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Barriers to the Adoption of Alley Cropping as a Climate-Smart Agriculture Practice: Lessons from Maize Cultivation among the Maya in Southern Belize

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Abstract: Climate-smart agriculture (CSA) is proposed as a necessity, as the agricultural sector will need to adapt to resist future climatic change, to which high emissions from the sector contribute significantly. This study, which is an exploratory case study based on qualitative interviews and field observations, investigates the barriers to making a CSA-adjustment in maize production among Maya communities in southern Belize. The adjustment is alley cropping, which is a low-input adjustment that has the potential to result in both adaptation and mitigation benefits, and furthermore, to enhance food security. The findings show that a CSA-adjustment in small-scale maize production in Maya villages in southern Belize is possible in principle, though several barriers can make the overall climate-smart objective difficult to implement in practice. The barriers are of a proximate and indirect nature, exist at different spatial scales, and involve various levels of governance. The barriers are shown to be land tenure, market access, and changes in the traditional culture, however, these barriers are not homogenous across the villages in the region. To break down the barriers an overall district-level strategy is possible, but the toolbox should contain a wide variety of approaches. These could happen, for instance, through alterations to land tenure and the land taxation system nationally, enhancement of the agricultural extension system to ease access to knowledge and input at the district level, and support to a less complex governance structure at the village level.

Keywords: adaptation; Belize; Central America; climate-smart agriculture; deforestation; livelihoods; maize; Maya; mitigation; shifting cultivation

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) estimates 24% of global anthropogenic emissions of greenhouse gases in 2010 originated from agriculture and land use change [1]. Around 10–12% came directly from agriculture [2,3] and 10–13% from changes in land use largely associated with food production [4]. Likewise, it is realized that agricultural production and food security in the Global South and North are already being affected by climatic changes [5], and that land use systems globally will have to change in response to future climate change, which will cause major changes in livelihoods and landscapes [6]. Smallholders practicing rainfed farming in tropical regions are particularly exposed to climatic changes and low food security [7–10].

On this background, climate-smart agriculture (CSA) has been proposed as a broad framework of techniques and measures to promote synergies and circumvent trade-offs between adaptation and mitigation in the agricultural sector [6,11]. CSA includes, for example, practices to improve soil water-holding capacities by adding crop residues and manure to arable soils, which not only affects

soil properties and nutrient cycling, but also lowers emissions [6,11]. However, technologies for CSA are useless unless they are translated into actions, i.e., adopted, by farmers. Barriers are challenges, obstacles or constraints that impede implementation of actions or that restrict options [12]. Studies of adoption of agricultural technologies have found a variety of barriers to adoption, for instance, land tenure arrangements, access to credit, farmers' attitudes to risk [13], the lack of tenurial security, low output prices [14] and additional labor expense [15]. In a review of 23 studies of conservation agriculture, Knowler and Bradshaw [16] found 46 factors relevant to adoption, which were divided into four groups: farmer and farm household characteristics (i.e., age and gender), farm biophysical characteristics (i.e., farm size and slope), farm financial/management characteristics (i.e., tenure and labor requirement) and exogenous factors (i.e., price fluctuations and access to extension services). Others again have emphasized up-front investment costs as a key barrier to adoption, together with institutional and policy barriers [17]. Thus, it can be concluded that progress in CSA (and similar approaches) will have to be tailored to the specific conditions, as few if any of these factors and barriers are universal.

Consequently, adoption of adjustments by farmers has been identified as an important knowledge gap [6,8,18,19], and it is "critically important to identify and analyze barriers to adaptation to identify possible opportunities to overcome them" [19]. Further, detailed case studies, like this one, "can contribute to our causal understanding of the multiple conditions that create barriers, to resolve possibly diverging evidence and explain interdependencies of barriers" [19]. Hence, this study undertakes a detailed investigation of barriers for adoption of alley cropping of maize with contour tree planting in southern Belize, a technique that has been promoted as an alternative to shifting cultivation. The study builds on 125 qualitative interviews with actors directly or indirectly involved in the adoption decision. The paper proceeds as follows. Section 2 describes the case study area, which is followed by a description of the research method applied in Section 3. Section 4 presents the empirical results, followed by the discussion in Section 5. Finally, Section 6 concludes the paper.

2. Case-Study Area

2.1. Physical and Cultural Setting of the Study Area

Belize is the second smallest country in Central America. It is located at the northernmost point on the Caribbean coast of the Central American isthmus and is bordered by Mexico, Guatemala and the Caribbean Sea (Figure 1). With a population of only 322,453 (55% rural), Belize's population density is the lowest in the region. Nonetheless, due to increases in fertility and immigration, the population increased by 30% from 2000 to 2010. For its size, Belize is extraordinarily ethnically diverse. Mestizos (Spanish/Latino), Creoles and the Maya are the three largest groups, with 49%, 21% and 10% of the population respectively, and there are also populations of Garifuna (5%), Mennonites (5%), East Indians (2%), Asians (1%), Caucasians/Whites (1%) and certain others [20].

Toledo District in southern Belize, where this study was conducted, is classified as wet tropical lowland with 3000–3800 mm of rainfall a year, a distinct wet season (January–December) and a dry season (January–May). The annual mean temperature is 24 °C, with little annual variation, and elevation is below 1000 m. The district has the most rural (83%), least educated and poorest population [20,21]. Maya Indians, who make up 61% (19,000) of the population of the district [20], are divided into two different groups (Q'eqchi or Mopan), who are settled in the 38 Maya villages. The Mopan Maya are largely located in the northeastern hills, the Q'eqchi Maya in the lowlands and the lowland margins [22]. The population growth rate in Toledo was 5.5% a year from 1990 to 2010, which is ~2% higher than the national average [20]. The primary activities in the villages are a mixture of subsistence and cash-crop agriculture, but wage labor and petty trade are also essential [22,23].

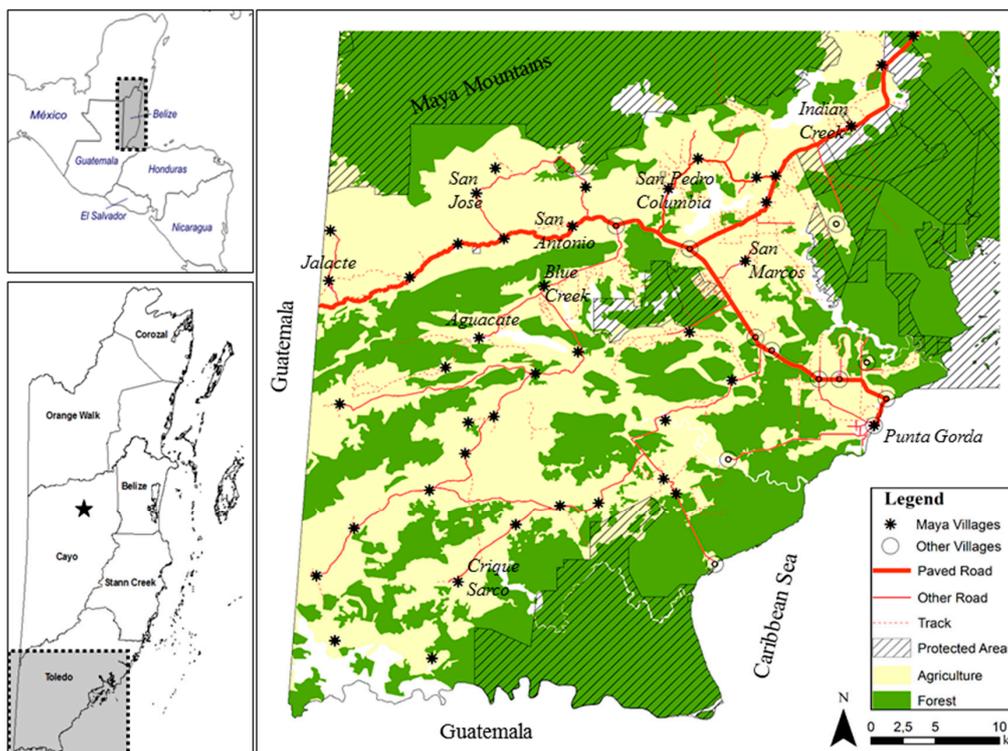


Figure 1. Regional map (upper left), Belize with districts (lower left) and Toledo District with villages (right).

Maya agriculture is a combination of shifting cultivation (so-called milpa) and permanent agriculture which provides subsistence production, mainly of maize (*Zea mays*), beans (*Phaseolus* spp.), root crops and vegetables. Other important products for both subsistence and cash purposes include cacao (*Theobroma cacao*), pigs (local landrace), cattle (*Brahma*) and rice (*Oryza sativa*) [21,22,24–28]. The Maya have a long history of being independent smallholders with extensive knowledge of local flora and fauna, hence hunting and gathering is widespread [21,22,28]. The extent of cultivated land, whether permanent or in cycles, has followed the trends in population growth, which has strained available land assets, causing declining fallow periods, declining crop production and seasonal out-migration [20,24,29].

With regard to land tenure, the country is divided into national land (owned by the government, including lease-land), forest reserves, private land and Indian reservations. The forest reserves are owned and administered by the government. However, large tracts of current forest are logging concessions, while others are protected. Some of the latter are co-managed by conservation NGOs (non-governmental organizations). In Toledo District, 52% of the land is private and 13% leasehold, which is considerably below the national average (63% and 25% respectively), and the figures for the Maya villages being only 30% and 8%. However, 24% of the district is managed as reservation land [20], which is the land around many of the Maya villages. It includes agricultural land and forest managed by the village council, but owned by the state. The reservation land system was drawn up in 1924, but since the 1940s the government has taken steps to privatize land in reservations. Hence, the system around the villages is a mixture of reservation land, leases, private land and informal arrangements, all of which operate pragmatically through continuing negotiations and the exercise of political power, but disputes over land ownership and frequent court cases are common [22–24,30]. Furthermore, beyond the smaller private court cases is the political struggle to preserve Maya land rights running in the Supreme Court of Belize. The rulings have been in favor of reservation land, but little action has occurred in terms of delimitation, demarcation, and land titling [23].

The Maya are interesting for this study, as they have changed agricultural practices and culture in the past century [22–24,31,32]. Since the 1940s, they have moved from a subsistence-based to a market-based economy, which mainly was triggered after the government constructed a road from Punta Gorda (the primary market town) to San Antonio (the largest Maya community). However, the degree of change depends on the proximity to markets and roads [33]. The educational pattern in the villages has also changed dramatically, especially for women, since several development projects have focused on them, resulting in more empowered women postponing matrimony in favor of education, wage labor, or petty trade [29]. These changes have led to a turnover of the political, economic and religious hierarchy, and status is now associated with monetary wealth rather than age and experience. Furthermore, politics have moved from being locally based to the increased influence of the two major national parties in the villages, while at the same time the Catholic Church has lost its superiority [33].

2.2. Mitigation: Emissions from the Current System

Globally, Belize's emissions are insignificant [34], and small-scale farmers like the Maya can hardly be held accountable for climate change. However, expansion of agriculture in many developing countries is contributing to climate change through deforestation and unsustainable land management practices [8]. Moreover, land use represents the largest climate mitigation potential in many countries [2], especially in developing countries like Belize, where the other sectors are very small. It was estimated that 92% of greenhouse gas emissions in 2000 in Belize came from land-use change and forestry, and the figures for this sector went from 2 up to 12.3 megatons of carbon from 1994 till 2000 [27]. Around 5000 acres of forest were lost yearly in Toledo between 1980 and 2010, with forest cover dropping from 85 to 71%. This deforestation was assessed to occur in proximity to the villages [35,36], and milpa farming was identified as the primary cause. GIS data [37] classify that in 2010, there were approximately 30,981 ha of milpa farmland, of which 23,825 ha were cleared between 1980 and 2010. Logging (legal and illegal) and infrastructure (road construction) were secondary drivers [26,38–40]. Though, disagreement about the significance of milpa farming for deforestation is an ongoing politicized debate between scholars, the Forest Department, and Maya organizations [23,41].

2.3. Adaptation: The Need for Adaptation in the Current System

Toledo is vulnerable to natural hazards and climate change. The IPCC's 2050 projections for Central America [42] predict increasing temperatures causing increasing evaporation losses, decreasing precipitation, shorter rainy seasons and longer dry seasons, increased frequency and intensity of heavy rain events causing rapid run-off or flash floods with consequently increasing erosion, more intense hurricanes and a general rise in extreme events like droughts and floods. The expected decrease in precipitation, increase in temperature and less predictable seasonal weather patterns will unequivocally have an adverse effect on the agricultural production cycle and therefore on food security. Prolonged dry seasons have already resulted in damaging droughts, and intense rainfall events have resulted in flash flooding that has wiped out subsistence crops and increased run-off and erosion. The expected increase in the intensity of hurricanes will lead to them traveling further inland, with impacts on the agriculture that is a decisive factor in the Belizean economy [43,44]. For example, in 2001 hurricane Iris caused severe damage (25% of national GDP [45]), and 85% of cacao trees were damaged [24]. The typical Maya household is threatened, as their most important crops, maize and beans, are expected to suffer in the future [21], and the suitability and yield of these two crops are expected to decrease significantly [5,46–48]. The main problem is that the traditional shifting cultivation system relies heavily on the wet–dry seasonal weather pattern, which is becoming less predictable [42].

3. Research Methods

To locate potential overlaps between adaptation and mitigation, Murdiyarsa and colleagues' [49] framework was applied, where the three key parameters are: (1) which social groups to target

for adaptation and mitigation activities and do they coincide? (2) where are the locations of the need for adaptation and effective mitigation and do they coincide? and (3) which activities affect adaptation and mitigation the most and do they coincide? Information to feed into this framework was located by a literature review e.g., [21,22,24,26,28–33,50–53]. Information also included GIS layers (e.g., infrastructure, protected areas, settlements, hurricane tracks/damage, and land use) and population and agricultural statistics.

Furthermore, data collection was conducted over a seven-month fieldwork period (August 2013 to February 2014), of which the last three months were spent in Toledo District. First, villages were visited to interview community representatives and farmers in order to obtain an insight into the practices being used. A special focus was put on three villages (Crique Sarco, San Jose, and Jalacte), where around ten farmers were interviewed about farming activities and practices. The literature review revealed that Maya villages in Toledo have similar agricultural practices e.g., [21,22,28,33], hence only a small number of farmers were interviewed to obtain knowledge about general styles in the villages. The majority of these interviews were conducted in English, but interpreters (Q'eqchi, Mopan, and Spanish) were used if the interviewee preferred so. Together with a semi-structured interview guide, transect walks, a seasonal calendar and maps were used to guide the interviews. These tools allowed the interviewer rapidly to obtain an overview of the various agricultural production activities. Information regarding community functioning, dynamics, diet, decision-making mechanisms, division of labor, and community work, were obtained from previous studies conducted in the villages by others. Together these sources helped to determine the activity in the Maya villages that take up the most land, as this activity contributes with the largest emissions and theoretically holds the greatest mitigative effect (directly or indirectly), and it is theoretically the most important activity for the adaptive capacity.

Subsequently, to enhance the CSA objectives, an adjustment to lower emissions and decrease the vulnerability of the selected activity was suggested. The adjustment was focused on farmers and took its point of departure in the mitigation and adaptation literature related to rural settings in developing countries in the tropics. Furthermore, recommendations from the Agricultural Department of Belize, local NGOs, agricultural institutions working in Belize and people knowledgeable about local conditions were included. Radical changes, e.g., in activity, area, or use of costly inputs and machinery, were not taken into consideration, as the notion was to suggest a realistic adjustment (i.e., an external low-input technology)—and not hypothetical changes that were difficult for farmers and informants to relate to. Furthermore, the suggested adjustment was already implemented in some locations in Toledo, which indicates that it is achievable, but it also raises the question of why it did not spread to all the villages.

During the fieldwork, key informants coming from governmental and multilateral institutions, NGOs, academia and farmers' organizations directly linked to the villages or knowledgeable about local circumstances were interviewed (Table 1). The majority of these interviews were conducted face to face, but a few were completed by Skype. Around half were semi-structured interviews (open-ended questions) that were audio-recorded, while the rest consisted of brief talks, informal talks, preliminary interviews, or shorter interviews. Interviewees were mainly asked questions in proportion to affiliation, education, location, position in the organization and knowledge about the villages, among other things, meaning that interviewees were not given exactly the same range of questions. The objectives of these interviews were to: (1) obtain general background information about the study area; (2) discuss the adaptation and mitigation effects of the suggested adjustment, including potential synergies and trade-offs; and (3) assess the feasibility of making the suggested adjustment, especially if different social, cultural, economic, and political barriers were likely to influence adoption of the adjustment. Barriers were defined as (1) impediments (2) to specified actions (3) for specified actors in their given context that (4) arise from a condition or set of conditions. And a barrier can be (5) valued differently by different actors, and (6) can, in principle, be reduced or overcome [19].

Table 1. Organizations and persons interviewed for agricultural survey in Belize (see detailed list of interviewees in Table S1). ^a Three community meetings are excluded from this figure.

Institutions/Person	Number of Interviewees	Number of Meetings or Encounters
Government and Multilateral Organizations	22	26
Academia	11	22
Non-Governmental Organizations	32	42
Farmers' Organizations	5	8
Others	14	22
Local authorities and farmers in Maya villages	35 ^a	15
Local authorities and farmers in other farming communities	6	6
Total	125	141

To protect the sources and ensure anonymity, none of the interviews are referred to directly, but for purposes of verification, the findings were supported by various interviewees from dissimilar affiliations. QSR International's NVivo 10 qualitative data analysis Software was used to organize the data from the recorded interviews. The coding was divided into a hierarchical structure of nodes (Figure 2). The content of the nodes (i.e., clippings from the interviews) was subsequently scrutinized to examine the scale of the barriers (household, village, district, national, or international), the types of barriers (political, cultural, labor, etc.), the institutions involved (e.g., non-governmental, governmental, multilateral organizations), and geographical areas (e.g., certain villages).

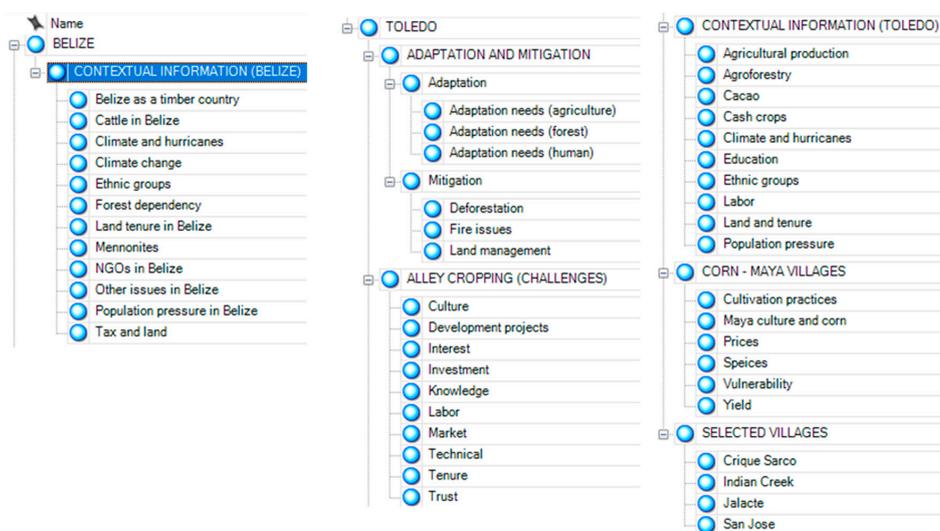


Figure 2. Overview of nodes used in NVivo to code interviews from agricultural survey in Belize.

Finally, community meetings with villagers were held in three villages (Crique Sarco, San Jose, and Jalacte) to determine whether the most distinct features of the perceived farming system was understood correctly and to obtain additional feedback from farmers about feasibility and barriers concerning the suggested adjustment. This last step was repeated with four key informants (Interviewees 12, 19, 20 and 31 in Table S1, respectively), that were selected because of their different backgrounds and affiliations (CEO, Agriculture Department; Country Representatives, Caribbean Agricultural Research and Development Institute (CARDI) and Inter-American Institute for Cooperation on Agriculture (IICA); and anthropologist, University of Belize), and because they had extensive knowledge concerning the research questions and all-round knowledge about Belize. Both villagers and the four key informants accepted, with minor corrections, the information presented to them, and they added some final input to the interpretation of the findings.

The unit of analysis was Maya villages in Toledo District in general. The “traditional” household approach was eschewed, because several scholars already have conducted extensive household-level research in the area [21,22,24,26,28,31,33,50–53]. Thus, culture and practices in the region have already been described in detail, hence repeating such an approach only would have revealed few new insights. The strength of this study is the combination of inside and outside viewpoints, which gives a further nuanced understanding of the situation.

4. Findings

By using the framework by Murdiyarso and colleagues [49], maize cultivation around the Maya villages was found as the activity with the largest potential overlap between adaptation and mitigation. Maize is the most important crop for the Maya and will continue to be, as it is deeply embedded in Maya culture. All meals are centered around maize, and it is the crop the Maya pay the most attention to [22,23,54]. Indeed, maize forms the core foundation of Indian societies in Central America, however, its social and religious status often seems to exceed its nutritional and economic importance [55]. It has been noted that the milpa concept is a sociocultural construct that involves complex interactions and relationships between farmers, and that making a milpa is a dominant and most sacred act, one which binds together the family, the community and the universe [56]. Thus, the following sections will solely concentrate on the production of maize around the Maya villages.

The maize production relates to adaptation by being exposed to climatic change and because the Maya’s adaptive capacity depends heavily on their maize production. It also affects mitigation, as shifting cultivation causes deforestation and degrades forest, but also the cultivation practices applied affect mitigation. The boundaries of the system concerning mitigation are primarily the deforestation caused directly by maize cultivation around Maya villages and secondarily the maize cultivation itself. The milpa system is a no-till farming system making very limited use of inorganic fertilizer, and fuel use related to marketing is limited as well, which is why these sources are assessed as being inconsiderable. However, use of insecticides and herbicides is widespread, which is why the adjustment technique is seeking to reduce these applications.

4.1. Adjustment

The suggested adjustment technique, alley cropping, is described together with the expected adaptation and mitigation effects in Table 2. The arrows indicate the expected causal relationships and if an increase or decrease is expected of that particular effect. The technique and the enclosed benefits emerge from a combination of a literature review, information from interviews, and from materials such as flyers and homepages issued by organizations (Ya’axche Conservation Trust (YCT), Agricultural Department, Maya Mountain Research Farm, Plenty Belize, Sustainable Harvest International, Sarstoon Temash Institute for Indigenous Management, Inter-American Institute for Cooperation on Agriculture, Caribbean Agriculture Research and Development Institute) working with sustainable farming in Maya villages. The feasibility of the adjustment has been proved by the organizations concerned and are being implemented in some areas. In addition, the IngaFoundation [57] has proved the viability and potentials of the system in Honduras under comparable conditions. The designated benefits are not meant to be exhaustive, but they should demonstrate some of the potential effects. Moreover, it can be expected that several of the effects may have positive or negative effects on the other objective, so-called synergies or trade-offs respectively.

4.2. Barriers

The barriers described here apply to the proposed adjustment, but are not exclusive for this particular adjustment. The barriers are exclusively based on information provided by interviewees, which is not meant to be exhaustive, but merely to provide an impression of the complexity of employing the adjustment in the current system. Table 3 provides an overview of barriers described by interviewees, key informants applied, and selected statement examples from the interviews.

Table 2. The suggested adjustment to enhance Climate-smart agriculture (CSA) in maize production among smallholders in Maya villages of Toledo district, southern Belize. (Legend: → cause, ↓ decrease, ↑ increase). References used in locating the effects: [57–62].

Adjustment Technique: Alley Cropping with Contour Planting as an Alternative to Slash-and-Burn			
Description	Specific Detail about the Practice in Toledo	Adaptation Effects	Mitigation Effects
Along contours rapid growing nitrogen-fixing trees are planted as seedlings in series of hedgerows forming alleys. Maize is then planted in contours in between the trees. The trees are pruned, and the biomass is used as mulch, which improves soil fertility and soil structure (water holding). Mulches also protect the soil from solar radiation and rainfall impacts, and they minimize weed growth. Alley cropping is capable of maintaining yield over many years, thereby breaking the cycle of shifting cultivation.	<p>Species: bri-bri (<i>Inga edulis</i>), madre cacao (<i>Gliricidia sepium</i>) and leucena (<i>Leucaena leucocephala</i>)</p> <p>Trees are established from cuttings, using stakes of 5–6 months of age, 1.5 m long and with a diameter of 3.5–4.0 cm</p> <p>They are planted at 5.0 m between rows (distance decreases with slope) and 2.5 m between plants at 20 cm depth</p> <p>Plant population is 582 trees per acre</p> <p>East-west planting is optimal to maximize sunlight interception</p> <p>A month after planting the legume, maize is sown at a distance of 0.9 m between rows and 0.5 m between plants</p>	<p>↓ run-off and erosion + ↑ soil moisture → ↑ soil fertility and quality → ↑ yield → ↑ food security</p> <p>↑ fuelwood availability → ↓ deforestation</p> <p>↓ weed, diseases, and pest → ↓ chemicals → ↓ input costs</p> <p>↓ travel time to fields → ↑ time for other activities</p> <p>↑ biodiversity → ↑ access to bush meat → ↑ food security ↓ deforestation → ↑ forest products → ↑ food security</p> <p>↑ land availability → ↓ migration from rural areas</p> <p>↑ wind protection → ↑ yield → ↑ food security</p>	<p>Primary benefits</p> <p>↑ soil fertility and re-fertilization of previously degraded land → ↓ deforestation → ↓ emissions from forests</p> <p>Secondary benefits</p> <p>↑ carbon absorption by alley trees</p> <p>↑ organic matter → ↑ soil carbon</p> <p>↑ fuelwood availability → ↓ deforestation → ↓ emissions from forests</p> <p>↓ chemicals → ↓ emissions</p> <p>↓ escaping fires → ↓ deforestation → ↓ emissions from forests</p> <p>Adverse feedbacks</p> <p>↑ legumes → ↑ N₂O release</p> <p>↑ soil carbon → ↑ N₂O release</p>

Table 3. Left: The main barriers pointed out by the interviewees of agricultural survey in Belize. Number refers to the interview ID in Table S1. Right: Statement examples from the interviews.

<p>Culture 4, 6, 14, 19, 20, 31, 37, 38, 47, 49, 61, 62, 63, 70, 84–94</p>	<p>It is harder to change the practices used in maize, rice and beans, as it is their livelihood and a cultural thing, whereas the cash-crops are differently. They were very reluctant to make these changes and many are still. They said: “how can I grown maize without burning” or “that cannot work”, but after they have seen it working they change (38). I have seen it (alley cropping) and it works, but it has not been adapted culturally (62). But many farmers (and agricultural department officers) are stuck in traditions—they aren’t innovative and do not come up with new crops—do not see other or new markets. So you need to take the young ones and train them. Farmers in this country are not trained to see opportunities, they do what their fathers did—they do not know better (70).</p>
<p>Development projects 12, 19, 20, 61, 62, 69</p>	<p>They (Crique Sarco) always had conflicts. It is one of the “project-villages” (together with Aguacate and San Miguel). They are very good in seeing that a project is coming—working with it—and when it ends, they move on to the next project (61). But farmers stop during projects, when you stop the support, because they believe you should continue to give them fuel, seeds, chainsaw, etc. They do not see the benefits of the extra work—they are greedy (69).</p>
<p>Interest 12, 19, 31, 37, 38, 47, 49, 61, 62, 84–94</p>	<p>The Mayas are heavily discriminated—most backward—and especially the young generation is struggling with this issue, because they wanna remove them from that label and identity to be accepted in mainstream society, so they stop using the machete and work at a resort instead—something more recognized than being a farmer. So less and less of the young understand the cultural values we build our livelihood on. The elders know and understand the value of the traditions, where the respect for the environment is greater as they value what they use to maintain their livelihoods. But now people do not even plant together—they hire people (37). No future in farming—only subsistence, as there is no market—only the small local market in Punta Gorda (49).</p>
<p>Investment 12, 19, 28, 31, 37, 38, 61, 65, 67, 70, 84–94</p>	<p>We (The RED-SICTA project) gave them (villagers in Jalacte) the storage tanks, but at harvest they sold everything, and later in the season they are lacking maize, but at that time the price is higher. They say they need cash, but they do not save any of it. So they sell when the price is low, and buy when the price is high (19). Only small-scale or large-scale is viable—middle size farming is not possible. You cannot grow from being a small farmer to be a large-scale farmers. You need huge amount of money to investment, because if you grow you have to compete with established large-scale farmers, so you will lose money for many years (28). Farmers do not invest enough in their farming. You have to understand that the farming here is subsistence-based, with a very small revenue from the few sold items. Many farmers do not invest, as they would like to do something outside farming like road-construction, tourism . . . They don’t have the retention to restore some money to invest in the next harvest. The lack of a market is a major limitation for doing this (38).</p>
<p>Knowledge 12, 14, 19, 20, 27, 31, 38, 49, 61, 62, 65, 67, 68, 69, 70, 84–94</p>	<p>Extension services have been very bad in this country—lack of innovation and planning—there is no holistic point of view/approach. They only look at the production of maize, but what about sustainable aspects, environmental aspects, how do you build PES (payments for ecosystem services), and how do you build resilience and adaptation to climate change. So no long-term planning—politicians are not aware these issues (20). Some are not at the educational level where they understand new methods or how investments work (69).</p>
<p>Labor 12, 19, 27, 31, 33, 37, 38, 39, 49, 61, 62, 63, 65, 67, 84–94</p>	<p>There is cohesion and collective labor but it cannot be understood with the western society lens. It is hard to see and appreciate for outsiders—we only see what we are trained to see. And our organization (the organization in Maya villages) is different from the Mennonites and others (37). Alcohol is a great problem in some communities—in some you cannot buy alcohol. Especially the people working outside drink their salary and bring very little home, and that is why farming is important in all families (37). They need money badly, so if a project is not providing that they will leave (63).</p>

Table 3. Cont.

<p>Market 12, 21, 28, 31, 49, 64, 84–94</p>	<p>And also make them produce other things than maize and beans—more marketable crops. And crops you can process and add value to (12). The boom-crisis cycle repeats again and again, so they keep one foot on the ground with the stable foods and the other foot is hoping up and down with the booms (banana, pigs, rice, cattle, and cacao)—this is their strategy. To survive under these conditions you have to be very smart—they are far from stupid people (28). No future in farming—only subsistence, as there is no market—only the small local market in Punta Gorda. There is a lack of organizations that provide a market for the products produced—especially in Toledo. Only cacao is working. The small farmers are not a part of the large citrus and banana industry in Belize (49).</p>
<p>Technical 12, 19, 20, 61, 83, 84–94</p>	<p>They also have to improve planting technics and use improved varieties. Weevil is not a problem if they harvest on time (when it is dry), and then dry it and store it properly. I have the same variety and have stored it for more than one year. They leave it in field and it catch weevil, which their local variety also do (19). I sell yellow and white, and hybrid [maize seeds] (both white and yellow), which mature in 7 weeks. No red maize or other varieties are sold. People in Crique Sarco cannot afford the hybrid one, but around 15–20 farmers in San Jose use it (83).</p>
<p>Tenure 6, 12, 19, 20, 27, 28, 31, 37, 38, 40, 49, 61, 62, 67, 84–94</p>	<p>But in the south it to a certain degree boils down to tenure! For the Maya the tenure is just a piece of it—the argument is taken from a human rights standpoint—the right to self-determination—the idea as a people (as a culture) the resources locked up in the reserves is what is required for them to survive—essentially in determines the quality of their life (6). Private ownership could change that, but communal land/private ownership is a difficult topic right now with the court cases. But I believe that private ownership in the villages is the only way. I cannot mention any homogeneous communities where things are working without problems (27). You cannot use the western conception of private ownership here—it is a clash between two different systems. The only thing that stands between complete impoverishment is their land and if you privatize the land, they will sell it as in rest of Belize. They will eliminate land and the Mayas will become wage-workers in Toledo and in the rest of Belize (28). Nobody what to sell their land, but they will be pressured to it. They will come in a situation where they have to sell—that is how the system is structured. It is competition—who will survive? (31) What we have fought for is recognition and respect of the ownership of the land we use and occupy, so the communities can manage these lands collectively in regard to what is best for them. Not for one person or family—but as a community. However, even with the communal lands the communities can decide to have individual parcels. And if I have worked a milpa for 10 years I have the right inherently to pass it on to my kids. However, with the collective right no one can sell off land. So one of dangers in private ownership is that people will sell land to outsiders, and thereby less land is available for the community as a whole (37). People that have land in Jalacte rent it out to Guatemalans, and people that rent land do not care if they deplete the land, as they just can rent somewhere else next time (40).</p>
<p>Trust 6, 12, 19, 20, 27, 28, 31, 37, 38, 47, 53, 61, 62, 65, 69</p>	<p>Since colonial time we have almost been taught not to trust each other—so it is a huge problem in the villages. Divisions between families, religion, politics and classes. So the strong cohesion needed to increase the adaptive capacity is not easy to find. How do we feel about each other—do we feel that we belong to the community? And what are the structures with the leaders so people feel they belong—are they working? The leaders at several levels are not doing that much to create this feeling of belonging (31). One farmer said that telling about his farming practices at a public meeting “would be the same as taking his clothes off”. Farmers think they are in competition with each other (47).</p>

First of all, the Maya base the cultivation of maize on tradition, and most farmers do what their forefathers did, which can be an impediment for them to adopt new practices. They are more reluctant to change their maize-growing practices compared to other crops, as maize is the most important food crop, which is why crop failure can be devastating. Nevertheless changes do occur, for instance, farmers have changed to slash-and-mulch in some of the northern villages (e.g., Indian Creek) after 15 years of support from a local NGO, or the introduction of chemicals in the villages adjacent to the Guatemalan border (e.g., Jalacte). Thus, even where traditions of maize cultivation are strong, the culture has changed dramatically in the district in the last century, and multiple impacts from the modern world (e.g., consumerism), religion, NGOs, and politics have affected households and villages. Food preferences and educational levels have changed, which has increased the need for cash while at the same time degrading cultural identity and practices. Concerning maize production, these new circumstances have affected interest in farming and ecological knowledge, as well as traditional labor exchange arrangements.

Interest in farming has decreased and with it the enthusiasm for changing to sustainable practices. When transportation improved, most children started to attend educational programs, which removed them from the labor force for some years, possibly after graduation as well, as they were eager to obtain off-farm employment with greater prestige (typically in the military, the police, schools, tourism, NGOs, or construction). The Maya have been labeled backward, which impacts on the younger generation, so that they want to obtain wage labor to remove that tag and identity from them and allow them to be accepted in mainstream society. This change is diluting traditions like farming practices and ecological knowledge, which have been passed down through the generations from parent to child orally in the fields. This is followed by their gradual removal from the traditional relationship to nature and farming, lowering respect for traditional and cultural practices. Furthermore, Maya children do not see any possibilities for progression in the current subsistence-based system, with its limited contact with the market. However, paid work is limited in the district, as no larger industrial or service sectors exist, and the few jobs available are low-paid and might not cover the enclosed expenses (e.g., transportation). Thus, young Maya have to resort to farming, but now without the required skills. Besides, institutionalizing children has increased cash needs, thus removing other labor from maize production, as household members have to migrate temporally for paid work or pursue cash-generating activities (cash crops, cattle, and handicrafts). These activities remove the time needed for the cultivation of other subsistence crops, such as beans, rice and root crops, with consequent effects on nutrition.

In addition, outside work and cash needs have eroded the traditional labor-exchange arrangements in the villages, causing several adverse impacts for maize production: (1) cooperatives of any kind are rare, and collective work in the maize fields is vanishing, causing farmers to have to pay people if they need assistance; (2) access to cash has unfortunately increased alcohol abuse, which again takes away time from farming, and the men, who control the economy in most families, bring less salary home; (3) chemicals have replaced labor for weeding, fertilization and pest management, resulting in environmental damage and affecting farmers' health.

Another issue affecting the eagerness to change is the impact of development projects run by religious groups, NGOs, and changing governments. These projects have increased expectations of handouts like land, inputs, technical equipment, cash, commodities and labor support. Once the support ceases, the majority of farmers leave the project or opt out of the implemented practice, and quickly return to their former practices. For example, in the case of the RED-SICTA project in Jalacte, which implemented a system of processing and storing improved maize to avoid having to sell when prices were low, many farmers left partly because the handouts had ended. Some villages have even been labeled "project villages", as they are adept at seeing when a project is coming, working with it, and then moving on to the next project.

The current situation with land tenure was mentioned as being the primary barrier to making adjustments in order to attain sustainability, but it is also the most sensitive issue in this regard.

The government wants to privatize land in Toledo District as has happened in the rest of Belize, but the pressure on the government from externally-funded local organizations (Maya Leaders' Alliance (MLA) and Toledo Alcaldes Association (TAA)), the Inter-American Development Bank and the World Bank to give the Maya certain rights is high. Currently, maize is mainly cultivated on reservation land without individual security, which according to some can lead to poor stewardship of the land, as there are few incentives to invest money or labor in the land or to prevent its depletion. If land is available, farmers move to the next plot when the nutrients are exhausted to avoid decreasing yields. This can require deforestation inside the reservation land or in protected areas. Some villages allow farmers to rent out land to outsiders, who have no incentives to farm sustainably—another reason why soils are degraded. Furthermore, in the reservation system, the right to land only applies as long as it is in use, which can entail overuse. Another concern with, for example, alley cropping is the dislike of planting trees on reservation land, as it is regarded as removing land from the community pool. For instance, about half of the cacao trees are on reservation land, which have caused problems, thus new cacao expansions are preferred on leased land. Overall, villagers are dissatisfied with the land management practiced by local officials, which has led to serious conflicts and even villages splitting up.

All the same, population growth has caused villages to out-grow reservation land, and many will soon follow. Farmers then must lease government land, which is the first step to obtaining private land. For the Maya this transaction is not easy, as they must go to public offices, where they are discriminated against, experience language barriers, and where corruption is a major problem. Furthermore, they need cash to survey the land, which is a large, unsecured investment. However, taking out a lease or acquiring private land is not a magic potion. The tax system is structured in such a way that undeveloped land is taxed higher than agricultural land, and land can be taken away if it is not developed. This is to prevent land speculation, which is an enormous problem in Belize, but it may involve clear-cutting as a way of demonstrating development, which shortens fallow periods. Additionally, private land ownership brings with it the possibility of selling the land, which poor people like the Maya can be pressured to do. Alternatively they can be tricked, because of their unfamiliarity with the system. Examples already exist from San Marcos and San Pedro Colombia, where farmers have sold land, which has increased their exposure, as the only thing that stands between complete impoverishment for some is their land. Hence, local organizations are fighting the government to obtain community titles they can distribute to individuals, who can then pass them on to their descendants, but without the right to sell. The government is against this, as they want national rules. Others believe the reservation land system will maintain the Maya as a perpetual underclass because they will not be able to make any improvements. As a compromise, long-term leases have been suggested in order to push investments in infrastructure, sustainable soil, and water management.

Nevertheless, even if the problem of tenure is disregarded, farmers are reluctant to reinvest their earnings in maize production, many simply because they have limited resources to invest, others because retention is not in the mentality of the culture. Some say that they have not acquired the sort of mentality that recognizes that money invested might take years to return, and long-term planning is also unusual, as farmers mainly think in terms of short-term cycles. In the RED-SICTA project mentioned above, in which the main idea was improved storage of maize, most farmers sold everything right away at a low price because they wanted or needed cash immediately. Consequently, they had to buy maize later at a higher price. However, some invest in non-monetary ways, for example, by having longer periods of fallow in some areas, teaching their children to farm, or helping other farmers and then having favors in the bank. With regard to alley cropping, that is a system in which the time invested upfront will be released later, as, once established, it requires less work than shifting cultivation.

Related to investing is the question of keeping money. The Maya have limited understanding of banks, which are anyway several hours away, and keeping money at home is risky. However, attitudes and access to banking and micro-credits for smallholders in Toledo are changing, which has increased usage but it is still primarily related to cash-generating activities like cacao, cattle, and edible pumpkin

seeds (so-called pepitos; genus *Cucurbita*). For most Maya, except for farmers close to the Guatemalan border and a few others, maize is mainly a subsistence crop with limited market potential. Therefore, an organization that provides training, processing, collection, and a market, as is the case for the well-functioning cacao sector in Toledo, could be a solution for maize as well. However, it would be challenging to create a member-based organization or to find an organization that could be trusted with this vital business.

Regarding the latter, mistrust is a severe issue that exists both internally within the villages and to external institutions. Internally the current combination of the traditional Maya system and the Belizean governance system, in which leaders have different understandings about the separation of powers, is making it problematic for organizations to operate in some villages. The undermining of the traditional system by the government, which has introduced a politically elected chairperson, has caused turmoil in many villages. The chairperson is officially in charge of land management and distribution, which used to be a collective decision made at community meetings, reflecting the more holistic way of thinking in the past. However, some note that such mistrust is far from being new, as the Maya have been taught not to trust each other since colonial times. They refer to the “crabs in a bucket” mentality, a reason for cohesion and feelings of belonging being weak in many communities, this also being a reason for the low number of cooperatives among the Maya.

Further, the distrust of external institutions makes it challenging for the Agriculture Department and NGOs to persuade farmers to adopt more sustainable practices. Historically, the Maya have been marginalized, discriminated against, exploited and violated by the state, for example, by governments handing out logging concessions to foreign companies which have exploited the region and left nothing of value, or the long-standing conflict over tenure. Among other things, the state was involved in a mechanized rice-farming project in Blue Creek and Aguacate in the early 1980s, when the market suddenly collapsed, and farmers understood too late that their land had been pledged as collateral. Other organizations introduced closed pollinated seeds without informing farmers sufficiently of the consequences. Incidents like these have exhausted their relationship with external bodies and made farmers reluctant to take advice from them. For instance, the Agriculture Department avoids talking about tenure in the villages because village leaders think that the Department intends to use projects as a back door to changing the system. On the other hand, some villages like San Jose are welcoming and open-minded to outsiders, and they may still retain a strong element of collective labor, traditional practices and cultural values. This attitude is partly explained through the existence of a well-functioning local leadership and a sound self-image in the village.

Finally, the lack of capacity building is stalling progress in achieving sustainable agricultural development. This occurs at three levels: (1) politically (e.g., a vague desire to establish markets for smallholders); (2) research and administration (e.g., a lack of knowledge about climate change and agriculture in the Agriculture Department and in local research institutions); and (3) the local level (e.g., weak distribution of agricultural information and knowledge to smallholders and the wider public). Coordination between levels is filled with examples of mismatches or undesirable governance in carrying out sustainable practices. For instance, this has occurred between levels 1 and 3, by withdrawing farming education in schools; between levels 2 and 3, because the Agriculture Department regards agriculture as a business and thus focuses inadequately on subsistence products; or between levels 1 and 2, by giving only a low priority to agricultural research. A major issue is that agriculture is becoming more knowledge-intensive, and human resources have to keep up with these advances in order to implement resource management that allows maximum yields while sustaining the natural resource base. Consequently, a growing need to update farmers, technicians, and extension workers is required, together with increased presence by the latter in the villages. Local pilot plots and farmer field schools, where local farmers pass on sustainable practices to other villagers, have been shown to be a suitable approach to changing practices in some villages. For example, more than half of the farmers in San Jose successfully use mucuna beans (*Mucuna* spp.) as a cover crop, which is an achievement of a persistent and passionate project worker in the 1990s.

5. Discussion

Initially, some reservations should be taken into consideration. First, the need for adaptation might not be as pronounced as indicated above. Archaeological and paleoecology research in New Guinea, the Amazon, and Central America have indicated that tropical agricultures have the potential to be enormously resilient in the face of climatic change (e.g., [63]), and Ancient Maya agricultural practices have shown to be both highly resilient and dynamic, despite popular assumptions to the contrary (e.g. [64]). In some instances, increased Ancient Maya farming intensity may even have led to a cycle of deforestation, erosion, and population collapse [65], while in others, Maya farming strategies, with shifting cultivation, dynamically have avoided major catastrophes, through periods of climatic change [66,67]. Second, the benefits of the adjustment are taken for granted, which may be naïve, as it may be shown not to work practically: for example, does alley cropping provide enough nutrients to make consecutive planting feasible? Though, few of the interviewees questioned the overall technical feasibility of the adjustment as a barrier, which can be explained by the fact that the adjustment has already been successfully established in the district, at various intensities and with various time spans. Third, the description of the agricultural system is a simplified model, as the actual agricultural system is more complex, since it intervenes with the social, economic, and political system. There are differences between villages and households with regard to labor exchange arrangements, planting systems (schedules and crops), crop diversity, soil conditions, subsistence/cash product ratios, market affiliation, ethnicity, style of household clusters, labor market involvement, political affiliation, land distribution, and forest availability. And these features are far from being stable, as it is a constantly changing system in which social groups adapt to new emerging structures [22]. The instability also applies to the barriers, that are not static but change over time, which complicate matters [19], and the study is therefore meant to be a snapshot of the contemporary situation.

Nevertheless, the maize planting system in Toledo has some relatively common characteristics, including over time, which makes it possible to handle it in this way, despite the realization that partly isolating single activities can be problematic, as they closely interact with other parts of the production system, as well as with the socioeconomic system in general. This is also the reason why barriers are the focus in this study, as this makes possible interaction with the non-agronomic external factors. It is likewise important to emphasize that these barriers do not apply to all villages or households, but were mentioned by several interviewees in a broad fashion when they were asked about the hurdles in making the suggested adjustment in the current maize system. Furthermore, it turned out that the barriers that were uncovered probably are not unique for the suggested adjustment, but also relate to the implementation of other adjustments in farming practices in the region in general.

Related studies found similar barriers, determinants or factors at work in making comparable adjustments. Kassie and colleagues [68] found that social capital and networks, the quality of extension services, reliance on government support during crop failure, the incidence of pests and diseases, resource constraints, security of tenure, education, and market access all influenced the adoption of sustainable intensification practices in maize and legume farming systems in Ethiopia, Kenya, Malawi, and Tanzania. In another study, Kassie and colleagues [69] revealed that rainfall, insect and disease shocks, government effectiveness in the provision of extension services, the tenurial status of plot, social capital, plot location and size and household assets all influenced farmer willingness to invest in sustainable agricultural practices in 60 villages in rural Tanzania. However, both studies use a multivariate probit model with household data, which makes direct comparison problematic. Nonetheless these studies strengthen the impression from the findings section that the barriers, determinants, or factors for adopting changes are multi-faceted [16]. Other studies have presented similar findings on small-scale agricultural mitigation in the tropical regions of Latin America, Amazonia, and Central Africa (see case studies in [70]).

The intention with the adjustment was to suggest a win-win solution that, according to Jarvis [8], are coping strategies providing opportunities to transition the systems in the long run. The suggested adjustment was deliberately of the light weighted type, or what Rickards and Howden [71] refer to as

incremental changes (e.g., change in varieties, planting times, spacing, and nutrient management), and not the more challenging system adaptation (e.g., climate change-ready crops), or transformational adaptation (e.g., new products such as ecosystem services). Discussing system and transformational adaptation with some interviewees, resulted in insurmountable barriers, which tended to turn this part of the interview into an intangible and hypothetical conversation. Nevertheless, it is necessary to discuss action plans regarding these levels with organizations and institutions in Belize, because larger-scale systemic and transformative changes, such as major shifts in diet, food supply chain management, and the localities of agricultural production, will become increasingly necessary in agriculture and food systems globally [5]. In fairness, in the case of Belize, some work has been carried out, for instance by the Caribbean Community Climate Change Centre [72].

Consideration of levels of adaptation give rise to discussions of geographical differences in attitudes and responses regarding sustainable practices (i.e., techniques that benefit both the adaptation and the mitigation objectives), because changes were found, which is why some villages are singled out as examples (Table 4). Jalacte, close to the eastern border, is known for its passive attitude, with no viable actions being undertaken to respond to increasing soil depletion. The higher demand for maize and beans in Guatemala has increased the area under cultivation, and most of the forest has been lost. In this area, unsustainable practices are widespread. Land is rented for short periods by Guatemalans using irresponsible methods, as they have few incentives to introduce sustainable farming. The use of chemicals is common, which has degraded soils, causing farmers to expand to maintain output (see also [73] study area A). Crique Sarco, in the south has developed a reactive approach to adapting to changes, for example, by altering planting seasons to fit the changed weather conditions. This village has followed these developments with a wait-and-see strategy and has had to change gradually out of necessity (see also [21]). San Jose, close to the Maya Mountains in the north, is a good example of a village with a pre-active attitude. This village has made itself prepared for changes by practicing sustainable maize production with cover crops, combined with organic agroforestry cacao as a cash crop (see also [73] study area B). Anticipation in projects and other initiatives has been the strategy followed, and the village has considered the future evolution of their actions. Last, Indian Creek in the north is an example of progressive villages along the highway that have oriented changes and modified their evolution by moving here from many of the other villages. The strategy they have adopted was to influence their futures by moving closer to the market and job opportunities, while still practicing a mixture of subsistence farming and cash cropping.

However, labeling certain villages, as in Table 4, does not mean that all farmers are equally aware of the strategy or that climate change is their greatest concern [74], although climate variability can explain regional variation in farmers' adoption and rejection of particular practices [75]. Besides, farmers are aware of the difference between risk management and progressive adaptation, which some think is largely a temporal distinction; that is, climate risk management denotes approaches that are too short-term to cope with impacts and which may be inadequate in dealing with climate change further into the future [8]. For many Maya farmers, progressive adaptation is not an option, as many are impoverished and powerless, which is why risk management is the only affordable possibility. For all farmers, risk management related to weather/climate is carried out with no or only very limited awareness of climate change. For example, farmers may experience difficulties in predicting the weather and are alert to the changes that occur, but they articulated these as coincidences not related to climate change.

In general, poor producers are less likely to adopt new practices because adoption implies additional costs before the benefits can be realized, and as a result food security and health will counteract incentives [6]. Furthermore, climate mitigation measures in agriculture (rather than land-use change) among vulnerable communities may actually not be desirable for farmers, as it can create trade-offs with, for example, yields or labor inputs. Thus, even though poverty can drive collective action, as with risk-sharing and the pooling of labor among the Maya [22], then agricultural economics literature on poverty traps describes bifurcated wealth dynamics, where producers fall into two

different categories separated by a threshold. Above the threshold asset accumulation occurs and below people are restrained in the cycle of poverty. Also, households in a poverty trap are more strongly impacted by climate variability and shocks because risk aversion has minimized asset accumulation before the shock, which makes recovery harder [8].

Table 4. Farmer attitudes and responses in the face of changes in southern Belize (*italics* from [76]). See Figure 1 for location of villages.

Attitude	Meaning	Action	Strategy	Village Example
Passive	Accept changes	None	Submit	Jalacte (east)
Reactive	Adapt to changes	Follow evolution	Wait and see	Crique Sarco (south)
Pre-active	Prepare for changes	Think about evolution	Anticipate	San Jose (north-east)
Pro-active	Orient changes	Modify evolution	Influence	Indian Creek (north)

Nonetheless, slow-adapting non-progressive farmers are not less resilient by default. They can uphold the ability to withstand shocks and stresses and can maintain a certain level of well-being (e.g., food security) by utilizing the options available to the household [77]. These risk-averse small producers often employ conservative coping strategies [8] and seek to reduce vulnerability not by maximizing income, but by developing and diversifying their portfolio of capital assets, producing tradeoffs between security and income [78]. This, for instance, is an effect seen in Blue Creek and Aguacate (Figure 1) since the failed rice project, where farmers have now returned to low-risk, low-pay livelihood strategies [23]. In addition, Wilk [22] describes the Maya household as a site where adaptive groups perform a large number of different economic, reproductive, and social activities, making a direct relationship between resilience and wealth difficult to rationalize. Such farmers are relatively rich in food but poor in cash, which is more than many people with higher incomes have in, for example, Punta Gorda (Figure 1), as their disposable income is low because of their higher levels of expenditures. Nevertheless, farmers who have reorganized their subsistence farming to be more diversified by mixing subsistence and non-subsistence (farm and non-farm) activities have a more stable situation than the first group. The mixture of activities is essential, as cash crops are vulnerable to diseases and market fluctuations, and the past has shown evidence of booms and busts in the cash-crop market in Toledo, e.g., with banana, pigs, and rice [23,79]. Hence, farmers are aware that they should not rely too much on cash crops, which is why they all still have maize. Nevertheless, cultivation of other subsistence crops, such as root crops and vegetables, and the harvesting of forest goods is decreasing, and the traditional ecological knowledge that used to be an important part of the adaptation strategy is being eroded. Zarger [80] argues that this occurs in southern Belize because the younger generations are spending less time in daily activities around the village, directly impacting on the acquisition of traditional ecological knowledge, as the nature of that process is observational and participatory. Moreover, this type of knowledge works not only in the objective sense, but as a spiritual whole, a unity of mind and nature (F. Berkes in [81] box 6.1), and rituals used to be a vital part of maize cultivation [22,30], but many Maya farmers no longer conduct such ceremonies [23].

The recommended adjustment is related to sustainable agricultural intensification or climate-smart forms of agriculture that have a wider scope than just intensification [82–84]. Nevertheless, old-fashioned intensification (i.e., increased yield per land unit, known as Borlaug’s [85] hypothesis) is a principal driver in the adjustment because the yield gap in the currently extensive forms of land use is evident and is causing emissions related to deforestation. However, the problem with intensification is that the presumption is quite normative, and studies have questioned the land-sparing effect of intensification [86–88]. The expected might not occur, as the system, as mentioned above, is highly complex and does not always follow prevailing economic and agricultural models. For instance, farmers can act irrationally because of internal quarrels in the village. It is also suggested that higher agricultural productivity will be accompanied by an expansion in land area—the so-called “Jevons paradox” [88]. Currently, farmers will most likely not be motivated to cultivate more land if yields

increase because of the limited market access enjoyed by the majority of villages. However, the improved infrastructure currently being constructed (i.e., the highway into Guatemala [89]) will improve this access, and it might well change the region considerably if areas remain unmanaged [73].

A de facto barrier [90] mentioned with greater emphasis than others was the land tenure issue. At the national level, the land tax and tenure system promotes deforestation, as farmers clear land to demonstrate their occupation of it in what might be referred to as a “weapon of the weak” [91]. Thus, to avoid this behavior, lessons should be taken from Brazil’s new forest code, according to which a percentage of private land parcels shall stay in their native state, with no clear-cutting of the total parcel being allowed [92]. In Toledo, the current situation in the Maya villages, which have insecure property rights, is a matter of great concern when it comes to implementing the suggested adjustment. For instance, the privatization versus reservation land issues, already mentioned, as well as the suggested long-term leases cause problems, as some are not in favor of any kind of individualization of reservation land (see [23] for an extended discussion of land tenure in Toledo). Other studies have also suggested that land tenure is a barrier to the adoption of climate-smart practices, as there are few incentives to invest time and money in transitional management practices. Consequently, clarification of tenure rules and rights is a necessity if climate change impacts on natural resource conditions are to be responded to [93].

To close, the complexity of barriers for alley cropping are summarized and illustrated (Figure 3). Alley cropping constitutes a greater level of adjustment and connected barriers that were revealed are many: Lack of clear tenure, as the planting of perennial trees vs. annual crops is a concern in the villages, since this approach leads to the confiscation of common land; Lack of technology, as access to seeds/seedlings of the correct hedgerow species is challenging in the region; and Culture [...], as the system will require increased labor input and interest, which most farmers are not willing or able to provide. The five other barriers affect this adjustment indirectly for the reasons described earlier. The figure is an attempt to illustrate the overall level of complexity by showing all the potential connections between each of the barriers to the actor(s) (According to the conceptualization by Moser and Ekstrom [90], barriers arise from three sources, where the actor(s) is one of them, and the context, and the system are the others). However, the barriers can be remedied, though this requires efforts and compromises by the actor(s) involved because none of the barriers exist in a vacuum. Furthermore, barriers are often interdependent and co-occur (or cluster) in sets of multiple barriers, and some even reinforce each other in a system where the root cause of a particular barrier often is untraceable [19]. Hence, the connections in the figure are indeed debatable, but it would go beyond the scope of this article to clarify them all here. Nevertheless, one will be explained briefly for reasons of exemplification (Figure 3: right). The barrier Lack of clear tenure can only be regulated by law by the national government of Belize, but international development actors (e.g., Inter-American Development Bank (IDB), United Nations Environmental Programme (UNEP), CARDI, IICA), local NGOs (e.g., YCT, TAA, MLA, Toledo Institute for Development and Environment (TIDE), Sarstoon Temash Institute for Indigenous Management (SATIIM)) and local governance (i.e., village and district leaders) must all participate in the process to achieve a sustainable solution. The figure also shows that overcoming these barriers individually might not be successful and that it would be more sustainable to address this using an interconnected approach, which is, having interventions support the farmers and the governance and market systems simultaneously. In this process it is important to understand both the conditions under which these actors operate and the science and resources upon which technological change hinges, because policies attuned to local conditions have shown to have the most success in overcoming barriers [2].

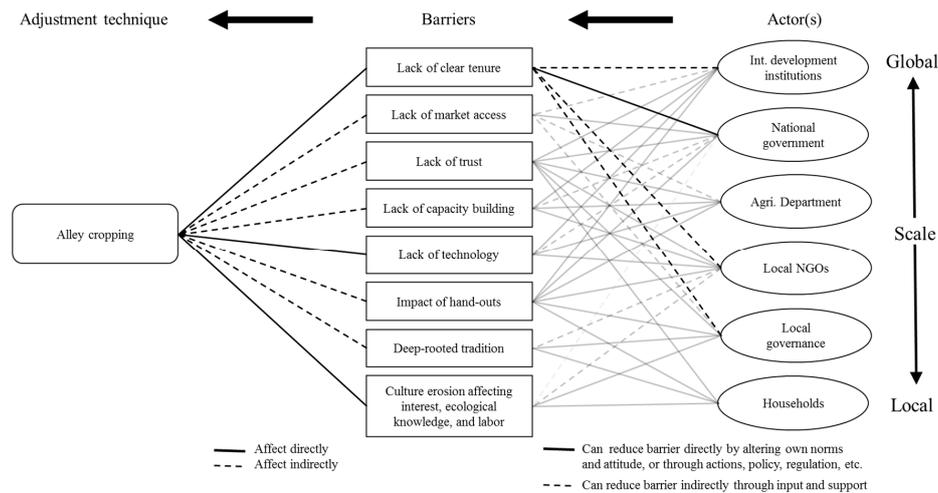


Figure 3. Flowchart showing the complexity and interaction of barriers for adoption of alley cropping in Belize. The arrows at the top indicate the direction of impact (i.e., right to left). Right side: connections indicate which actor(s) should potentially be involved in order to reduce barriers in adopting the suggested adjustment. Left side: the connections shows which barriers affect (directly or indirectly) implementation of the adjustment. All connections are potential and are not valid for all villages. The black lines illustrate the example described in the text.

6. Conclusions

The present study has shown that an adjustment to enhance CSA in small-scale maize production in Maya villages in southern Belize is possible on paper, but that several barriers can make the overall climate-smart objective difficult to implement in practice. It was found that barriers exist for farmers at different spatial scales, it therefore being important to acknowledge that the suggested adjustment technique has barriers at various levels of governance, which call for mainstreaming of the objectives. Resistance to change is universal: external actors highlight local barriers and farmers highlight external barriers, but the truth is rather that barriers exist at all scales and involve several actors, being far from uniform across villages and households. In this case, many actors perceive this little area to be monolithic, but in fact it is highly diversified and complex with regard to livelihoods, making it hard to encapsulate or construct simple strategies. However, an overall district level strategy for enhancing CSA is possible, though the toolbox should contain a wide variety of approaches. A common problem for climate change scientists dealing with mitigation is the hope that, if only the newly developed system would deliver better yields or other benefits, then farmers will adopt it, thus producing a mitigation effect as a bonus to the global climate. But we need to acknowledge that mitigation might not always be in the interests of the farmer, as it can be affected by trade-offs, for instance, with regard to food security when forest land is spared. Thus, the actor's willingness to participate in CSA could be increased by rewarding smallholders for sequestering carbon in agricultural land, as others have suggested (e.g., [94]).

Supplementary Materials: The following are available online at www.mdpi.com/1999-4907/8/7/260/s1, Table S1: List of individuals and organizations interviewed in Belize.

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