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Milpa: One Sister Got Climate-sick. The Impact of Climate Change on Traditional Maya Farming Systems

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Abstract. The *milpa* is a traditional Mesoamerican polycropping system involving rain-fed cropping of maize (*Zea mays*), squash (*Cucurbita moschata*) and legumes (*Phaseolus vulgaris*, *Phaseolus lunatus*, *Vigna unguiculata*), crops which in this part of the world are known as the three sisters. Despite alterations due to socio-economic changes during the twentieth century, *milpa* farming still characterizes subsistence production systems of peasants of Maya ethnicity in the central Yucatan Peninsula, Mexico. In Dziuché, a community in the state of Quintana Roo, more 'classical' interpretations of the *milpa*, commonly cultivated by the older generation of peasants, are competing with systems that are essentially hybrids of the *milpa* and conventional maize farming; however, management and output of both variants are affected recently by changing precipitation patterns associated with global climate change. In the present study, implemented in Dziuché in 2012–2014, we recorded and analysed recent changes in *milpa* production systems. Particularly, we compared the *milpas* of two peasants from different generations – one is 30 years old and the other 56 years old. Through a triangulation of participatory and qualitative methodologies, including dialogue between interlocutors, focus groups, and participatory elaboration of an agricultural calendar, we recorded their perceptions of the impacts of climate change on crop management, yield and agrobiodiversity. This information was enriched with economic data related to these production systems. The data was then validated with the entire peasant assembly of Dziuché. It was observed that, regardless of their age, traditional farmers responded to the late arrival or non-arrival of the early summer rainy season by shifting their maize planting dates and by reducing agrobiodiversity, mainly by eliminating beans. The results contribute to the current discussion around the impacts of climate change on traditional production systems. It was shown that despite resilience mechanisms inherent to peasant farming, the magnitude of climate change is challenging farmers to an extent that they respond

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with objectively counterproductive measures, such as decreasing agrobiodiversity. It must be added that in the case of Maya peasants, these reactions are not only caused by altering climatic conditions but also by socio-economic developments like the loss of empirical knowledge transfer, a decreasing number of family members available for unpaid agricultural work, and changes in land tenure.

Climate Change and Traditional Farming

The global average temperature has increased at a rate of 0.5 °C per century in the last 150 years (Ortiz, 2012, p. 2). This rise accounts for changes in precipitation patterns and more frequent extreme weather events (Kotschi, 2006). The phenomenon is principally ascribed to the anthropogenic emission of greenhouse gases (GHG) into the atmosphere, of which CO_2 is the most prominent and CH_4 and N_2O (30 and 300 times more harmful than CO_2, respectively) are the most damaging ones (VCS, 2011, p. 9). Agriculture accounts for approximately one-third of global GHG emission, mainly due to tropical deforestation, CH_4 emitted by cattle and N_2O coming from rice production and fertilization (Ortiz, 2012). Yet, farming is not only an offender but also a victim of climate change: especially regions populated by small-scale farmers will be affected by its consequences (Altieri, 2009). This problem worsens with escalating rates of per capita food consumption: with a world population of up to nine billion by 2050, total food production will have to be increased by 70% (FAO, 2009, p. 2), while the price of crops such as maize will double due to lower yields (Nelson et al., 2009, p. 7). Indeed, with an atmospheric CO_2 concentration of at least 550 ppm forecasted for the end of this century (IPCC, 2007), global agroecosystems will be facing further drastic alterations. Most mathematical models used to forecast the hazards caused by climate change do not consider small-scale agriculture, which makes the real impact of this trend on traditional farming hard to predict (Oreskes et al., 2010).

Latin America with its diverse traditional farming culture has not been exempt from the impacts of climate change. Although representing only 12% of global CO_2 emissions (Verner, 2011, p. 1), the temperature is estimated to rise drastically in the first half of the twenty-first century (Battisti and Naylor, 2009). There is a trend toward dry summers (Neelin et al., 2006, p. 1), which simultaneously causes shorter rainy seasons and more intense precipitations. Climate change is also related to increased night-time temperatures and extreme weather events, such as floods, hurricanes, droughts and landslides (Ortiz, 2012). In Mexico, climate change has already drastically affected its subsistence farmers who depend on rain-fed maize (Altieri, 2009).

Climate Change and Crop Management

An increase of atmospheric CO_2, one of the triggers of climate change, will stimulate the photosynthetic activity and resource-use efficiency of C_3 crops (thus, improving their yield). However, CO_2 combined with the expected rising temperatures will have a preponderant negative impact on productivity (Reich, 2009) due to accelerated vegetative growth and increased water consumption (Ortiz, 2012), which in turn would favour C_4 plants, including weeds. Yet, the indirect effects of GHG on agriculture will be more harmful than CO_2 per se (Führer, 2003, p.1); shifts in nutrient cycling, crop–weed interactions, ecology of pests and diseases, and the distribution of crop varieties are expected (Dwivedi et al., 2013), going hand in hand with altered biomass accumulation (Ortiz, 2012) and decreasing nutritional potential of relevant crops (Kelly and Goulden, 2008). The impact on agriculture may be as variable as the effects of climate change: it depends on the type and the intensity of the phenomena, on the interactions between them (e.g. drought and heat), cropped soils, agrobiodiversity, surrounding vegetation, land use, crop stage and, of course, management. Among the negative consequences on production and agrobiodiversity (Table 1), soil moisture (altered by less, excessive or irregular precipitation) and the profusion of pests and diseases are the areas more likely to be affected (Dwivedi et al., 2013). Furthermore, loss of biodiversity in the surrounding environment will harm pollination (Garibaldi et al., 2011, p. 2); and natural disasters, the most visible consequence of climate change, cause physical damage to production and infrastructure.

Out of the crops that are associated with milpa,[1] maize (*Zea mays* L.), legumes (*Phaseolus vulgaris* L., *Phaseolus lunatus* L., *Vigna unguiculata* (L.) Walp.) and squash (*Cucurbita moschata* Duchesne), legumes will probably be most affected, particularly by droughts: they require the bean to invest nutrients and energy in non-productive growth;[2] to develop a deep-rooting system to extract soil moisture; and to increase sugar transport to seeds and early maturity (Dwivedi et al., 2013). Regarding quality, elevated heat decreases oil and increases sugar in beans (Thomas et al., 2009, p. 4). Maize yields will diminish due to less rainfall during flowering (Dempewolf et al., 2014, p. 3). Drought stress will affect quality of maize: reducing protein and increasing carbohydrates (Ali and Ashraf, 2011), as well as modifying oil and metal composition (Rastija et al., 2010). For Brassicaceae, it is reported that prolonged drought results in earlier and reduced flowering, as well as in descendants with thinner stems and fewer leaf nodes (Dwivedi et al., 2013, p. 44).

Traditional Farming and Agrobiodiversity

Due to an expansion of industrialized farming, agricultural land now occupies 55% of the Earth's ice-free terrestrial surface (Ellis et al., 2010, p. 5). This development affects biodiversity directly through the use of synthetic pesticides, fertilizers, and through monocropping, where non-native species become competitive invaders in neighbouring ecosystems (Rand et al., 2006); and indirectly, principally through groundwater contamination. As a result, today only 15 crops provide most of the world's food (Motley et al., 2006, p. 7). For the future, climate change is likely to have an equal, if not greater, impact on biodiversity than industrial agriculture (Kotschi, 2007).

In contrast, traditional agroecosystems are characterized by high diversity of (domesticated and wild) crop and animal species. Peasants respond to climate variability by a continuous adaptation of crop management, based on their personal experience and their historical background (Wilken, 1987; Kahneman, 2011; Rogé and Astier, 2013). Their adaptive capacity is determined by a complex interaction of socio-economic and political factors, existing infrastructure, and experience dealing with climate change (Adger et al., 2009). Thus, withstanding external shocks depends not only on the individual peasant but on the social infrastructure he is embedded in (Nicholls et al., 2013). Both agrobiodiversity and empirical knowledge guarantee built-in resilience and robustness that help peasants to cope with disturbances (Altieri and Toledo, 2011; Morales-Hernández, 2014; Altieri et al., 2015).

Table 1. Effects of climate change on crop management and agrobiodiversity.

Parameter	Process	Cause	Consequence	Limiting factor	Impact on agrobiodiversity	Reference
Plant physiology	Increased photosynthetic activity	Altered soil C fluxes induced by CO_2	Accelerated vegetative growth	Soil moisture and nutrient availability	Favours C_3 plants	Führer, 2003; Dwivedi et al., 2013
	Physical damage	Natural disasters	Devastation of agricultural infrastructure; increased risk of soil erosion/leaching and wildfires	Favourable soil structure and intact surrounding ecosystems	Favours fast-growing weeds after perturbations	Morton, 2007
Soil microflora	Increasing reproduction	Higher temperature and elevated CO_2 levels	Increased competition for soil nutrients and water; faster mineralization; increase of soil-borne pathogens; faster decomposition of mulches and dung; increased C:N ratio	Disposability of nutrients; low soil humidity	N/A[a]	Pimentel, 1993; Swaminathan and Kesavan, 2012
Soil organic matter	Augmented decomposition rates					
Nutrient uptake	Reduced nutrient assimilation (decreased soil humidity)	Higher temperature, less rainfall	Increased need of irrigation	Increased mycorrhizal activity due to elevated CO_2	Favours C_3 plants tolerant to drought	Compant et al., 2010
	Increased dry matter production	CO_2 stimulates vegetative growth	Decreased generative development	Heat	Altered polycropping systems	Führer, 2003
	Altered nutrient presence in rhizosphere	Increased N availability due to quicker mineralization and oxidation	Altered soil-fertility management	N/A	N-demanding plants more competitive	Führer, 2003; Hautier et al., 2009

Soil moisture	Increased evaporation	Higher temperature	Harvest losses; need of cooling and covering; negative impact on soil structure and nutrient availability	Mulching	Negative	Pimentel, 1993
Diseases	Shifts in geographical distribution	Changed spread of pathogens;[b] relocation of hosts	Harvest losses; decreased efficacy of established control-strategies	N/A	Disfavours determined pathogens	Dwivedi et al., 2013
	Abundance of pathogen fungi	Increased UV-radiation		Drought (determined species)	N/A	Biggs and Webb 1986
		Heat combined with intense precipitation				Castro et al., 2009
		Increased crop photosynthesis[c]		Heat		Dwivedi et al., 2013
	Decreased mycorrhizal activity	Drought		Heat, increasing soil CO_2	Favours C_4 annuals; disfavours perennials	Augé, 2001
	Abundance of pathogen bacteria	Higher temperature combined with increased CO_2		N/A	N/A	Castro et al., 2009
Pests	Increased reproduction	Droughts or warmer periods (more reproductive cycles)		Shorter cropping cycles		Altieri and Koohafkan, 2008
	Abundance	More food for herbivorous insects		Soil N deficiency		
	Increased food intake	Increasing leaf C:N		Abundance of *Rhizobium* spp.		Coviella and Trumble, 1999; Compant et al., 2010
Virus	Changes in virulence	CO_2 accelerates pathogen-evolution		Changes in host fauna		Dwivedi et al., 2013
	Increased transmission	Abundance of vectors		N/A		Juroszek and Tiedemann, 2012

Table 1 *cont.*

Parameter	Process	Cause	Consequence	Limiting factor	Impact on agrobio-diversity	Reference
Weeds	Abundance	Elevated CO_2 reduces stomatal aperture and increases water-use efficiency	Modified control-strategies; competition for water/nutrients/O_2	Reduced soil moisture; altered respiration	Favours C_3 plants[d]	Patterson, 1995
Harvest quality	Decreased protein content (grains)	Drought, heat	Reduced nutritional quality	N/A	Dwivedi et al., 2013	
	Increased C:N ratio	Elevated CO_2			Hamilton et al., 2005	
Storage	Elevated postharvest losses by pests	Drought	Post-harvest losses	Traditional farming techniques	N/A	Rogé et al., 2014
	Rising mycotoxin contamination	Droughte heat		Non-susceptible species		Whitlow and Hagler, 2005

Notes: [a] Indifferent/not predictable/no evidence found; [b] altered wind patterns; [c] rising carbohydrate content favours sugar-dependent fungi; [d] increased water-use efficiency also favours C_4 plants; d except aflatoxins.

A study by Rogé et al. (2014) offers insight into the ability of traditional farming communities in Oaxaca, Mexico, to respond to climatic variations: since the 1980s, a later beginning of the rainy season causes the peasants there to shift the maize sowing date from May and June, the traditional season, to July. Recently, Oaxacan farmers also learned (or remembered) that biodiverse fields and surroundings, as well as fallows, bring rain, retain groundwater, accumulate soil organic matter and prevent pests. Another common Meso-American adaptation strategy is planting drought-tolerant and precocious local varieties (Altieri et al., 2011, p. 4). Maize landraces show especially high adaptability to diverse climates (Ruiz-Corral, 2008). In this context, Bellon et al. (2011) found that in mountainous central Mexico, germplasm for almost all climate scenarios predicted for 2050 is available locally. Similarly, in the Yucatan Peninsula, the vast majority of communities prefer maize landraces to commercial hybrids, considering them to be more drought resistant, nutritious and tastier, as well as easier and cheaper to obtain (Weiss, 2012). In fact, all over Latin America small-scale farmers cope with climate change by combining traditional and contemporary sustainability practices (Browder, 1989). Their strategies are regionally adapted (Cunningham et al., 2013) or even farm specific (Niles et al., 2014).

Current State of *Milpa* Farming

Milpa, which literally means cornfield, is the most relevant traditional Meso-American production system (Hernández, 1985). Long before and after the conquest, it has sustained large indigenous communities in a relatively secure food situation. Since agriculture has been the dominant economic activity of the Maya people, today, as in the past, there is an intrinsic relationship between Maya culture and the *milpa* (Ebel and Castillo Cocom, 2012). Yet, Yucatec peasants are not limited to the *milpa* but usually manage simultaneously a variety of different production systems, of which home gardens stand out for their agrobiodiversity.

In the *milpa*, usually two varieties of maize (Toledo, 2003) are associated with legumes, squash and a varying number of other crops. Usually, a maize landrace with a shorter cropping cycle is polycropped with a longer-growing one. Farmers maintain this inter- and intraspecific diversity as insurance to meet future environmental change and economic needs. The interaction of these crops creates benefits for all involved plants causing ‘overyielding’: increased production of each crop compared to when grown alone (Altieri, 2009, pp. 106–108). Gliessman (1998, p. 102) demonstrated in a groundbreaking experiment that 1.73 ha of maize in monoculture produce as much food as 1 ha planted with *milpa*.

Central to the *milpa* is slash-and-burn farming (Gliessman, 2006). In this type of shifting cultivation (Turner et al., 2003), a plot of jungle is cut, allowed to dry, and then burned. After one or two growing seasons it is abandoned to fallow. Since there is always more land under fallow than actually cropped, this land-demanding method (Cowgill, 1962) creates a landscape with patches of secondary vegetation at different ages of succession (Saenz-Pedroza, 2015). Even now, all agricultural activities are done manually in the *milpa*; sporadically applied pesticides and fertilizers depend more on the availability of financial resources rather than on agronomic reasons (Ebel and Castillo Cocom, 2012). Sophisticated tools are rare: for planting, a dibble stick is employed to make holes at regular intervals into which maize and other seeds are dropped without any plugging (Cowgill, 1962).

During the second half of the twentieth century, changes in production and in the social composition of Maya communities have been observed. Redfield (1970) noted growing frustration among subsistence farmers due to declining maize yields. This statement by the Mayor of an indigenous community reflects the spirit of this era: 'We must modernize our agriculture. It depends on the government to save the fields' (Don Eus, mayor of Chan Com in Redfield, 1970, pp. 171–174).

As history shows, his wish was satisfied in the decades to come. The Mexican government implemented the green revolution, which not only transformed (in the case of richer farmers) or influenced production (peasants), but also initiated a kind of social change: a new class of peasants, known as rich *campesinos*,[3] was born – and became more and more separated from the remaining modernization-resistant ones (Ebel and Castillo Cocom, 2012). They achieved high yields from then intact soils due to the considerable application of synthetic products. Their selection of crops corresponded to the needs of the market, not to the nutrition needs of their families. They became dependent on foreign food, and cash became vital for their economy (Eastmond, 1991).

At the end of the twentieth century, neo-liberal policies in the context of Mexico joining NAFTA (in 1994) served as a further transformer of the social structure. Changes in land tenure were notably momentous: historically, the farmland in Mexico is divided into so-called *ejidos*, a land grant mechanism wherein each peasant family has usufruct rights over a parcel of land, access to common lands, the right to an urban plot and voting rights in the *ejido* assembly (Eastmond, 1991). Following a liberalization policy of landownership in the 1990s, more and more *ejido* land has been converted into private property. Additionally, peasants who in the past had benefited from subsidies and soft credits, now largely had to carry on with farming without considerable public support (Rosset, 2009; Carte et al., 2010). In 1995, *Alianza para el Campo* (Alliance for the Countryside) was introduced, a programme that provided funding for profitable and export-oriented commodities but not for the *milpa*. The government also withdrew from the commercialization process, and middlemen (so called *coyotes*), who capitalize on the vulnerability of small-scale farmers, stepped in (Carte et al., 2010). On top of that, prices for staple crops decreased significantly in this period, a consequence of the World Bank and IMF forcing Mexico to sell off its public-sector grain reserves (making the country dependent on imports) and of price-fixing of the few corporate monopolies that emerged in a widely unregulated market. Even when crop prices recovered after the food crisis in 2008, peasants scarcely benefited, as costs of the synthetic inputs they were now dependent on also rose (Rosset, 2009). Maya peasants are clearly aware of the political and economic causes for the changes in their livelihoods (Carte et al., 2010).

A study by Ebel and Castillo Cocom (2012) gives insight into the impact of these changes on the situation of contemporary Maya farming in X-Pichil, Quintana Roo. There, the children of *campesinos* are being continuously disconnected from farming, resulting in increasing migration and loss of empirical knowledge. Significant is a notable aging of the active agriculturally-employed population: 94% of *ejidatarios*[4] are older than 40 years and only 4% of their children plan to continue working on the farms. According to the youth of X-Pichil, there are three reasons for this tendency: agriculture is seen as too labour intensive; *milpa* output became unstable due to a changing climate; and traditional farming suffers from a poor reputation in society.

An additional factor for the decline of subsistence agriculture on the Yucatan Peninsula is the emergence of mass tourism in the nearby 'Riviera Maya' that has been absorbing workers from indigenous communities (Re Cruz, 2006). Behind this development is a national policy to strengthen currency import through tourism, while weakening low-profit sectors such as small-scale farming. This policy has totally shifted the economy and society of Quintana Roo: agriculture contributed to a third of the state's GDP in 1970 and is now under 1%; at the same time, tourism became the biggest economic sector (INEGI, 2011). As the first generation of migrants to the tourism hotspots was widely successful economically, outmigration from the Maya communities rose significantly and the reputation of 'poor' agriculture worsened (Carte et al., 2010).

This development is not alien to older peasants: many of them have the perception that the youth are leaving because their traditional way of farming is no longer competitive with a globalized and continually intensified production. Ironically, most peasants want a 'prosperous' future for their children out of the field, but lament the consequent loss of empirical knowledge about *milpa* and perceive increased consumerism among young farmers: 'Every father who loves his children wants them to get out of the field… Young people have no idea about *milpa*. They have nothing to do but they want a lot of stuff' (Emilio Tuk Aké, *campesino*, in Ebel and Castillo Cocom, 2012, p. 8)

Study Area

The study was caried out from 2012 to 2014 in the community of Dziuché, Quintana Roo, in the central Yucatan Peninsula (19°53′52″N, 88°48′25″O), 37 metres above sea level, a town that historically was built during the *chicle*-boom.[5] Dziuché has 2,870 inhabitants. The total extension of communal land is 27,000 ha; of these, in 2013, 14,000 ha were cultivated with citrus fruits and *milpa* or used for cattle farming (INEGI, 2011; Green-Chi, 2014). There is tropical savanna on the limits between Köppen climate classes Aw1 and Aw2. The raining season is from May to October, characterized by less rainfall in August than in July and September (Giddings et al., 2005). The annual precipitation is 1,195 mm and the temperature 25.4 °C (CNA, 2015). Comparing the mean monthly temperature and annual precipitation of the years 1980 to 2010 and 1950 to 2010,[6] both variables have decreased with time: –0.6 °C (with maximums +0.6 °C and minimums –1.8 °C) and –100.1 mm respectively (Figures 1 and 2). During the same period, maximum temperatures as well as total evaporation augmented, while night temperatures fell notably.

Methodology

The study focused on the members of the *ejido* assembly of Dziuché. Data were collected using a triangulation of participatory action research (PAR), qualitative social research methods, and a quantitative survey tool. Given their wide use in studies of ethnic minority groups, special importance was attached to focus group discussions (Morgan, 2008), which were applied in an initial stage of the study (in order to specify research questions) and in the follow-up (for validating data). Additionally, dialogue between interlocutors, selected PAR tools (workshops, in-depth case studies, participant observation, farmer-generated seasonal calendars), and multisite ethnography were used. The study was carried out in four stages (Table 2).

Stage I consisted of stakeholder identification, which included a meeting with community members (after an *ejido* assembly), in which the purpose of the study

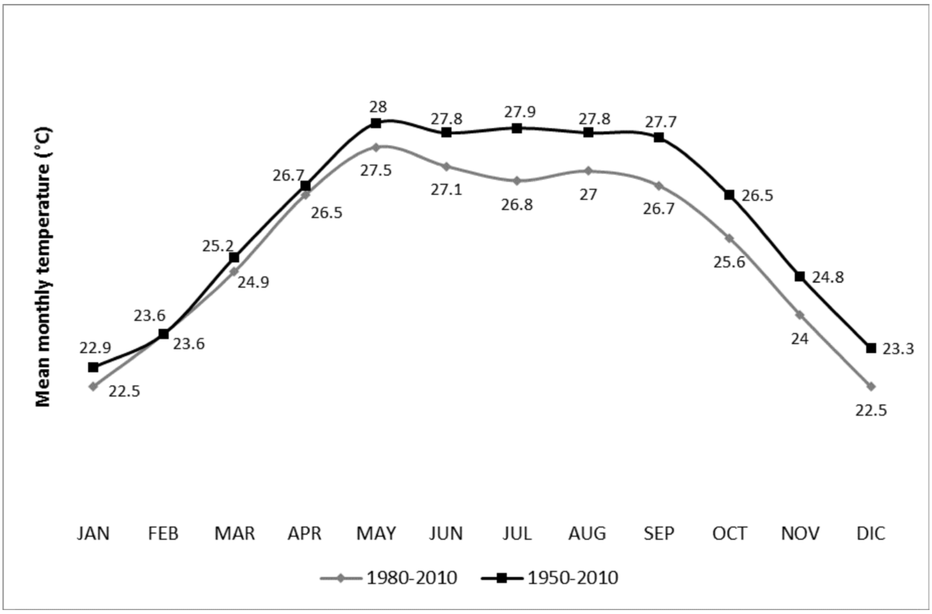

Figure 1. Monthly temperature (°C) in Felipe Carrillo Puerto (100 km from Dziuché). Comparison of the years 1980–2010 and 1950–2010.

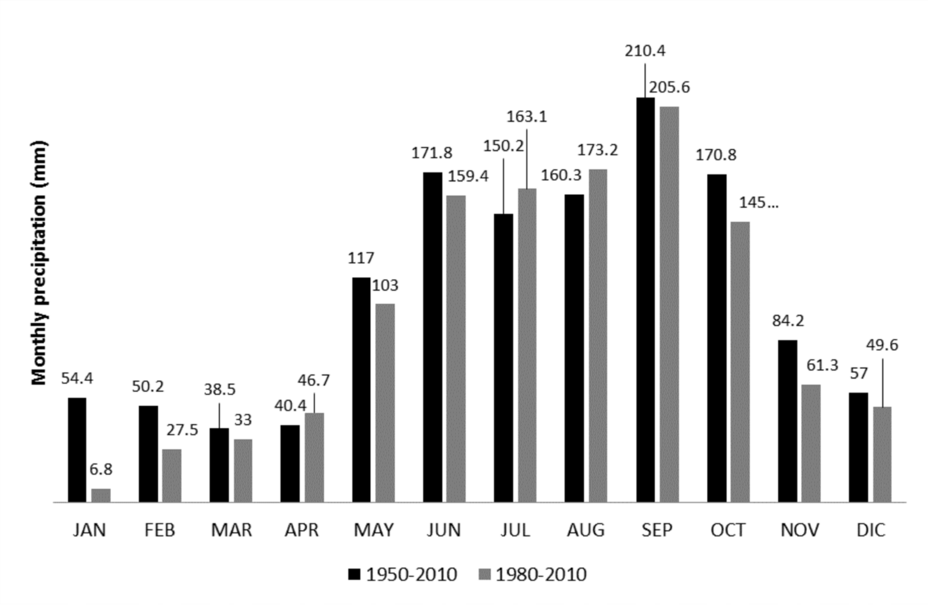

Figure 2. Monthly precipitation (mm) in Felipe Carrillo Puerto. Comparison of the years 1980–2010 and 1950–2010.

was presented. Participating farmers were also asked about their crop management (traditional/conventional), the size of their production areas and current threats for

Table 2. Methodology, main stages and temporal development.

Stage		Participants	Date
I	Stakeholder identification	*Ejido* assembly	July 2012
II	Fact-finding and listening	1. Focus group (5 peasants) 2. Two selected peasants	July 2012–June 2013
III	Analysis	Focus group	July 2014
IV	Sharing of information and validating	*Ejido* assembly	August 2014

agriculture in their region. A co-researcher served as moderator. In order to bring together farmers with a similar background and interest in the topic (Morgan, 2008), we identified volunteers for the focus group using the criteria that they must be active farmers with minimum 15 years of *milpa*-management experience. Applying a stakeholder rainbow (Chevalier and Buckles, 2013), other selection criteria were enthusiasm and age. Finally, a focus group of five farmers was recruited and a respondent moderator was appointed (Hennink, 2007).

Stage II focused on fact-finding and listening. In a workshop, the focus group conversed about recent changes in farming techniques and in environmental conditions. Data was obtained by recording the group discussion, which was guided by a co-researcher. One outcome was the agreement of a seasonal calendar (Chambers, 1994) regarding actual crop management in the *milpas* of Dziuché. Then, the *milpa* of each peasant was visited and adaptation strategies to changing climatic conditions were discussed. There, field notes were taken to record the statements of the peasants, as well as any other important events.

After becoming familiar with the views of the five participants of the focus group, we compiled the information and then processed for structuring the subsequent in-depth case studies (Table 3). Two members of the focus group of different ages (Table 4) were then selected for follow-up interviews (Morgan, 2008). At this stage, the research team had developed a trusting relationship with the peasants, and interactions became more personal. This circumstance facilitated the next step, which were narrative life-story interviews of each selected peasant. These interviews were largely unstructured; we only occasionally guided interviewees using structuring questions as suggested by Atkinson (1998). Interviews lasted 90 minutes and were audio recorded.

We then discussed changes in the peasants' *milpas* and causes for these changes in semi-structured interviews, facilitated by a student from Dziuché, who served as research co-facilitator.[7] The structure was based on questions that emerged during the focus-group discussion. Each of a total of five interviews per farmer was based on a main research question (Table 3), which was open-ended. It was combined with more specific and close-ended questions, which (in the case of unconsidered information) were slightly modified during the interview (Chambers, 1992). Each interview lasted 30 to 60 minutes and was audio recorded.

Finally, economic aspects related to *milpa* were highlighted in a structured survey. The survey instrument was based on information gathered through the agricultural calendar and the semi-structured interviews with both peasants. It was answered

Table 3. PAR tools applied in Stage II.

Participatory technique	Target community	Date	Location	Procedure
Seasonal calendar	Focus group	July 2012	*Ejido* assembly	Peasants completed a monthly arranged matrix with their drawings considering the following parameters: precipitation, temperature, extreme weather events, seeding and harvesting, other activities in *milpa*, hazards (e.g. pests and diseases), other agricultural activities, off-farm activities, farm and off-farm income (subsidies), disposability of food from *milpa*, cash disposability.
Field visits		September 2012	Peasants' *milpa*	Unstructured interviews following the *tsikbal** methodology
Interview	Two selected peasants	November 2012	Peasants' home	Narrative interview about life story
Semi-structured, in-depth interviews		January–March 2013	Public places in Dziuché	Research question 1 (RQ1): How did your father do *milpa*? RQ2: How do you do *milpa*? RQ3: Since you became responsible for it, what has changed in your *milpa*? RQ4: Since you became responsible for it, what have you changed in your *milpa*? RQ5: Since you became responsible for your *milpa*, what has changed in your community?
Survey		June 2013	Peasants' home	Closed ended questions requiring numeric data

Note: * Multi-site ethnography, effective in fieldwork among Maya people. It promotes intimate conversations by generating confidence and empathy, constructing knowledge in a collaborative way (Ebel and Castillo Cocom, 2012).

Table 4. Peasants selected for the in-depth fact-finding process and characteristics of their production systems.

	Age	Cultivated area (ha)	Agricultural activities	Off-farm activities
Farmer I*	30	1.0	*Milpa*	Taxi driver, mason
Farmer II	56	1.0	*Milpa*, apiculture (15 hives)	Tricycle driver, farmworker

Note: *Farmers demanded explicitly not to be mentioned by name.

in approximately 30 minutes and involved questions regarding farm and off-farm income, yield in *milpa*, as well as the duration and costs of diverse crop management activities.

Stage III consisted of data analysis. The data gathered in Stage II were summarized, structured and discussed with the entire focus group. There, the most significant findings were identified and their validity for the entire community was assessed. Validating findings communicatively in the focus group ensured that different perspectives entered into the analysis process (Bergold and Thomas, 2012, p. 18) and gave participants ownership of the research (Russo, 2012, p. 10).

Stage IV focused on the sharing and validation of the research results. In an open participant group, accessible for all *ejidatarios* of Dziuché, a co-researcher presented the resumed and synthetized findings to the peasant community. On a scale from 0 to 10, the farmers evaluated both the sufficiency and validity of evidence of the study, as well as their consensus on the findings (Chevalier and Buckles, 2013). Values superior to 6 in both categories were agreed as requirements for the validation of the findings, while inferior values would initiate a reopening of the fact-finding process. Any value inferior to 8 would open a critical evaluation of the methodology.

Findings

Through stakeholder identification it was confirmed that the *milpa* is still the predominant production system in Dziuché; its *ejidatarios* cultivate areas from 1 to 4 ha; however, the number of traditional farmers is continuously decreasing and crop management techniques are changing, especially among younger farmers. Particularly, polycultures are being simplified. As a consequence, considerable sources of energy formerly obtained in the *milpa*, such as diverse legumes, cassava (*Manihot esculenta* Crantz), jicama (*Pachyrhizus erosus* (L.) Urb.), yam (*Dioscorea alata* L.), habanero pepper (*Capsicum chinense* Jacq.), tomato (*Solanum lycopersicum* L.), and honey, now have to be bought. Moreover, low yields due to unpredictable rainfall and high production costs are forcing peasants to earn money off-farm in order to buy maize for family consumption.

The focus group stated that there is decreasing use of landraces and a growing dependency on synthetic products in the *milpas*. Summer drought, shifting precipitation, higher exposure to natural disasters (hurricanes) and excessive weed-growth were cited as the causes of these changes. The term 'climate change' was mentioned explicitly in this context. Furthermore, peasants claimed a loss of empirical knowledge about traditional farm management due to fewer youngsters involved in *milpa*. They also revealed that the improvement of infrastructure in rural Mexico (which they principally favour) and relatives that work in urban regions or abroad brought the spirit of a consumer society to Maya communities.

Comparing two peasants of different ages, the younger peasant (Farmer I) inherited the responsibility of the *milpa* when he was 12 years old and his father died. Back then, synthetic products were not used, as they were difficult to obtain and costly. Now, he applies fertilizers and herbicides, with the aim of controlling tree shoots. Another technique that has changed is that slashing was formerly done by axe; now he uses a chainsaw as this implies less work. He intercrops maize and squash: 4–5 seeds are sown at once in one hole, adding 15 plants of sweet potato (*Ipomoea batatas* (L.) Lam.) in an area of 20x20 m inside the *milpa* (Tables 5 and 6). Likewise, the farmer now hires farmworkers during the crop cycle. Formerly, family members did the fieldwork. This is possible because he has funds to invest in the *milpa* thanks to off-farm activities and support from PROCAMPO[8] (Tables 7 and 8).

Farmer II assisted his father since he was 10 years old, and assumed charge of his *ejido* at 28 years old. At first, he worked alone; now, his two children occasionally, and his brother regularly help him. In his *milpa*, squash is planted in June (3,000

Table 5. Characteristics of *milpas* of a younger (I) and an older (II) peasant in Dziuché.

Farmer, age (years)	Maize planting density (plants per ha)	Distance between maize seeds (cm)	Distance between maize rows (cm)	Intercrops
I, 30	10,375	80	120	Squash, white sweet potato
II, 56	5,000	100	200	Squash, white sweet potato, cucumber, *coyol* palm*

Note: * *Acrocomia aculeata* (Jacq.) Lodd. ex Mart.

Table 6. Management of *milpas* of a younger (I) and an older (II) peasant in Dziuché.

Farmer, age (years)	Weed management	Pesticides	Synthetic fertilizers	Slash-and-burn farming
I, 30	Manual	Systemic herbicide (2, 4-D),[a] 3 weeks after planting	N-P fertilizer applied immediately after planting (40 g per plant)	2 cropping seasons after burning[b]
II, 56	Manual			1 season

Notes: [a] 2,4-Dichlorophenoxyacetic acid used for controlling broadleaf weeds; [b] first cropping season: new *milpa*, second cycle: *cañada*.

Table 7. Cropping cycle and main tools used 2013 in a *milpa* of Farmer II (56 years old) in Dziuché, compared to the routine of a Farmer I (30 years).

Month	Period	Activity (Farmer II)	Used tools (Farmer II)	Difference between Farmer I and II
December/ January[a]	Preparation	Selection of production area: Flat lots with soil depth > 30 cm, few stones and without 'problematic'[b] flora; after a fallow > 10 years[c]		2 crop cycles per area; minimum fallow > 15 years
January	Cleaning, *Rosa*	Cleaning beneath large trees, *Socoleo*	Machete	
January–March		Cleaning of herbs, *Chapeo*	Machete, *coa*[d]	
March/ April	Slashing, *Tumba*	Cutting off all large trees, *Bota*	Machete, axe	Uses chainsaw
		Breaking off trunks and branches in order to accelerate the drying process, *Desgaja*	Axe	
April		Total cleaning at an equidistance of 2 m around the field, done 1–2 days prior to burning, in order to prevent that the fire escapes, *Guardarraya*	Machete, rake	

April	Burning, *Quema*	Slashed vegetation must be completely dry or decomposed. Done at noon, at midday or twilight (moments with few wind); fire starts on two opposite borders and evolves to the centre[e]	With dry timber	
June/July	Seeding, *Siembra*	First squash (end of June), then maize after first intense rainfall in July[f] followed by other intercrops; seeding distances measured by steps[g]	Wood stock	All crops (except sweet potato) are seeded after 2–3 intense rainfalls; uses woody trellises for squash; measures with tape and uses a string for determining seeding lines; does not crop cucumber
July/ August	Application of herbicide and fertilizer			Uses 20 litre knapsack sprayer for herbicides; fertilizer granules applied manually
July– September	Weed removal, *Chapeo*	Selective, focusing on perennials; minimum every 2 weeks	Machete, *coa*	Only sporadically
September/ October	*Dobla*	Breaking of the stems for reducing vegetative growth, drying husks and improving soil moisture	Manually	Realizes *dobla* in November to prepare for *cañada*
September– November	Harvesting	Cobs are bent down for drying and harvested when dry		
September– December	Selection of seeds	Selection due to plant height, size and quality of ears, providing multiple seed lots; all seeds for the next season come from own collection		Occasionally buys seeds; has experimented with government -donated hybrids
September– December	Storage	Stored with husks in *cabañas*[h]		

Notes: [a] '/' depending on climatic conditions; [b] principally *Mimosa bahamensis* (Benth.) Britton and *Pithecellobium albicans* (Kunth) Benth.; [c] guarantees convenient soil depth, moisture, and fertility; [d] curved machete, similar to a sickle; [e] burning lasts approximately 1 hour, 3–4 fellow peasants assist observing and stay minimum 1 additional hour on the field; [f] the requisition is that soil is sufficiently humid and soft, otherwise they wait for 1–2 additional intense precipitations; [g] 1 step between plants, 2 steps between rows; [h] rustic granaries with thatch made of palm leaves.

plants per ha), followed by maize in July. The next full moon, sweet potato (10 plants per ha) and creole cucumber (*Cucumis sativus* L., 15 plants per ha) are planted in determined areas of the field. He stated that 'twenty years ago, the rains were more predictable', which is why he used to cultivate coriander (*Coriandrum sativum* L.), beans, and watermelon (*Citrullus lanatus* (Thunb.) Matsum. and Nakai). His only regular financial support is from PROCAMPO; an additional quarterly revenue is earned from field measuring and clearing activities for the *ejido*. Occasionally, he sells burned trunks as timber. He does not use synthetic products because of a lack of resources, but also because he considers them not essential. Similar to Farmer I, around 2005 he eliminated beans from his *milpa* due to their dependence on summer rain.

Table 8. Changes regarding crop management, comparing the years 2013 and 1998.

Period	Farmer I	Farmer II
Slashing	As now done by Farmer II; less wages	Less wages
Burning		Less people involved (less risk of wildfires)
Seeding	Arrangement and seeding of grains similar to Farmer II; intercropped bean, cowpea, watermelon, cilantro, yam, and radish	Seeded different maize landraces with varying production cycles and used a complex, cyclic crop arrangement; intercropped cilantro, bean (different landraces), pepper, and watermelon
Synthetic products	Without synthetic products	
Weed removal	As now done by Farmer II	No wages
Harvesting	Harvested approx. 50% more maize	No wages
Storage		Less storage loss

Farmer II yearly invests up to MXN1,500 more than Farmer I in his *milpa*, especially due to wages for weed management, which do not compensate for the costs of applying herbicides (Table 9). The production system of Farmer II is more labour intensive (+32 hours per cycle, Table 10) and also includes his brother's labour (who is paid with harvested maize). His family only helps during the harvest. In a new *milpa*, Farmer I is more productive than Farmer II (3 versus 2,500 kg per ha). Yet, each new *milpa* of Farmer II yields more than a *cañada* of Farmer I (2,000 kg per ha). Comparing a two-year-cycle of a new *milpa* and a *cañada* (as typical for Farmer I) and of two new *milpas* (Farmer II), both farmers harvest a yearly mean of 2,500 kg per ha maize. Although the older farmer sells 40% of his maize harvest, and the younger farmer sells 80%, both are far from being economically sustainable: summing two years, the younger peasant earns a profit of MXN1,720 and the older one loses MXN8,020 (Table 11).

Despite different management practices, the yield of both peasants is above the average *milpa* yield in Yucatan of 1,500 kg per ha (Castillo-Caamal and Caamal-Maldonado, 2011). Regardless of this remarkably high output, both farmers (each one with a family of five people) only obtain sufficient maize to feed their families for five months;[9] in the case of Farmer I, who sells most of the harvested maize, his poultry is fed with corn too. In turn, Farmer II, who sells less, gives two-thirds of his unsold yield to his brother; he also feeds his chickens and turkeys with maize and saves seeds for the next year. According to both farmers, they obtain 80% of their family's annual squash, and 50% of their sweet potato consumption from their *milpa*; Farmer II additionally harvests cucumber and honey[10] and gathers timber. Both farmers must purchase beans (an essential element of the Yucatec diet), and other food.

The peasants of Dziuché rated the sufficiency and validity of these findings with a value of 9 on a scale from 0 (low) to 10 (high). They appreciated our 'willingness to listen to their problems'. Regarding our conclusions, their ranking was 8.

Table 9. Comparison of monetary investment in wages and materials in two *milpa*-cycles of different-aged peasants (in MXN).

		Farmer I, 30 years old						**Farmer II, 56 years old**					
Year, production cycle		2012, new *milpa* (MXN)			2013, *cañada* (MXN)			2012, new *milpa* (MXN)			2013 new *milpa* (MXN)		
Parameter		Units	Cost/ Unit	Cost	Units	Cost/ Unit	Cost	Units	Cost/ Unit	Cost	Units	Cost/ Unit	Cost
Wages*	Slashing	25	80	2,000	25	50	1,250	25	80	2,000	25	80	2,000
	Burning	3	50	150	3	30	90	3	50	150	3	50	150
	Sowing	25	40	1,000	20	40	800	25	40	1,000	25	40	1,000
	Application of herbicides	12	50	600	12	50	600	0	–	0	0	–	0
	Weed control	0	–	0	0	–	0	25	80	2,000	25	80	2,000
	Harvesting	75	20	1,500	50	20	1,000	64	30	1,920	60	30	1,800
Materials	Fertilizer (1 unit = 1 kg)	1	570	570	1	570	570	0	–	0	0	–	0
	Herbicide (1 unit = 1 litre)	1	75	75	1	75	75	0	–	0	0	–	0
Total 1 year (MXN)		5,895			4,385			7,070			6,950		
Total 2 years (MXN)		10,280						14,020					

Note: *Wages per hour vary depending on the activity and on whether it is about a new *milpa* or a *cañada*; harvesting is paid per yield.

Table 10. Comparison of working hours of a younger (I) and an older (II) peasant for an entire production cycle of 1 ha *milpa* in hours.

Activity	Parameter	Farmer I, 30 years	Farmer II, 56 years
Slashing and burning	Hours per day	9	10
	Persons involved	3	4
	Days	5	11
	Subtotal	135	154
Sowing	Hours per day	5	4
	Persons involved	3	4
	Days	1	1
	Subtotal	15	16
Application of fertilizer/ herbicides	Hours per day	8	–
	Persons involved	4	–
	Days	2	–
	Subtotal	64	0
Weed control	Hours per day	2	4
	Persons involved	2	3
	Days	1	6
	Subtotal	4	72
Harvesting	Hours per day	4	4
	Persons involved	3	4
	Days	2	4
	Subtotal	24	32
Total	242	274	

Note: 'Temporal investment in new milpa and cañada is the same' (Farmer I).

Discussion

In Latin America, (mostly indigenous) small-scale, traditional production delivers at least half of the food produced for domestic consumption (Altieri, 2004; ETC Group, 2009). It persists due to complex ecological interactions in biodiverse environments, which provide yield advantages of at minimum 20% per crop compared to monocropping. Additionally, low disease and pest pressure, and high efficiency in the use of water, light and nutrients (Altieri, 2009) guarantee independence from commercial inputs. Since output in subsistence farming is based on the nutrition needs of the peasant's family, not on the maximum resource exploitation (Rosset, 1999), yields per area tend to be lower than in conventional farming.

As for Maya peasants, this indifference to output may be changing. This is motivated by political and social pressure to 'modernize' farming communities; additionally, although adapting crop management to changing conditions has been an essential part of the historic evolution of Maya farming (García-Frapolli et al., 2008), the current climatic change is more complex, extensive and prejudicial than what was experienced by former generations (Table 1). Consequently, stakeholder identification confirmed that all over Dziuché production systems are being modified. Two climate-related driving forces for this tendency were mentioned. First, a generally uncertain climate; this perception agrees with the actual meteorological

Table 11. Costs, benefits, maize harvest and its use of the *milpas* of two different-aged peasants (two production cycles).

Year, cropping cycle	Parameter	Farmer I	Farmer II
2012, new *milpa*	Expenses (MXN)	5,895	7,070
	Harvest auto-consumed (kg)*	500	1,500
	Harvest sold (kg)	2,500	1,100
	Income (MXN)	7,500	3,300
	Profit (MXN)	1,605	–3,770
2013, *cañada* (Farmer I)/ new *milpa* (Farmer II)	Expenses	4,385	6,950
	Harvest auto-consumed (kg)	500	1500
	Harvest sold (kg)	1,500	900
	Income (MXN)	4,500	2,700
	Profit (MXN)	115	–4,250
Total	Expenses (MXN)	10,280	14,020
	Harvest auto-consumed (kg)	1,000	3,000
	Harvest sold (kg)	4,000	2,000
	Income (MXN)	12,000	6,000
	Profit (MXN)	1,720	–8,020
	Subsistence consumption (%)	20.8	60.1

Note: Farmer II gives about 1,000 kg harvested maize to his brother (not considered as wages).

data for central Yucatan, where rainfall decreased drastically in June, the key month for seeding maize in this region (CNA, 2015).[11] The second trigger is reduced soil humidity due to accelerated evaporation attributed to deforestation (as a consequence of expanding cattle farming, urbanization and wildfires).

Through the comparison of two farmers, it was found that younger peasants tend to respond more strongly to these alterations than older ones. Both took charge of their *ejido* as young men, which at that time had a classical *milpa* management, and changed it within the last 15 years:

- While maintaining maize, squash and sweet potato, both reduced agrobiodiversity by eliminating legumes, watermelon and coriander. Yam, cowpea (*Vigna unguiculata* (L.) Walp.), and radish (*Raphanus sativus* L.) were excluded only by the younger farmer, while the older farmer no longer cultivates pepper.
- In terms of interspecific variety, they now seed one particular maize landrace; formerly, they established at least two different ones.
- Seeding of maize was usually done after the first intense rainfall of the cropping season, at the end of June or beginning of July. Now, they wait for up to three intense rains before seeding.
- Both simplified their seeding procedure. This change is more drastic in the case of the younger farmer (Table 7).
- Since family members have become less involved in their *milpas*, the peasants now have to pay more wages to farmworkers, especially for slashing and burning (Table 10).

Besides age, three particularities distinguish the younger farmer from the older one: the younger sells approximately 80% of his maize harvest, which gives him a more market-orientated approach to farming. Due to his diverse off-farm activities, he also has to be more time efficient in the field. Finally, he became the only one responsible for his *ejido* at a very young age; thus, he missed a considerable part of the usual empirical introduction to *milpa* by experienced peasants. Bellon et al. (2011) state that farmers respond to climate change by intensification, crop diversification, or agriculture retirement. The young peasant chose intensification of his *milpa* by using synthetic products, a common tendency in contemporary slash-and-burn farming (Toledo, 2003). Under these circumstances, five change responses were made only by the younger peasant:

- he experiments with foreign seeds;
- he seeds two crop cycles on the same field before abandoning it for fallow in order to spend less on wages for slashing-and-burning;
- instead of the traditional cyclical field design, this farmer prefers a linear arrangement;
- he uses more diversified and contemporary agricultural tools;
- he now applies herbicides and, therefore, invests less time in weed control.

Evaluating the magnitude of the responses, the most outstanding is undoubtedly the decision of both peasants to exclude beans from their *milpas*. Apart from their relevance as food, beans have an essential agroecological function, endowing the polyculture with N-fixing bacteria (Altieri, 2009). Especially in poor fertile soils (as in Dziuché), NO_3 uptake and biomass production are up to 7% greater in polycultures with legumes than in maize monocultures (Postma and Lynch, 2012, p. 1). Both farmers mentioned poor rainfall as the reason for this response; beans are more susceptible to changing rainfall patterns than maize. This decision can be attributed to the limiting factor theory of Niles et al. (2014), whereby immediate limiting factors (in this case decreasing rainfall) are likely the most urgent issue for an agroecosystem and result in short-term responses (eliminating beans).

However, it was also found that the responses of the peasants of Dziuché are not only due to changing atmospheric conditions but are also related to personal experience and technical questions. Finally, there are political, historic, cultural and social reasons that force changes in peasants' production and livelihood styles. In Dziuché, six such non-environmental triggers could be identified.

- The strategies for adaptation to climatic change, inherent to traditional agriculture, are empirically transmitted from one generation to the next. Now, this knowledge transfer is affected by an aging peasant population, whose children tend to more conventional production, influenced by what they learn at school, or abandon agriculture.
- In the Yucatan Peninsula, a trend towards increasing consumption of industrialized food is observed. Changing nutrition habits also apply to other indigenous communities, where demand for *milpa* products is steadily decreasing (Pérez Izquierdo et al., 2012). As for Dziuché, squash especially is becoming a less popular food under younger peasants.
- Across the Yucatan Peninsula, fallow periods in slash-and-burn farming formerly lasted over 30 years, but now last 12–16 years (Castillo-Caamal et al., 1998), which is related to the ongoing debilitation of the *ejido* system (Eastmond, 1991). In Dziuché, most farmers took advantage of the recent possibility to sell *ejido* land and consequently reduced the fallow time per parcel.
- Since peasants count on a decreasing number of family members available for

unpaid work on the fields, they have to pay external workers; this requires cash. Ergo, peasants appeal for subventions, sell a considerable part of their harvest, focus on maize varieties with market potential, sell land, or seek out off-farm income. This increases the need for time-efficient crop management, which for many means the use of synthetic products – a vicious cycle, which demands additional cash.

- Traditional agriculture suffers from a poor social reputation in Maya communities (Ebel and Castillo Cocom, 2012). This point of view is not only shared by the (formerly young) rural residents but also by local and national decision makers, who promote 'successful' livelihoods and desirable lifestyles in tourism (Carte et al., 2010) or in commercial agriculture (or cattle breeding), even if this eventually means cropping (breeding) high-input crops (races), which are not adapted to the local environment.
- The 'modernization' of indigenous communities, mainly driven by their contact with ongoing neo-liberal tourism development (Carte et al., 2010) and the consequences of the restructuring of Mexican agriculture (Re Cruz, 2006), has also encouraged plausible demands like better education or higher mobility, which require additional spending power – money that cannot be gained in the *milpa*.

Conclusion

Traditional farming systems, such as *milpa* polycropping, typical in the central Yucatan Peninsula, are currently facing multiple developments that do not favour traditional farming: economic, socio-cultural, environmental and technical. But the most challenging threat combines all three of these: climate change. In this context, the ability of peasants – key actors in agroecosystems – to find answers to this threat is at least as important as finding technical solutions to predicted atmospheric developments. As shown in this study, even experienced peasants do not only adapt to climate change (shifting the maize seeding date), but also react to it by eliminating beans from their *milpas*. This means that despite the potential of traditional farming to resist and adapt to climate change, the magnitude of it is apparently challenging peasants to an extent that they respond with measures like decreasing agrobiodiversity, which actually harms resilience instead of improving it. In this context, it was also observed that a younger peasant disconnects easier from traditional strategies than an older one. Thus, our findings underline the need to update *milpa* in a way that corresponds to the perceptions and the needs of its future protagonists, the rural youth. As the study demonstrates, this update must involve technical solutions (such as finding ways to maintain the agrobiodiversiy of *milpa* by simultaneously reducing its labour intensity) but cannot be limited to them; *milpa* is also seriously jeopardized by the consequences of neo-liberal politics that complicate its traditional implementation and lure away youngsters from Maya communities.

Across the Americas, the maize-bean-squash polyculture is commonly referred to as the 'three sisters' (Lewandowski, 1987). Now, one of the sisters (beans) has become sick. It is time science and politics provided concrete suggestions for confronting the threats sustainable farming is facing. Time is short. *Milpas* without beans are a serious warning signal, since they become a simple cornfield.

Notes

1. Prognostics correlated to conventional monocrop systems; few information is available for polycrop-

ping.

2. Except varieties with enhanced drought adaptation (Beebe et al., 2008, p. 1).
3. Spanish for peasants.
4. Members of the *ejido* assembly.
5. Natural gum used for chewing gum production generating an important export industry during the first half of the twentieth century.
6. There is no historic meteorological data available for Dziuché. This information is from Felipe Carrillo Puerto, 17 metres above sea level, 100 km from Dziuché.
7. Thus, the procedure can also be considered as participant observation.
8. The federal 'Farmers Direct Support Program', created 1993 in order to compensate peasants for expected declining prices after the initiation of NAFTA.
9. The annual maize consumption in Mexico is 115 kg per capita (SAGARPA, 2011).
10. Principally for familiar consumption; if there remains honey, he sells it.
11. Following this trend, the Yucatan Peninsula is forecasted to transform from mainly wet to exclusively dry lowland by the year 2050 (Bellon et al., 2011).

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