

## Article

# Farmer Perceptions of Adopting Novel Legumes in Traditional Maize-Based Farming Systems in the Yucatan Peninsula

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**Abstract:** Intercropping constitutes the traditional farming system practice used in various forms for maize production in the Yucatan peninsula. Although practiced for centuries, problems persist with competition for water, nutrients and light between crop species in traditional farming systems. Furthermore, little is known about farmers' perceptions regarding changes to traditional maize-legume intercropping systems and their interest in novel crop adoption to increase yields in the system while maintaining the practice. The objective of this study was to investigate the maize-based traditional cropping system by assessing the underlying motives and concepts of farmers to practice intercropping in the Yucatan Peninsula and to examine the association between farmers' level of knowledge about legumes and decisions to adopt intercropping and related practices therein. Farmer surveys were conducted in nine different regions of the Yucatan Peninsula. We selected Xoy, Euan, Muna, Mama, Tahdziú (Yucatan), Becal, Hecelchacam, Dzitbalché and San Antonio Sahcabchén (Campeche) which are representative of agroecological small-scale farming systems. We used a mixed methods case study analysis involving key informant interviews in eight associations of farmers. A sample frame with 73 farmers was selected in total during February 2021 and April 2021. Basic information such as land use, labor inputs, agricultural production and farmer's perceptions regarding their intercropping systems were collected. Our research shows that the primary motives for intercropping were due to the ability of intercropping to offer a more diversified range of food for human and animal consumption, as well as to take advantage of different harvest periods that this practice offers. The majority of respondents were likely to favor the idea of introducing new legume species in their maize-based cropping systems. Factors such as the type of cropping system (i.e., intercropping or monocropping), access to water and level of knowledge about legumes influenced their decision to adopt intercropping in their farming systems considerably. This paper contributes to the knowledge on the current state and farmers' perceptions of intercropping systems in the Yucatan Peninsula.

**Keywords:** cereal-legume; intercropping; maize yield; Yucatan Peninsula



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## 1. Introduction

In Mexico, maize is the most culturally and economically important cereal, and represents the staple food of the Mexican people [1]. In the Yucatan Peninsula, specifically, rain-fed maize intercropping systems are responsible for the continuous cultivation of maize (*Zea mays* L.) [2]. However, the traditional farming systems of the region face a host of challenges. The absence of traditional fallow periods, overexploited land, and shortage of terrain with secondary vegetation are the greatest constraints to enhance

maize productivity and are considered as part of the major threats to the region's food security [3]. In particular, factors related to overexploited land and the decrease of available nutrients for cultivated cash crops have been considered the major causes of depressed maize productivity in the region [4]. The association of cereals with legumes can play a key role in improving maize yields in Mexico's farmlands, while addressing sustainable agriculture challenges [5,6]. This is due to the ability of legumes to provide multiple well-known benefits in cereal–legume intercropping systems [7,8]. Intercropping is also considered an alternative to enhance sustainability in agriculture by playing a crucial role in the efficient utilization of resources [9]. Other studies have also reported on the ability of intercropping to reduce the environmental impacts of agriculture, such as soil degradation, soil erosion, soil, water and air pollution, nutrient leaching etc., but the potential benefits beyond the field-scale have rarely been examined by scientists [10].

Overall, the multiple benefits provided by maize–legume intercropping systems include increased maize yields [11], reduction of weeds by physical competition and chemical inhibition through release of allelochemicals [12,13], affecting pest and pathogen population dynamics [14], enhancing nitrogen use efficiency [15,16], and decreasing soil erosion [17,18]. Although, intercropping legumes with maize may benefit the cropping system as a whole, the biophysical conditions and the type of intercropping management may cause interspecific competition problems for cash crops [19].

In Mexico, historically, maize has been commonly intercropped with squash and legume species such as *Phaseolus lunatus* L., *Phaseolus vulgaris* L. and *Vigna unguiculata* (L.) Walp. (Álvarez-Buylla et al., 2011) legume species in the traditional Milpa system (Terán et al., 1998). Maize–legume intercropping systems have been shown to maintain the maize yields of 2.8–4 t ha<sup>−1</sup> in the southern region of Mexico, in addition to the reduction of the negative environmental impact of the production system [20]. A maize–velvet bean (*Mucuna pruriens* (L.) DC) intercropping system increased to 6–7% the amount of soil organic matter (SOM), when compared to a system of only maize (>3.4–5.0%) after four years of experiments [21].

In addition, the presence of legume species (e.g., *Vigna* spp., *P. vulgaris* and *V. unguiculata*) may contribute to weed control in intercropping systems. In recent decades, efforts to include new legume species in the system have not been entirely successful, due to not meeting the needs of the traditional producer [22,23]. In this area, the traditional legume species (*Vigna* spp., *P. vulgaris* and *V. unguiculata*) that have been commonly used in this system, given their role in this system, contribute little to weed control, pest control and nutrient supply. This type of crop combination may create competition problems between crop species, even though farmers have practiced this type of intercropping for centuries.

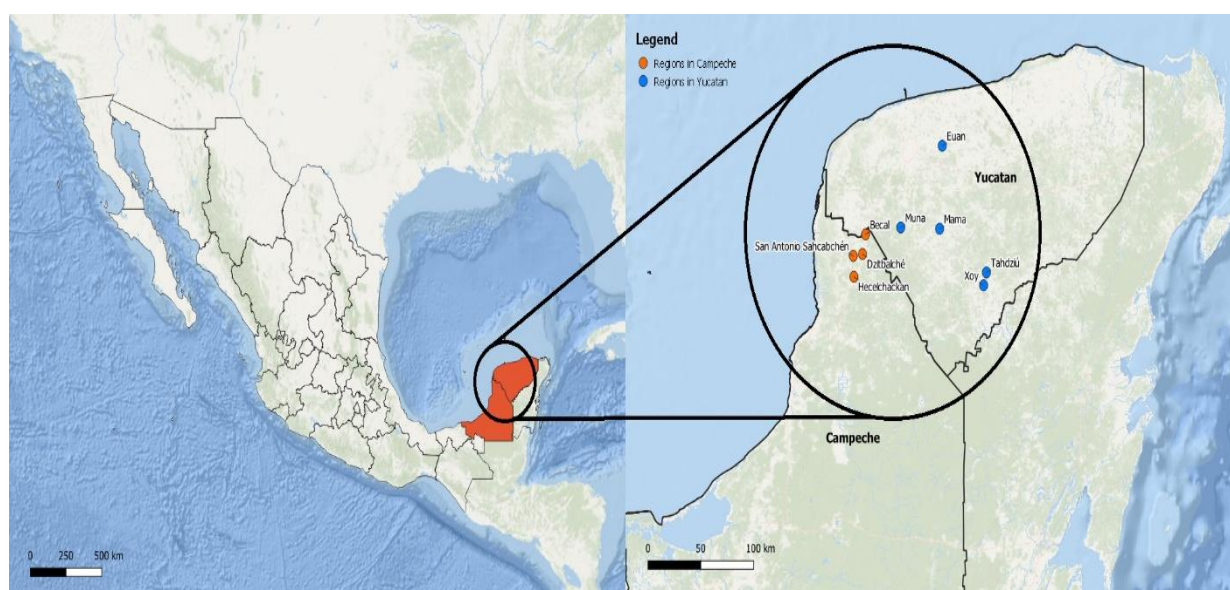
Furthermore, little is known about the reasons farmers choose traditional legume species over others. Little is also known about planting dates or spatial arrangements among the cereals–legumes in order to help reduce competition between species. Lack of such information about traditional production practices and farmer perceptions of changes and adaptation hinders the potential efficacy and applicability of future studies and outreach efforts to maintain the viability of traditional farming systems [24].

In order to investigate the state of legume intercropping with maize and farmer perceptions on tradition and novel farming practices in southeastern Mexico, in this study we draw upon a representative sample of 73 maize producers with key informant interviews from eight localities in two states of the Yucatan Peninsula. The objectives of our study are threefold: (1) to investigate the current state of the maize intercropping system in southeastern Mexico; (2) to assess the underlying motives and concepts of farmers to practice intercropping in the Yucatan Peninsula and (3) to examine the association between farmers' level of knowledge about legumes and decisions to adopt intercropping and related practices therein. The findings of this study will provide a better understanding of maize–legume intercropping adoption by smallholders, thereby contributing to related policy designs for improving the sustainability of maize–legume farming systems.

## 2. Materials and Methods

### 2.1. Description of the Study Sites

This paper is based on a survey conducted during the months of February to April 2014 in the Yucatan Peninsula, located in the extreme southeast of the Mexican Republic between  $20^{\circ}24'1.5012''$  N and  $89^{\circ}8'5.4852''$  W (Figure 1). The Yucatan peninsula has a warm sub-humid climate with an average annual temperature is 25.8 to 26.3 °C, with an average minimum annual temperature of 16 °C [25]. The region has little topographic relief and altitudes below 400 m above sea level. The region is predominated by shallow, calcareous and stony soils. Cambisols and Leptosols that are typically less than 0.25 m in depth [26]. In the region, rainfed maize is normally grown once a year and often intercropped with legumes (*P. vulgaris*, *P. lunatus* or *Vigna* spp.) and sometimes with other species, such as squash (*Cucurbita* spp.) and pepper (*Capsicum* spp.). Production is mainly practiced under the traditional intercropping system called Milpa [27].



**Figure 1.** Map of Mexico with the Campeche and Yucatan provinces (left) and villages surveyed (right).

### 2.2. Data Collection

In an effort to investigate the traditional cropping system by assessing the underlying motives and concepts of farmers to practice intercropping in Yucatan Peninsula and to examine the association of farmers' level of knowledge about legumes and the adoption decisions, we conducted a household survey in southeastern Mexico with eight focus groups of smallholder farmers in 2021. A stratified random sampling approach was used [28], after the method of Roscoe [29]. Sample size was determined using 20% sample of the population, as described by Gay and Diehl [30]. Utilizing a total of 365 smallholder farmers, a sample frame of 73 maize producers were sampled across the study sites (Figure 1). These included 9 households in Xoy, 11 households in Euan, 5 household in Mama, 4 households in Tadziú in the State of Yucatan; 11 households in Beal, 10 in Hecelchackam, 11 in Dzitbalché and 3 in San Antonio Sahcabchén in the state of Campeche. Study sites were chosen based on their agroecological characteristics, varying from marginal environment to high-agricultural potential (e.g., rainfall distribution, temperature regime). Local authorities and a local research center provided a list of households to sample from each village, from which a random selection was made.

We used a comprehensive household and plot-level questionnaire consisting of information on household characteristics and management aspects of the maize–legume cropping system in the most recent production period. A pilot test of the questionnaire was carried out with a group of farmers of the region to identify and eliminate possible

problems. All interviews were conducted by the lead author in Spanish, and when required, by a native Maya interviewer-translator from Spanish to Maya (the local language spoken by indigenous people in the study region). Farmers used their own terms and spoke in the manner that was logical for them about the crops they grow, the reasons for growing them, the importance of the crops to their livelihood strategy, and the reasons for preferring certain crop management types over others. Most of the respondents (98%) were male, with an average age of 56 years. Most farmers had a low level of formal education, which is common in smallholder farmer populations in southeastern Mexico, where most obtain a primary education level [31].

For the purposes of this study, farmers who have access to less than 5 ha of land were considered smallholder farmers. In the region, there are two types of land ownership, one that can be entitled as “common use” which can be classified as Ejidal property (land collectively belongs to every person who is part of the ejido) and communal property (land individually belongs to the person it has been given to) in which in both cases the land belongs to everybody; and a second type of land ownership that can be entitled “private property” in which the land completely belongs to the owner).

The survey was applied using a door-to-door approach, visiting the farmers’ households. When farmers were not found at their house, the interviewers visited their farms in order to complete the questionnaire. The surveyed farmers were asked questions related to socioeconomic and demographic characteristics as well as information related to land use, labor inputs, agricultural production, and income (Appendix A Table A1). Farmer’s perception regarding maize–legume intercropping system and the integration of new legume species in their cropping systems were also included in the survey instrument. In addition, questions were chosen based on the need to assess farmers’ perception of intercropping. The answers to survey questions enabled us to estimate the current states of intercropping by assessing the underlying motives and concepts of farmers to practice intercropping in the Yucatan Peninsula and to examine the association between farmers’ level of knowledge about legumes and decisions to adopt intercropping and related practices therein. Responses from participants referred to the 2020 growing season.

This study used a descriptive survey design, which enabled it to obtain requisite information from a large segment of smallholder farmers over a short period. We use a qualitative case study analysis involving research tools with eight focus-group discussions. The collaborative relationships with farmers were critical in providing a trusting environment in which interviews and observations could be conducted with farmers. In-depth, semi-open-ended interviews were carried out once during the dry growing season in 2021 with 73 farmers who participated in the field level survey. The survey lasted approximately 35 minutes, using an interview guide and conversation-specific follow-ups to gain depth and detail [32].

### 2.3. Data Analysis

All data were analyzed using SPSS Statistics for Windows (Version 28.0, IBM Corp. Armonk, NY, USA). To describe, summarize, and organize the data, descriptive statistics such as frequencies and means were used. Pearson’s correlation coefficient analysis was used to assess the strength of the relationship between farmers’ growing conditions (i.e., rain fed or irrigated land) and the adoption of intercropping practice into the cropping system. In addition, a Chi-square test of independence analysis was used to determine whether there was an association between farmers’ level of knowledge about legumes in general, and the adoption of intercropping.

## 3. Results

### 3.1. Characteristics of Sampled Households and Their Farms

The first theme of inquiry sought demographic information about farm households in the study region. In the survey of 73 farm households, the results showed that the average age of household heads was 56 years. The mean household number of children



was 2.4, with a range of 0–6 children. More than 80% of household heads were married. The agricultural units or associations selected to participate in this study were primarily men's groups; as a result, more than 98% of the participants in the survey were men. Most of the surveyed region are characterized by small-scale and subsistence farming practices. The results indicated that the total average of farm size was 4.51 ha, with a range of 1–25 ha. However, responses to the question related to farm size differ significantly among states ( $p > 0.05$ ).

The second theme of inquiry sought information regarding farm acreage, farm access to water and equipment and the use of chemical fertilizers and pesticides by farmers (Table 1). In southeastern Mexico, the survey revealed that 74% of the respondents planted their crops in rainfed conditions, 4% in irrigated conditions, while the remainder 22% had access to both (irrigated land, rainfed land). Respondents were also asked to indicate if they had access to farm machinery and, if not, what were the main reasons to not make use of farm machinery? This response would aid researchers and stakeholders in understanding farmer motivation, desires and access to farm equipment. Findings showed that 60.3% of the surveyed farmers had access to farm equipment, while the remaining 39.7% of respondents did not have access to farm equipment. Those who had access to farm equipment belonged to an Agricultural Unit (i.e., communal land) or rented that equipment during planting, fumigation or weeding and the majority of those who did not have access to farm machinery indicated that the lack of economic resources was the main reason they could not make use of these technologies.

**Table 1.** Characteristics of the traditional farming systems sampled in Mexico's southern Yucatan region. Farms ranged in size from 1–25 ha, with mean farm size of ~4.51 ha.

Characteristics	Frequency	Percent (%)
Access to Water		
Rainfed	54	74
Irrigated	3	4.1
Both	16	21.9
Hired in Labor		
Yes	52	71.2
No	21	28.8
Chemical Input		
Herbicide	7	9.6
Fertilizer and Herbicide	29	39.7
All of the above	36	49.3

Findings show that the majority of surveyed farmers (49.3%) used fertilizer, insecticide and herbicide in their previous cropping cycle, 39.7% used fertilizer and herbicide, while the remaining 9.6% only used herbicide in their farming system (Table 2). Related to farmers' ability to hire in labor, the majority of respondents indicated that they hired in labor (71.2%), while only 28.8% of the respondents did not hire in labor. From those who hired outside labor, 60.3% of the respondents did so related to farm equipment rental, while the remainder claimed that they to hire in labor due the high demand that the planting, pesticide spraying and weeding activities required for labor.

**Table 2.** The most common crops species used in intercropping systems in the surveyed locations, as described by focus group and interview participants.

Maya Common Name	Scientific Name	Varieties
Chak-bu'ul	<i>Phaseolus vulgaris</i>	Xcoli-bu'ul Tzamá Xmejen-bu'ul
Ib	<i>Phaseolus lunatus</i>	Chac-ib Sak-ib Xtup-ib
X'pelón	<i>Vigna unguiculata</i>	Espelón Común
Maize	<i>Vigna sinensis</i> <i>Zea mays</i>	Guia Hybrid Dzit-bacal, Blanco Maíz Pais Maize Landrace and Hybrid Naltel, Blanco Nalxoy, Amarillo Tuxpeño, Blanco Variedad Mejorada Xmejennal Xmejen-nal, Blanco Xnuk-nal, Amarillo Xnuk-nal, Blanco
Squash	<i>Cucurbita moschata</i> Not Identified <i>Cucurbita moschata</i> <i>Cucurbita argyrosperma</i>	Xnuk-ku'um Xcaita Xmejen-ku'um Xtop

### 3.2. Prevalent Cropping Systems in the Surveyed Villages

All farmers considered maize as the main commercial crop in their farming systems. Maize is generally sown in both monocropping and intercropping systems in southeastern Mexico. In this study, the results indicated that about 69% of the surveyed farmers grew maize as an intercrop, while the remainder (31%) grew maize as a monocrop. Intercropping has been considered as the predominant cropping system in the surveyed villages. Varieties grown included local open-pollinated (i.e., non-hybrid) varieties, composites and hybrids (Table 2). Eight types of maize cropping system were identified. About 31.1% grew maize as a monocrop; 24.3% intercropped maize with lima beans and squash; 14.9% of the respondents intercropped maize with common bean (*P. vulgaris*), lima bean (*P. lunatus*) and squash (*Cucurbita moschata* Duch; *Cucurbita argyrosperma* Huber, *Cucurbita pepo* L.); 14.9% planted maize alone and one week later, interplanted common bean–lima bean–squash with the maize; 6.8% intercropped maize with lima bean–squash–cowpea (*V. unguiculata*); 4.1% intercropped maize with bean–lima bean–squash–cowpea; and finally, 1.4% intercropped maize with bean–lima bean in the farming system.

Overall, land under intercropping systems accounted for a small proportion of field size (2 ha), while land under monocropping systems was much larger (7 ha). The prevalence of intercropping was largest in villages that belong to the state of Yucatan, and somewhat lower but still notable in those villages located in Campeche. There was a large diversity of crop species combinations in the surveyed areas (Table 2). For intercropping, maize combined with lima bean and squash and maize combined with bean–lima bean–squash were the most dominant combinations. Maize sown as a monocrop appeared to be predominant, especially in those areas where farmers had access to water and farm machinery. For example, in one of the surveyed villages called Becal, relay intercropping was the predominant cropping system in which farmers grew maize as a monocrop; however, a few days after maize germination, they proceed to interplant bean–lima bean and squash manually in order ensure access to a more diversified food system.

### 3.3. Types of Cropping Management Practices Adopted by Surveyed Farmers

Nine types of maize cropping system were identified (Table 3). Maize is mainly intercropped with lima bean and squash together by the majority of the respondents (37%). Around 6.8% grew maize with common bean and lima bean during the same time and in the same hole (vine), while a considerable number of surveyed farmers (6.8%) first planted the squash variety called “Xcaita”, and a few weeks later followed with maize intercropped with lima bean as a way to avoid competition between the squash and the other crop species. Maize intercropped with lima bean at the same time + squash constituted 2.7% of the cropping system; 2.7% of maize intercropped with bean-lima bean-squash at the same time; 1.4% of maize intercropped with lima bean at the same time + bean; maize-lima bean-squash-cowpea intercropped at the same time constituted 2.7%; maize intercropped with lima bean-squash-cowpea at the same constituted 4.1%; 6.8% of maize-bean-lima bean intercropped at the same time; the variety of squash called “Xtop” sown ahead + maize-lima bean-bean intercropped at the same time constituted 2.7%.

**Table 3.** Physical distribution and spatial arrangement of crops species by Surveyed Farmers, 0 Same Day with maize; – Days before maize; + Days after maize, V if crops are intercropping during the same time or separately.

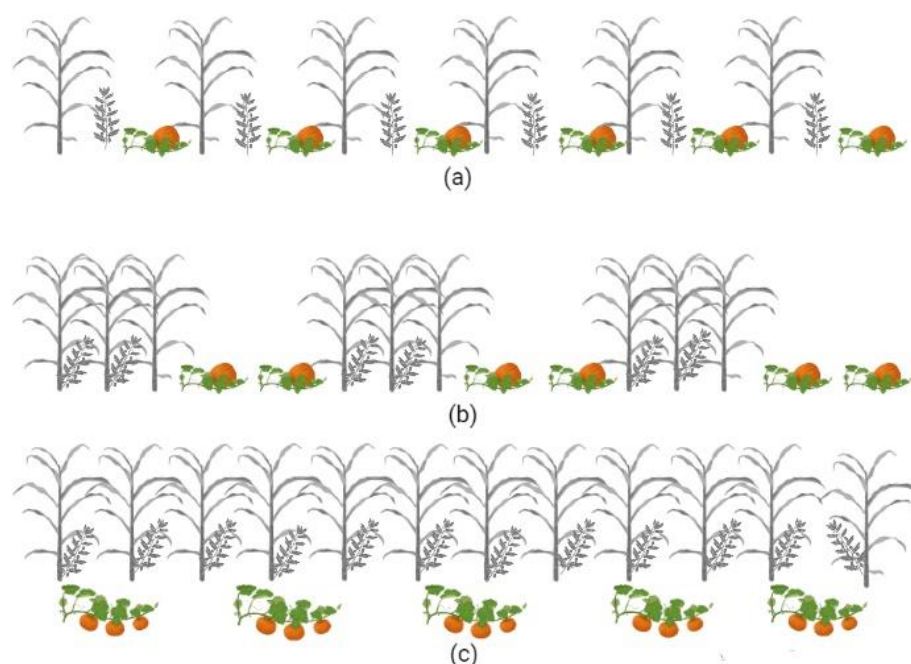
Field Description Type	At the Same Time	Separately	Maize-Relative Planting Date	Percent (%)
Maize-lima bean-squash	V		0	37
Maize-common bean-lima bean	V		0	6.8
Xcaita + maize-lima bean		V	–(15-30)	6.8
Maize-lima bean + Squash		V	+(10-15)	2.7
Maize-bean-lima bean-squash	V		+30	2.7
Maize-lima bean + bean		V	+8	1.4
Maize-bean-lima bean-squash-cowpea	V		0	4.1
maize-common bean-lima bean	V	V	0	6.8
Xtop + maize-lima bean-common bean			+(15-30)	2.7

In relation to the planting date used by farmers before associating their crops species, farmers were asked “How many days after planting maize do you intercrop the other crop species in your production area?” Five types of maize sowing intervals were identified (Figure 2). The majority of the surveyed farmers planted squash between 15–30 days before maize, and then intercropped maize with common bean and lima bean at the same time. The second predominant type of crop sowing interval was maize intercropped with legumes and squash planted on the same day. The third predominant type of crop sowing interval was 30 days after the maize planting date, 15–30 days after the planting date of maize and finally 8 days after the planting date of maize.

### 3.4. Farmer’s Opinion of Intercropping Practices

The majority of farmers (25%) wanted to practice intercropping based on the ability of the system to offer a more diversified range of food for their own consumption and to feed animals. About 18% of the respondents decided to practice intercropping in order to take advantage of different harvest periods that this practice offers them. For example, during the first rainfall, some farmers sow different maize crops with early and late cycles and harvest each one of them based on their maturity period; as a consequence, intercrops allow farmers to always have some crops available for their consumption during the full crop season. Another group of farmers (15%) decided to practice intercropping based on the capacity of this system to add nutrients to the cropping system and reduce weed populations, while the remaining 8% think that intercropping is part of their culture and heritage. It has been practiced for centuries by their ancestors, in this context, and they

decided to practice intercropping because it is a cultural practice that plays an important role in their lives.



**Figure 2.** Illustration of (a) the traditional row intercropping system (maize intercropped with legumes and squash); (b) the traditional mixed intercropping system [maize and legumes in the same hole intercropped with squash] and (c) the traditional intercropping where squash sown first and then maize and legumes sown in the same hole.

In a few cases, farmers planted a few crops in the cornfield, but in different plots. We asked farmers, what was their main reason for this practice. The survey found that the majority of respondents sow cowpea, bean, watermelon, cassava, taro, peanut, squash and habanero pepper in different plots. Farmers said they decided to grow these crops in a different plot because they wanted to avoid competition among crop species. Additionally, some of the crops farmers listed cannot grow in association with maize due to differences in planting season or other aspects of their growing cycle, growth habits or compatibility with pesticides used in the intercropping systems. For example, for farmers utilizing herbicides in their maize cropping systems, some of those crops farmers listed growing separately cannot tolerate herbicides. Based on that, farmers have decided to adopt this cropping strategy by growing those crops separately, in the same plot but physically distanced.

Farmers from all of the surveyed villages were likely to favor the idea of introducing new legume species in their cropping systems (Figure 3). The results indicated that 79.5% of the respondents considered the integration of newly introduced legumes in the region's cropping system as a good option. Others (20.5%) claimed not to have any problem integrating newly introduced legumes, but they revealed that it would not be a viable option for their cropping system.





**Figure 3.** (a) Mixed intercropping of maize, bean and squash; (b) strip intercropping of maize with cowpea and (c) maize monocropping in Yucatan in October 2020.

### 3.5. Factors Affecting Intercropping Practice and the Adoption of New Legume Species into the Cropping System

There was a significant relationship between farmer's growing conditions (i.e., rainfed or irrigated land) type, and factors affecting intercropping practice in the cropping system. Among the respondents, farmer's growing conditions (i.e., rainfed or irrigated land) was moderately positively correlated with ( $r = 0.515$ ) (Appendix B Table A2) with the decision to practice intercropping. Specifically, farmers with access to water were likely less interested in adopting intercropping. However, the type of cropping system currently practiced (i.e., intercropping or monocropping) had a low negative correlation ( $r = -0.312$ ) (Appendix C Table A3) to factors affecting farmers' decision to practice intercropping.

In addition, in a chi-square analysis, we found a relationship ( $p < 0.05$ ) between the type of cropping system (i.e., intercropping or monocropping) and farmer's level of knowledge about legumes to adopt intercropping in their farming systems. Farmers were likely to favor the idea of introducing new legume species in their cropping systems. Factors such as the type of cropping system (i.e., intercropping or monocropping) ( $\chi^2 = 18.681$ ,  $df = 2$ ,  $p = 0.000$ ) (Appendix D Table A4), and farmer's level of knowledge about legumes ( $\chi^2 = 7.922$ ,  $df = 2$ ,  $p = 0.019$ ) (Appendix E Table A5) influenced the farmer's decision to adopt intercropping in their farming systems.

## 4. Discussion

### 4.1. Traditional Intercropping Use Declines with Younger Farmers

Presently, the traditional farming system of the Yucatan Peninsula is characterized by older farmers within the surveyed villages with an average age of 56 years old. This is in agreement with previous studies, like those of other scientists [33,34], in which the majority of the surveyed farmers were over the age of 60. This shows that the future maintenance of the region's intercropping system may be at risk because of the low interest of youth to practice this cropping system type. We found that the low yields from this practice is the main motive for low youth involvement in practicing intercropping. Most of the younger farmers surveyed preferred to practice monocropping and made use of farm equipment in their fields.

This may demonstrate that the younger people prefer to adopt technologies that can increase yield and economic farm benefits over other ecosystem services offered by intercropping systems. This is consistent with a study conducted in Eastern Kenya by Ouma et al. [35], who reported that age was likely to influence the adoption rate of improved maize varieties by farmers. However, in a study conducted in rural Tanzania focused on identifying key factors influencing simultaneous adoption of several agricultural

technologies and practices, and their impact on household welfare in the maize-legume cropping system zones, Kassie et al. [36] did not find that age significantly influenced the decision of a farmer to adopt a new technology. According to the same authors, this may be attributed to the fact that increased exposure to technologies and production environments, as well as a bigger accumulation of physical and social capital, comes with age. However, this is balanced with the trends that as people get older, they lose energy, have shorter planning horizons, and are more risk averse [36].

#### *4.2. Characteristics of the Traditional Farming System*

Overall, the mean farm size of the surveyed farmers was 4.51 ha. However, the average of those under intercropping systems in the surveyed Yucatan State was 2.4 ha. This is consistent with those of other scientists [37], who reported an average farm size of 2.5 ha in Pomuch, Campeche. Our results show that the region's farming system is dominated by a subsistence farming system which is generally practiced under rainfed conditions (74%). This is in agreement with other authors [2] who reported that intercropping is generally practiced under rainfed conditions in southern Mexico. Our results found that the majority of respondents (either in intercropping or monocropping) made high use of agrochemicals (e.g., pesticides and fertilizer), even though it was a little bit lower in intercropping systems. Findings from our study also show that most of the respondents rented some sort of farm machinery during planting, fumigation and weeding activities (60%). However, our results found that respondents who practiced intercropping tended not to use any sort of mechanization. The disadvantages of polycultures are their low mechanization potential and demand for labor, especially during planting, weeding and the pesticide spraying period [38]. This is similar to the findings of others [39] who reported that polycultures usually have a high demand for labor.

#### *4.3. Unsustainable Practices May Affect the Future of Intercropping*

In recent decades, the region's farming system has become more dependent on external inputs, and as a consequence, production costs have increased. Overall, the adoption of conventional farming practices has become more popular in developing countries and, as a result, farming systems have become more dependent on external inputs. This has documented negative impacts on the environment, such as the decrease of farming systems biodiversity [40–42]. In addition, soil depletion has been considered as another factor that affects the farming system negatively due to the intensive use of the land by surveyed farmers and the fact that the fallow period that used to give the land area time to regenerate soil fertility has been decreased in recent years. In the State of Yucatán, more than 50,000 families rely on maize production for their basic food consumption; however, due to the lack of secondary vegetation and land required for the rotation practice in the system, maize-legume intercropping is facing severe threats that might affect its continuity [3].

#### *4.4. The Most Important Crop Combinations in the Cropping System*

Overall, in most of the surveyed villages, intercropping was preferred by most of the farmers (69%); however, a significant group of farmers preferred to grow maize as a monocrop (31%). Varieties grown included local open-pollinated (i.e., non-hybrid) varieties, composites and hybrids. Our findings show that maize intercropped with lima bean–squash and maize intercropped with common bean–lima bean–squash were the most important crop combinations in the surveyed villages. When maize is intercropped with legumes and squash, each crop benefits from the other associated crops. Among the main crops, maize serves as supports for the legumes which fix and supply nitrogen to the soil; squash helps reduce the incidence of weeds and conserves soil moisture [43]. Mixed intercropping was found to be the prevalent type of intercropping system practiced by the surveyed villages. The majority of the respondents, mixed maize–lima bean–squash seeds first and then sowed them on the same date of planting. This type of crop combination may

create competition problems between crop species, even though farmers have practiced this type of intercropping for centuries.

#### 4.5. *The Prevalent Motives of Farmers for Practicing Intercropping*

The prevalent motives of farmers for practicing intercropping in the study area included access to a more diversified food production system, ensuring some of the crop's harvest, reducing weed and pest competition problems and keeping their customs and traditions alive. Farmers in the majority of the research sites expressed a strong attachment to this practice, relating the importance that intercropping has for them to maintain a more diversified food system which can help them reduce their economic expenses in buying additional crops for their basic food consumption. One other important aspect to mention about farmers' motives for practicing intercropping was the fact that a considerable group of the respondents indicated that intercropping provides environmental benefits such as the reduction of weed and pest competition in their cropping system. This is consistent with a study conducted in five districts of Malawi and Tanzania by others [44], who reported that the majority of those farmers perceived the implementation of sustainable intensification practices in their farmland as a technique that can have an economic impact as well as environmental benefits such as improving productivity and food security, reducing soil erosion and mitigating the effects of climate change for their farming systems.

Farmers were likely to practice intercropping as a way to ensure food availability for home consumption. Regarding the ability of intercropping to safeguard food security of the region, intercropping can help promote food security and environmental health due the economic and environmental values this practice offers to the cropping systems [10]. Short growing crop cycles were prioritized over the long growing crop cycles due their flexibility in allowing farmers to use part of their crops to make their favorite dishes while waiting for the remaining late crop varieties. Intercropping offers farmers the opportunity to conserve their culture, habits and customs that have been taught by their ancestors. This important traditional cropping system must be strengthened and empowered with adequate tools and technologies which aim to increase the sustainability of farms.

#### 4.6. *Farmers' Perception of the Intercropping Practice and the Introduction of New Legume Species in Their Maize Cropping Systems*

The farmers in the study understand the benefits of intercropping practice for their cropping systems. In the surveyed villages, the majority of respondents considered that the introduction of introduced legume cover crops in their production area would be a viable option to enhance their farming systems regardless of the type of cropping system (i.e., intercropping or monocropping).

Farmers suggested that they would be very motivated to adopt introduced legumes in their cropping systems if there was enough evidence from experiments and trials conducted in their Agricultural Units that showed that this technology could maximize farm benefits. This is consistent with the technique used by other scientists who reported that understanding farmers' many different preferences can help boost the adoption rate of intercropping practices [45].

There was a relationship ( $r = 0.515$ ) between the farmer's growing conditions (i.e., rainfed or irrigated land) and factors affecting their decision to practice intercropping; similarly, our study also found that the type of cropping system (i.e., intercropping or monocropping) slightly influenced ( $r = -0.312$ ) farmers' decisions to practice intercropping. Most of the respondents in either rainfed or irrigated conditions had previous experience with the use of traditional legumes species. According to most of the respondents, the traditional intercropping system is characterized by a low crop yield, however, when maize is sown as a monocrop, it is found to be easier to increase maize yield by using farm fertilizers and pesticides, and farm machinery, and avoid competition among crop species. In the surveyed villages, those who have access to irrigated land also had access to farm machinery. In this context, these farmers indicated they were likely not to favor the use of legumes.

However, overall, most of the respondents tended to favor intercropping practice in their farming systems.

In addition, the majority of respondents were likely to favor the idea of introducing new legume species in their cropping systems. The respondents who grew maize as an intercrop or monocrop as well as farmer's level of knowledge about legumes were like to favor the introduction of new legume species in their farming system. This may be attributed to the fact that the majority of the respondents have a certain level of knowledge about legumes. However, our study found that there was a low level of knowledge about the new legume species such as *M. pruriens*, *Mucuna deeringiana* (Bort) Merr., *Canavalia ensiformis* (L.) DC and *Crotalaria juncea* (L.) which have been recently introduced in the region by scientists especially as a cover crop and as a food source for cattle [23–47]. Those who mainly practiced intercropping under rainfed conditions tended to favor the adoption of new legume species in their farming systems, even though according to most of the respondents, new legume species might not be able to tolerate stress like their traditional legume species. As most of the respondents practice intercropping in rainfed conditions, this might be attributed to their hesitancy to adopt new legume species in their farming systems. As a consequence, the majority of the surveyed farmers understand that more on-farm research must be conducted with their participation, as a way to investigate the possible benefits delivered by newly introduced legume species.

In recent years, efforts from various stakeholders have failed to get farmers to adopt introduced legumes in the region's farming system. Based on this fact, future research should focus on conducting more on-farm research and trials with a more participatory approach that could allow farmers to inform treatment designs and engage with the research process and results. For example, farmers could be engaged to select varieties they prefer among new varieties tested in their fields. We must also consider the economic approach as well if we want to increase the acceptance and adoption rate of this technology among those farmers. They made it clear that they want legumes that will not compete with their maize which is considered the main crop in their farming system. Legume varieties should offer ecological benefits and at the same time be used for food consumption and maximize farm benefits. Future research must not only focus on evaluating the benefits offered by these crop species, but also focus on making available information about the management strategies required by these introduced legumes. Systematic data about the time of planting, distance between associated crops, and the time to manage legumes' biomass would allow farmers to make better use of this technology and could impact the yield of the crops. Lastly, this type of research would greatly increase information about farmers' perception in accepting introduced legumes in their farming system.

## 5. Conclusions

Intercropping is generally considered to contribute to higher yields and enhance sustainability of the region's traditional farming systems. This study developed the first systematic database for analyzing and estimating the state of intercropping and farmer's perceptions regarding the maize–legume intercropping system in southeastern Mexico. The results show that the primary motives for intercropping were the ability of intercropping to offer a more diversified range of food for human and animal consumption as well as to take advantage of the different harvest periods that this practice offers. The majority of respondents were likely to favor the idea of introducing new legume species in their cropping systems. The respondents made considerable use of agrochemicals (e.g., pesticides and fertilizer), even though it was a little bit lower in the intercropping systems. Based on these findings, this opens up perspectives for the development of new cereal–legume varieties that are more tolerant and resistant with biotic and abiotic factors and, as a consequence, this could result in helping farmers reduce external inputs while maintaining yield and diverse food supplies and food cultures. In addition, future studies should focus on conducting more on-farm research with farmers' participation as a way to encourage farmers interest in adopting intercropping systems which will improve their livelihoods.

Intercropping remains the dominant form of agriculture in southeastern Mexico and continues to be considered as one of the few economically viable options for farmers to enhance sustainability in the region's traditional cropping system.

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## Appendix A

**Table A1.** List of questions for survey participants in participating villages.

Characteristics of the households
Number of children
Marriage Status
Age
Gender
What is the size of your farm?
Type of sowing:
In rainfed
In irrigated land
Do you hire labor to carry out agricultural activities?
If yes, in which activity?
If not, why?
Do you use any agrochemicals (fertilizers or pesticides)?
Do you intercrop any other crop species with maize in your field plot?
If yes, which crops varieties did you sow in association with maize during the last growing season?
How large is the land area of your field plot?
What is the main reason for practicing intercropping in your plot field?
1. Ensuring the harvest of any of the crops
2. Fodder purposes
3. Grain for sale
4. Soil conservation
5. Soil fertility improvement
6. Weed control
7. Pest control
8. Customs and habits
What are the most important crop combinations that are grown under intercropping in the last season?
What do you think about intercropping? Would you be willing to adopt new legume species in your cropping systems?



## Appendix B

**Table A2.** Results from correlation analysis relating farmer's growing systems to their decision to practice intercropping.

	Farmer's Growing Conditions	Farmer's Decision to Practice Intercropping
Farmer's growing conditions	1	
Farmer's decision to practice intercropping	0.515 **	1

Note: \*\* Correlation is significant at the 0.01 level (2-tailed).

## Appendix C

**Table A3.** Results from correlation analysis relating farmer's decision to practice intercropping to the type of current cropping system.

	Type of Cropping System	Farmer's Decision to Practice Intercropping
Type of cropping system	1	
Farmer's decision to practice intercropping	−0.312 **	1

Note: \*\* Correlation is significant at the 0.01 level (2-tailed).

## Appendix D

**Table A4.** Results from chi-square tests of the relationship between the type of cropping system and a farmer's decision to adopt intercropping.

	Value	df	Asymp. Sig. (2-Sided)
Pearson Chi-Square	18.681 a	2	0.000

Note: a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 3.84.

## Appendix E

**Table A5.** Results from chi-square tests of the relationship between a farmer's knowledge about legumes and decision to adopt intercropping.

	Value	df	Asymp. Sig. (2-Sided)
Pearson Chi-Square.	7.922 a	2	0.019

Note: a. Two cells (33.3%) have expected count less than 5. The minimum expected count is 2.11.

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