and adaptive capacity—was given equal weight when aggregated into a final vulnerability score.

2.5 Identification of triple win options

The potential mitigation practices were classified based on their potential to (i) contribute to adaptation, (ii) improve farmer livelihoods and (iii) increase carbon sequestration or reduce the product carbon footprint. The potential for adaptation was based on whether or not the practice could contribute to one or more adaptation needs taking into account adaptation priorities as identified in the vulnerability assessment. A careful evaluation of possible trade-offs was conducted with regard to immediate and future unintended outcomes, based on a literature study and farmer feedback while discussing the identified activities. Farmer and other stakeholder feedback also ensured that the adaptation-mitigation activities that were prioritized were those that offered the greatest benefits for local livelihoods (Fig. 1).

Table 3 Indicators informing on sensitivity and adaptive capacity to climate change in coffee systems

Vulnerability	Capital	Indicator	Description
Sensitivity	Natural	Conservation	Deforestation, fires and pollution weaken ecosystems making them less resilient to stresses such as climate change.
		Soil properties and fertility	Agricultural land with good soil present less vulnerability and have higher adaptive capacity.
		Access to and availability of water	Reduced rainfall could significantly affect the sensitivity of livelihoods.
	Financial	Variability of annual productivity	Resolving the problem of variable yield is crucial for the survival of smallholders living in marginalized areas.
	Physical	Road type	Competitiveness and efficiency of the family to transport their products to the closest markets.
		Transportation type	Opportunity to access market and negotiate better prices.
		Housing quality	Bad sanitary infrastructures are less prepared to confront climate change. Housing material determines resistance to extreme events such as hurricanes or excessive rainfall.
	Human	Health and nutrition	Climate change influences the basic health requirements, clean air, potable water, sufficient food and secure housing. Many fatal diseases such as diarrhea, malnutrition, malaria and dengue are very sensitive to climate and it is expected that this will worsen with climate change.
		Migration	Migration could increase as a consequence of climate change.
Adaptive capacity	Natural	Conservation	Deforestation, fires and contamination weaken ecosystems making them less resilient to stresses such as climate change.
		Pollution	Negatively affects ecosystem services, resilience and human health.
	Physical	Viability of post-harvest infrastructure	Heavily dependent on water availability and relative humidity for drying.
	Financial	Access to credits	Favors investment and adoption of technologies.
		Income diversification	Reduces exposure of sensitive economic activities to climate, improving economic perspectives on the long term. Risk management.
		Access to specialty markets	Increases family income. If climate affects coffee quality then this will directly impact family income.
		Access to alternative technologies	Can reduce climatic stresses (e.g. irrigation, water storage).
	Social	Organization	Social capital can increase access to different resources.
		Policies related to the coffee sector, environmental laws and spatial planning	Knowledge of policies enables participation. Knowledge and fulfillment of environmental

Table 3 (continued)

Vulnerability	Capital	Indicator	Description
			laws and spatial planning can help improve conservation of ecosystem services.
	Human	Access to formal and informal education	Education contributes to sustainability by allowing critical assessment of environmental problems and potential solutions.
		Agro-ecological knowledge	Yield variability is mainly due to management factors rather than soil or temperature (Lobell et al., 2002).

3 Results and discussion

3.1 Characterization of production systems

All farmers managed a shaded coffee production system and used the prunings of their shade trees as firewood. Depending on farm size and management, between 2 and 17 species of shade trees were present with uses including timber, fruits, firewood, and Nitrogen fixation. Smaller farms tended to have higher total numbers of species than larger farms. There was a general trend of species homogenization towards *Inga* spp. x banana (*Musa paradisiaca*) systems, which was more evident in the commercial systems. Two soil conservation practices were predominant in the area, namely growing of coffee on contour lines across the slopes and terracing. All visited systems were organic certified, therefore none reported the use of chemical inputs. Instead they used compost made out of coffee pulp, manure, and foliage and prunings of shade trees. Organic pesticides were applied.

With regard to the post harvest infrastructure, 85 % of the farms had 1–3 infiltration pits for the waste water from coffee de-pulping and fermentation, while the remaining 15 % released their waste water directly into natural water courses contrary to environmental legislation. Some had waste water filters to reduce the contamination of surface- and groundwater.

Bean-maize production was based on traditional shifting cultivation. The crops were cultivated during 1–3 years after which the land was left fallow for regeneration. Because the fallow period was mostly reduced to 3–7 years, soil fertility tended to decline over time (Shaxson 2000; Sommer et al. 2004).

Livestock systems in the region were based on natural pasture without any trees. This system is especially vulnerable in the dry season due to the low quantity and quality of feed and in the rainy season due to high risk of soil erosion.

3.2 Mitigation potential

3.2.1 GHG emission sources in coffee production

The main sources of GHG emissions for the prevalent coffee production systems were identified as - in order of decreasing importance—(1) compost production, (2) coffee de-pulping and fermentation, (3) decomposition of tree litter and prunings in the field, and (4) compost application (Table 4). The emissions differed little between the two system types, therefore only average values are presented. Compost was produced either in a fully or

Table 4 Greenhouse gas emissions (in kg of CO_2 equivalent) per hectare and per kg of green coffee in organic coffee production systems in San Juan del Río Coco, Nicaragua, estimated with the Cool Farm Tool software

Production step	Source of emission	Kg CO_2 e ha^{-1}	Kg CO_2 e Kg^{-1}	%
Farming	Compost production	1′629	2.22	38
	Compost application	503	0.68	12
	Decomposition of tree litter and prunings	762	1.04	18
Post-harvest processing	Depulping and fermentation	1′295	1.76	30
Drying and selection	Energy consumption	23	0.03	1
	Transport	55	0.08	1
Total annual emissions		4,267	5.81	100

partially aerated way. Better composting methods such as biodigesters, which have no emissions, could reduce overall emissions by 13−38 %. Wastewater from depulping and fermentation was a major source of methane emissions. Decomposition of tree litter and prunings resulted in N_2O emissions, as did compost application to the coffee plants.

3.2.2 Carbon stocks within coffee plots

Carbon stocks were already relatively high in the current production systems, making it unlikely that further planting of shade trees in the coffee plots would be possible without compromising coffee yields (Table 5). This problem has also been encountered in another carbon project with coffee farmers in southern Mexico (Schroth et al. 2011). Only some farms with low shade tree densities at lower altitudes may have opportunities to plant more trees to regulate the microclimate (Lin, 2007). Where coffee growing becomes unviable in the future due to temperature increase, the carbon stocks preserved by these highly shaded coffee systems might be lost if shaded coffee farms are replaced with other land uses such as food crops or pasture as seems likely given the current land use situation in San Juan del Río Coco. If shaded Arabica coffee farms were replaced with cocoa or Robusta coffee agroforestry systems, the change in carbon stocks would be less dramatic.

3.2.3 Mitigation options outside the coffee plots

Among the evaluated practices, afforestation/reforestation, boundary tree plantings, and avoided deforestation could sequester significant amounts of carbon (Table 6). Reforesting with forest or coffee agroforestry systems on degraded lands could also improve other ecosystem services, such as soil and water conservation, and reduce land degradation. Boundary tree plantings can sequester substantial quantities of carbon (Torres et al. 2010;

Table 5 Carbon stocks in coffee production systems of San Juan del Río Coco, Nicaragua

Production system	Carbon stocks (t C ha-1)		
	Min	Max	Mean
Traditional polyculture	8	104	41
Commercial polyculture	4	39	16

N=10 for traditional polyculture and *N*=11 for commercial polyculture

Table 6 Climate change mitigation potential of management options in organic coffee farms in San Juan del Río Coco, Nicaragua

Practices		Carbon footprint reduction potential	Carbon sequestration potential	Financial feasibility	Comments
Afforestation/Reforestation	Forest on degraded land	–	High	Inexpensive	High area availability
	Coffee agroforestry systems on degraded land	–	High	Inexpensive	High area availability
	Boundary tree plantings	–	Medium	Inexpensive	High area availability
Avoided deforestation		High	Low	Inexpensive	Currently there is no pressure on forest, but this is expected to change due to suitability shifts of coffee and population increases
Waste water treatment		High	–	Expensive	Complex technical and infrastructural implementation due to decentralized post-harvest infrastructure on farms
Cooking stoves		–	Low	Expensive	No pressure on biomass. Pruning from shade-trees used as firewood.
Water filter		–	Low	Inexpensive	No pressure on biomass from water boiling since prunings from shade-trees used as firewood.
Sustainable agricultural land management on coffee plots	Soil conservation	Low	–	Inexpensive	Organic certified, soil conservation practices are already used
		High	–	Inexpensive	
	Optimal use of organic fertilizer				Knowledge of soil properties per plot required
	Incorporating more shade trees	–	Low	Inexpensive	Already high shade tree densities

–, not applicable

Luedeling et al. 2011) without compromising crop productivity. In another carbon project with coffee farmers in Chiapas, Mexico, boundary tree planting was the practice most commonly chosen by farmers (Schroth et al. 2011).

On the other hand, there was no potential of mitigation from improving forest management. Because the forests are not logged and are composed of native trees there was no possibility to reduce GHG impacts from unsustainably managed forests. There was also little potential for reducing GHG emissions by improving the efficiency of cooking stoves, which were already fairly efficient. Neither was there a potential for reducing the use of firewood for water purification because this was taken entirely from the prunings of shade trees. Generating energy from the biomass that was not already used as fuelwood was also unattractive since most of it was used for compost production.

3.3 Vulnerability to climate change

3.3.1 Exposure

The climatic suitability for coffee growing in the study area is predicted to decrease for all farmers in the sample (Fig. 3). According to the climate change models, total annual precipitation in Nicaragua is predicted to decrease from 1,740 mm to 1,610 mm by 2050, while the maximum number of dry months will remain constant at 5 months. The mean annual temperature will increase by 2.2 °C, while the mean daily temperature range will increase from 10.4 °C to 10.6 °C. The most decisive climatic variables for the predicted decrease in climatic suitability for coffee are the increase of maximum temperature of the hottest month (reducing coffee quality) and, to a lesser extent, the decrease in precipitation of the wettest month. Furthermore, precipitation variability (coefficient of variation) is predicted to increase which could cause erratic flowering and ripening cycles requiring additional harvesting effort. Since harvesting represents the majority of production costs, this could impact on the economic viability of coffee farming.

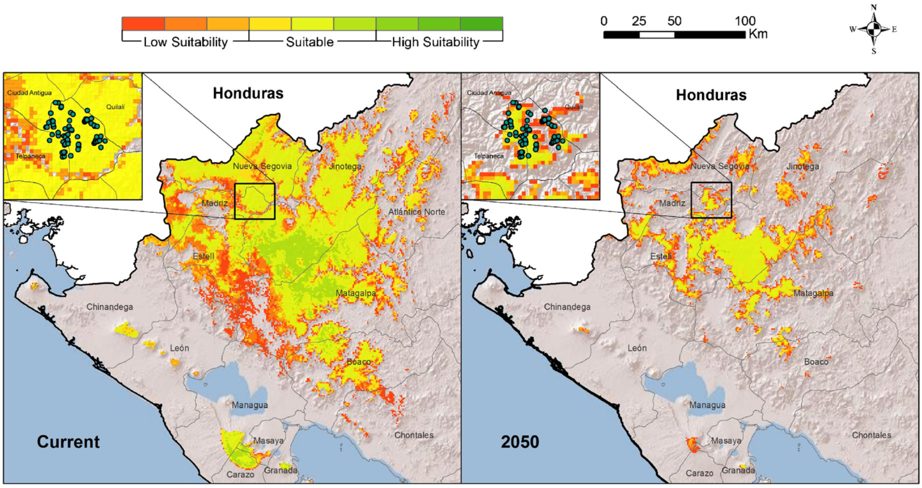


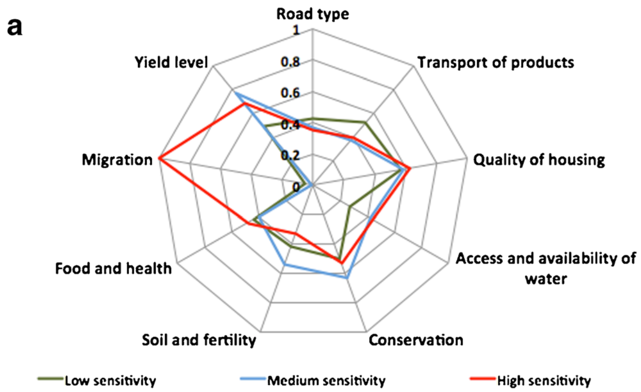
Fig. 3 Change in climatic suitability for growing Arabica coffee in San Juan del Río Coco, Nicaragua, between current and 2,050

We grouped the farmers into three groups depending on their degree of exposure (i.e. magnitude of change in suitability), namely highly exposed (24 % of farms), medium exposed (40 %), and little exposed farmers (36 %). Highly exposed farms were mostly located at relatively low altitudes, while little exposed farms were the ones located at the highest elevations.

3.3.2 Sensitivity and adaptive capacity

The highly sensitive group was characterized by currently high yield variability and high migration. Permanent migration of family members resulted in high sensitivity for the households' livelihoods while families without family members migrating were characterized with low sensitivity. Yield variability over 4 years per farm was compared to the local mean annual productivity, considering a yield variation above 35 % with a tendency of decreasing yield as indicator of high sensitivity. More than 74 % of the families had production levels at least 1/3 below the local average. This may be due to insufficient resources available and/or inappropriate management of production systems (Fig. 4a).

Farmers presenting low adaptive capacity were characterized by high dependency on coffee and little diversification of income with products such as maize, beans, bananas,



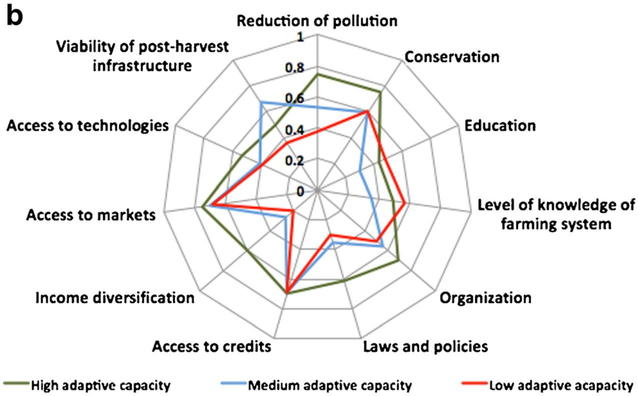


Fig. 4 Relationship between the indicators and the differing degrees of climate change sensitivity (**a**) and adaptive capacity (**b**) of coffee farmers in Nicaragua

citrus, poultry, eggs, livestock, and non-agricultural income such as day's wages, remittances, etc. This was aggravated by the fact that the income from coffee did not suffice for buying the required food during the entire year, resulting in seasonal food insecurity (Caswell et al. 2012). Further indicators characterizing families with low adaptive capacity were their lack of knowledge of policies related to the coffee sector, environmental laws and spatial planning, weak organizational links, and poor access to alternative technologies for example for coffee fermentation and drying (Fig. 4b).

3.3.3 Vulnerability and adaptation needs

From the 96 interviewed families it was possible to identify the relative vulnerability of 86 families due to some missing data from 10 farms. We classified the farmers' vulnerability into relative classes low, medium, and high. High vulnerability was determined by either the combination of high exposure, medium sensitivity and low adaptive capacity or the combination of medium exposure, high sensitivity, and low adaptive capacity and was represented by 5.2 % of the sample. High exposure was observed to be mainly in conjunction with low sensitivity and low adaptive capacity (10.4 %) which was attributed a medium vulnerability.

A medium and high impact of climate change was predicted to substantially affect coffee productivity and quality with significant risk of losses. This will most severely affect producers located at altitudes below 1000 m. Furthermore, the high dependency (on average 65 % to 75 %) of the families' livelihoods on coffee increased their risk of food insecurity, health problems and access to education in case coffee fails for climatic or other reasons. The farmers' vulnerability was reinforced by high variability of coffee production as well as migration, which reduced the availability of labor. Low access to information, alternative technologies and financial resources increased the vulnerability of the families' livelihoods.

Adaptation is therefore required regarding the decrease of climatic suitability for coffee growing, the high dependency on coffee, and the high variability of coffee productivity (Table 7). In order for farmers to implement these practices they need access to knowledge, financial resources, and labor. Therefore, capacity building and a financing mechanism are required. Adapting and improving living conditions may also reduce the high out-migration that restricts the needed labor and jeopardizes the permanence of coffee production in the region.

3.4 Synergies between adaptation and mitigation

Among the identified activities, some presented strong synergies, while others served either adaptation or mitigation but not both (Table 8).

While afforestation of degraded areas with forest trees would result in highest mitigation potential, afforestation with coffee agroforestry systems would result in a range of additional benefits that are more important for the local livelihood needs. These benefits would include increased income from coffee production and capacity strengthening for improving coffee productivity and adaptation to climate change. The vulnerability assessment allowed prioritizing agronomic practices that can improve productivity (e.g. improved soil conservation practices, optimized fertilization) and facilitate adaptation (e.g. revert trend of shade tree homogenization to maintain forest microclimate and increase pest suppression, increased water efficiency in post-harvest processing).

Table 7 Adaptation needs and options for coffee farms in San Juan del Río Coco, Nicaragua

Vulnerability	Adaptation options	Practices
Climatic suitability decrease for coffee growing	• Agronomic practices that adapt coffee crops to changing climate (temperature & water stress; increase of pest & disease incidents)	• Diversified multistrata shade management • Adapted varieties
	• Infrastructural practices that reduce water stress	• Irrigation • More efficient use of water in post-harvest processing
High dependency on coffee	• Diversification	• Improvement of bean-maize production
	• Crop insurance	• Improvement of fruit trees on coffee plots • Honey production • Livestock • Boundary tree plantings
High variability of coffee productivity	• Better agronomic management related to ○ Soil conservation ○ Fertilization ○ Pest & disease management	• Soil conservation practices • Site specific fertilization • Diversified shade trees for pest suppression

The predicted suitability shifts of coffee towards higher altitudes could lead to land use conflicts by putting pressure on existing forests or newly afforested areas at higher altitudes. To reduce the potential for such future conflicts, in areas where coffee suitability is predicted to remain constant or increase, preference should be given to afforestation with coffee agroforestry systems rather than pure forestry plantings. Secondly, payments to communities for avoided deforestation could help protect existing forests and compensate coffee farmers

Table 8 Synergies and trade-offs of practices with adaptation and mitigation potential of organic coffee farmers in Nicaragua. Mitigation potential is presented through carbon footprint reduction potential (CFRP) and/or carbon sequestration potential (CSP)

Category	Practice	Adaptation potential	Mitigation potential	
			CFRP	CSP
A-/Reforestation	• Forest on degraded areas	Medium	–	High*
	• Coffee agroforestry on degraded areas	High	–	High*
	• Tree plantings as windbreaks	High	–	Medium*
Sustainable agricultural land management	• Improved soil conservation practices in coffee agroforestry systems	High	Low	Low
	• Promote adequate fertilization	High	Low	Low
	• Improved slash and mulch agroforestry system for bean-maize cultivation	High	Medium	Medium
	• Silvopastoral system	Medium	–	Medium
Post-harvest processing	• Biodigesters and wastewater treatment	Medium	High	Medium*
Avoided deforestation		Medium	High	Medium*

* Viable carbon credit generating activities under Clean Development Mechanism (CDM), Verified Carbon Standard, and CDM Gold Standard.

for forgone opportunities to move their coffee farms to higher and cooler land (Cortina-Villar et al. 2012). Alternative crops or non-agricultural livelihood opportunities need to be identified for those areas where the climate will become unsuitable for cultivating coffee.

Diversification is an important aspect of the adaptation to climate change (Lin, 2011; Ruf & Schroth, 2013). The Quesungual system of maize and bean production through reduced fire use and better soil conservation has been identified as diversification strategy that results in synergies between mitigation and adaptation (Castro et al., 2008; Ayarza et al., 2010). Other practices that could have potential to both contribute significantly to adaptation and mitigation through diversification and increased productivity include silvopastoral systems (Hänsela et al., 2009; Peters et al., 2012).

3.4.1 Financing adaptation practices

While previous sections have considered the question of whether certain activities or changes in land use practices could simultaneously address adaptation needs and contribute to climate change mitigation (i.e. whether there is potential for synergies between adaptation and mitigation), we now discuss whether mitigation could contribute to financing adaptation actions. Possible mechanisms for this could include the generation of carbon credits from mitigation actions that could then be traded, thereby generating funding for activities that also have adaptation value. Another possibility would be the reduction of the carbon footprint of coffee, thereby making it more competitive on the market and possibly attracting price premiums, through actions that have simultaneous adaptation value. For related terminology see Table 9.

With regard to carbon credit generation potential, all above-mentioned a/reforestation activities are most likely to be implemented successfully due to low transaction costs, high availability of area and medium to high mitigation potential. Although the Quesungual, silvopastoral and waste water systems have medium to high mitigation potential, transaction costs would be very high, therefore reducing the success for

Table 9 Definitions of mitigation options as defined by the coffee industry

Carbon offsets	Any net greenhouse gas (GHG) emissions reduction or carbon sequestration, measured against a baseline, that can be used to compensate for GHG emissions elsewhere. Offsets are often traded as "carbon credits" on voluntary or compliance markets but other forms of compensation of the offsetting activity are also possible.
Carbon insets	Any carbon offsets or GHG reduction/carbon sequestration activity that is linked to the supply chain or direct sphere of influence of the company or individual that acquires or supports the insetting activity. This can take the form of credit trading or other forms of compensation or support for the insetting activity. Carbon insets are intended to generate mutual benefits between the partners that are additional to the climate change mitigation itself.
Carbon footprint reduction	Any reduction of the net GHG emissions resulting from a production process that are covered by a recognized methodology for measuring carbon footprints. Carbon footprint reductions can be compensated (as insets) but rewards are often more fuzzy, possibly providing an advantage on the marketplace for the respective product, support a specific labeling, and potentially result in a price premium. In many cases additional GHG reductions and carbon sequestration opportunities exist that are not covered by recognized methodologies for measuring carbon footprints but are nevertheless actionable by farmers.

generating carbon credits. Transaction costs in Quesungual and silvopastoral systems are higher compared to traditional a/reforestation activities because the available carbon credit standards' methodologies are more complex considering assessment of soil carbon changes. Regarding waste-water treatment high transaction costs result mainly from costs of required biodigester technology systems. The mitigation potential of the remaining activities would be too low for generating carbon credits.

Carbon insetting activities could reduce higher transaction costs by integrating reward mechanisms for mitigation activities into the coffee supply chain. Companies with high priorities in the social domain could also value livelihood benefits for their suppliers equally to mitigation goals and therefore support such activities through their supply chain.

Finally, there are practices that are not able to generate carbon credits because there are no suitable standards and methodologies, but that could help reducing the product carbon footprint and could result in advantages when commercializing the coffee, especially to companies with a strong environmental profile.

4 Conclusion

Coffee smallholders in Nicaragua are highly vulnerable and will be severely affected by predicted climate change. Farmers will struggle to adapt, therefore innovative strategies are required to improve livelihoods today and in a changing future. This study identified the relevant adaptation needs of organic coffee smallholders in San Juan del Río Coco, Northern Nicaragua and possible mitigation options. Furthermore, synergies among them were elucidated. We showed that especially a/reforestation activities offer high synergies. Further activities with high synergies include installing biodigesters for the waste-water treatment system or improving traditional slash-and-burn systems for food crop production. The applied methodology allowed for a holistic assessment of the relevant livelihood activities of smallholding farmers to identify synergies between adaptation to and mitigation of climate change. This enabled the prioritization of climate-smart practices. Due to the qualitative nature of the assessment a more detailed evaluation of the identified practices is required in order to define how to implement them correctly. Next steps would include testing these practices and evaluating the impact these practices have on the farmers' livelihoods and their adaptation to climate change.

We also discussed the possibility that climate change mitigation could help fund adaptation actions and considered several possibilities for this. Possibilities arise through carbon offsetting, carbon insetting, and carbon footprint reductions. These options differ in their level of transaction costs. We found that it is difficult to directly link carbon credit generation activities with the most urgent adaptation and livelihood needs of vulnerable organic certified coffee smallholders. Organic coffee farmers already do fairly well in terms of reduced emissions and carbon sequestration compared to conventional farmers. There is, however, still significant potential for GHG reductions and carbon sequestration within and outside the coffee plots. Furthermore, there are indirect benefits that strengthen adaptive capacity from the capacity building for afforestation of degraded areas with coffee agroforestry systems. Finally, the sustainable intensification of non-coffee activities (bean, maize, cattle (*Bos indicus*)) can improve ecosystem services on a landscape scale, e.g. through reduced soil erosion and degradation and improved fire management.

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