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CROP PRODUCTION

Maize legume intercropping systems in southern Mexico: A review of benefits and challenges

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ABSTRACT: *Intercropping is the process of planting two or more crops simultaneously in the same field in order to provide greater ecosystem services (i.e. services related to sustainable land and water use, climate change mitigation, and ecosystem restoration). In southern Mexico, the cereal-legume intercropping is a traditional cropping practice that is declining overtime. This paper provides a literature review of the potential benefits and constraints of a maize-legume intercropping for small-scale farms in southern Mexico. This review explored and elucidated the different ecosystem services delivered by maize-legume intercropping systems. This information will help farmers know how to make a better use of cereal-legume intercropping systems to increase maize yields, improve their socioeconomic conditions, and enhance conservation agricultural practices in southern Mexico.*
Key words: *cover crop, monocropping, nitrogen fixation, sustainability, yield.*

Sistemas consorciados de milho no sul do México: uma revisão dos benefícios e desafios

RESUMO: *Consórcio é o processo de plantar duas ou mais safras simultaneamente no mesmo campo, a fim de fornecer maiores serviços de ecossistema (ou seja, serviços relacionados ao uso sustentável da terra e da água, mitigação das mudanças climáticas e restauração do ecossistema) para as lavouras. No sul do México, o consórcio cereal-leguminosa é uma prática tradicional de cultivo que está diminuindo com o tempo. Este artigo fornece uma revisão da literatura sobre os benefícios e limitações potenciais do consórcio milho-leguminosa para fazendas de pequena escala no sul do México. Esta revisão foi escrita para explorar e elucidar os diferentes serviços ecossistêmicos fornecidos por sistemas consorciados de milho e leguminosa. Essas informações ajudarão os agricultores a saber como fazer um melhor uso dos sistemas consorciados de cereais e leguminosas para aumentar a produtividade do milho, melhorar sua subsistência socioeconômica e melhorar as práticas agrícolas de conservação no sul do México.*
Palavras-chave: *cultura de cobertura, monocultura, fixação de nitrogênio, sustentável, rendimento.*

INTRODUCTION

Maize (*Zea mays*, L.) is among the world's top three consumed cereal crops (60%-94%) (International Grains Council, 2018. Supply & Demand. London, UK. Available online:http://www.igc.int/en/markets/marketinfo-sd.aspx). Due to the increasing world population, which is projected to reach between 9.4 and 10.2 billion by 2050, there is a need to increase global world food production by 22 to 34% (World Water Development Report [WWDR], 2018). In Mexico, maize is the most important cereal crop (FERNÁNDEZ, 2013), central to farming systems and cultural foodways throughout the country. On average, maize is the most consumed cereal for human consumption; about 343 g per day per capita is consumed in Mexico (CEDRSSA, 2014). Furthermore, it is the basic food for most Mexican people, especially among smallholder farmers (i.e., farmers who own small areas land on which they usually grow subsistence crops) (TURRENT et al., 2012). More than half of the Mexico's cultivated agricultural area is dominated by this cereal, with approximately 7.5 million hectares, mostly (85%)

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in rain-fed conditions (SIAP, 2015). In Southern Mexico, intercropping is generally practiced under rainfed conditions due to the scarcity of irrigation systems (WOMMACK, 2018).

Intercropping is a type of mixed cropping and described as an agro-ecological system that consists of growing two or more crops together in the same plot of land (BEDOUSSAC et al., 2015). This traditional farming practice varies regionally, and as such, crops grown in this arrangement are diverse, and differ by species or cultivar. This practice is considered as an environmentally-friendly cropping practice, that among other things, is land-sparing and may produce more food quantity and diversity on less or equal land as crops grown in monoculture. The intercropping approach takes advantage of mutualistic relationships between crops species as well as differences in niche occupation over time and space (FRANCIS, 1986), which frequently results in increased profitability and ecosystem services (ZHI et al., 2007).

Intercropping systems have been shown to increase total crop yield per unit area through a concept called “overyielding” (GLIESSMAN, 2007). The greater ecological efficiencies, as well as the ability to buffer risk of crop failure of any one crop, as some of the reasons for farmers utilize the practice. Intercropping legumes, for example, can boost yield per unit area by making the best use of all available resources (nitrogen fixation from the legume species as well as weed suppression improvement) that a single crop would be unable to use (ZHANG et al. 2011; RAM and MEENA 2014).

Intercropping has been widely practiced in smallholder cropping systems for hundreds of years worldwide (BANIK et al., 2006). In addition to yield increases and stability, the practice has been reported to deliver several ecosystem services such as conservation of the biodiversity of soil microorganisms (NICHOLLS et al., 2016; HAMBURDĂ et al., 2015), better nutrient management (PUNYALUE et al., 2018, weed suppression, pest control, pollination benefits and soil conservation (JENSEN et al., 2020). Furthermore, intercropping maize with legumes improved farm sustainability and mitigate climate change (NICHOLLS et al., 2016), reduce soil erosion (BLANCO-CANQUI et al., 2015) and enhance water conservation (NICHOLLS et al., 2016).

Although, the potential advantages of maize-legume intercropping systems are well documented and numerous, management complexity and other agronomic challenges are present as well (KARIAGA, 2004). Intercropping may also require more effort in terms of field management, including in field preparation, seed combination, and additional labor throughout the crop grown and haverst process. Although, many studies have documented that intercropping can increase production per unit of land, a few studies have shown that maize-legume intercropping can reduce maize productivity. For example, YAP et al. (2017) reported that in a maize-legume intercropping system, maize yields are drastically reduced when compared to a monocropping system (YAP et al., 2017). As such, farmers practicing intercropping may trade higher overall yield for all crops grown in the intercropping system for lower yields of the maize crop in particular.

In Mexico’s southern states, maize-based intercropping is a traditional practice and is widely grown in the “milpa” system. The milpa system typically consisted of a polyculture in which farmers sow maize, squash (*Cucurbita moschata* Duch; *Cucurbita argyrosperma* Huber, *Cucurbita pepo* L.) and beans (*Phaseolus vulgaris* L. and *Phaseolus lunatus* L.) in the same piece of land (LARA-PONCE et al., 2012; GÓMEZ, 2011). In Mexico’s southern states, soils are volcanic in origin and are typically low in fertility, and milpa farmers utilizing the system are increasingly reliant on chemical inputs. In recent decades, researchers have been increasingly encouraging the incorporation maize-legumes into the region´s farming systems in order to attain sustainability or avoid negative environmental impacts such as soil erosion and chemical runoff.

The region´s tradional cropping system is an interesting option for the region’s farming system because of the ecosystem services they provide. In southern Mexico, more information regarding the current state of intercropping systems, including the benefits and drawbacks of this technique, is needed. Understanding the state of the intercropping system for this particular region, its advantages and constraints can lead to a more efficient use of the intercropping practice. In addition, recent reviews have addressed the potential of using intercropping systems to improve ecosystem services. Here, we reviewed the literature providing an overview of the potential benefits and constraints of a maize-legume intercropping system as well as the prospects for using maize-legume intercropping systems effectively to provide nitrogen (N) to crops, control weed populations, reduce pest and disease, and minimize soil erosion. Additionally, its effects on farm income and/or food security and challenges associated with maize-legume intercropping system of southern Mexico.

Types of intercropping systems in agriculture

Globally, intercropping systems that are most commonly used including mixed intercropping, tramline intercropping, alley intercropping, within row intercropping, row or strip intercropping and relay intercropping (BEETS, 1990). According to LICHTFOUSE et al. (2009), strip and relay are the primarily intercropping systems used worldwide because they are the greatest in economic importance; however, MOUSAVI & ESKANDARI (2011) reported that row intercropping, mixed intercropping, strip intercropping, and relay intercropping are the most forms of intercropping systems in agriculture.

Mixed and row intercropping

Mixed intercropping means simultaneously growing two or more crops on a portion of the field without consistent spatial arrangement. This is in contrast to row intercropping, where one or more crops are planted in different (generally alternating) rows. This system helps optimizing crops' light exposure, simplifies farm operations, reduces humidity, and decreases shading problems (BAREJA, 2010). This sort of intercropping is used for a variety of purposes, including pasture and forage production (DORDAS et al., 2012), grain and pulse production (AGEGNEHU et al., 2006), crop livestock integrated system (CRUSCIOL et al., 2012, 2013), and other rotating systems.

Tramline intercropping

In the tramline system, two rows of a crop are planted alongside two rows of another crop. This system has the potential to improve both crops' competition for light, nutrients, and water (GRAIN, 2015).

Intercropping using agroforestry practices

Alley intercropping (an agroforestry practice) is the process of growing vegetable crops and trees together (as in agroforestry), where the trees are grown in rows and the vegetable crops grown in the "alleyways" between the trees. In this arrangment water and nutrients can be easily extracted by crop plant roots and leguminous trees may contribute N to the system (EVERSON et al., 2007). Within-row intercropping is an agroforestry practice in which two or more crops are planted in the same row. Overall, agroforestry system a within-row intercropping system that involves the interaction of trees and shrubs and other kinds of forestry plant with the aim of achieving net economic and ecological gains, as well as enhancing productivity, profitability, diversity and ecosystem sustainability (NATIONAL AGROFORESTRY POLICY, 2014). However, this type of intercropping system may result in interspecific competition problems and attention to species selection and crop management must be taken into consideration.

Relay intercropping

Relay intercropping promotes the planting of one crop first followed by planting a second crop after the first crop has entered its reproductive stage but before it is ready for harvesting (YAMANE et al., 2016). Relay intercropping is commonly used in the production of grains, pulses and cotton (*Gossypium hirsutum*) (SU et al., 2014).

Strip intercropping

Strip intercropping is the process in which two or more crops are planted separately in narrow adjacent strips which allow contact between the various species (GHAFFARZADEH, 1999). This type of intercropping is generally employed for grain and pulse production (BIABANI et al., 2012)., as well as fodder production (PUTNAM et al., 1985, 1986). Strips can be harvested together or separately. Significant interspecific interactions, such as shadowing, root mingling, and competition for water and nutrients, are possible with this type of intercropping.

Milpa intercropping system

In Southern Mexico, crops grown in the milpa system utilize a variety of crop combination strategies, which vary by the location in which it is used. Mixed intercropping, relay intercropping, and strip intercropping arrangments are all practiced in the region.

Considerations in selecting legume species for the maize-based intercropping system

Characteristics of legume crops that have been shown to be successful in intercropping systems include traits related to germination, N fixation and water dynamics. Specifically, legume crops in intercropping arrangments should germinate and emerge quickly, be tolerant of extreme weather conditions, and be capable of fixing N from the atmosphere. Furthermore, ideal legume crops should be able to absorb nutrients from the soil by forming deep roots, produce more biomass in a shorter period of time, be easy to work and cultivate, not compete with the main crop, be insect pest and disease resistant, suppress weeds, and be cost-effective to cultivate (REDDY, 2016). Although, crops in intercropping systems may be sown at different times, to achieve maximum benefit of the mutualism, crops must be grown together for the majority of the growing season. Cereals grown in polyculture are frequently considered the main crop due to their primary importance for economic or food production reasons; although, other crops may add to make the system more profitable in a polyculture.

Understanding the mechanisms by which intercrops boost growth and yield

Cereal-legume intercropping has long been regarded as efficacious in low-nitrogen environments, due to the functional complementarity for N uptake that this system provides (PELZER et al., 2012). *Rhizobia* bacteria in the roots of leguminous plants "fix" atmospheric N and incorporate it into the biomass of the legume, increasing the abundance of N in the system through the biomass of the plant and root exudates. Cereals can use a considerable amount of the available N in the cropping system and have been shown to have complementary N dynamics (FAN et al., 2006). In addition to N complementarity, the rhizosphere exudation of phosphatases and carboxylates is suggested to aid legumes in acquiring phosphorous (P) from intercropped cereals (LI et al., 2014). Similarly, crop yields can be increased by improving P acquisition.

Cereal and legume intercrops have also been shown to utilize light resources more efficiently when compared to monocropping systems. Improved radiation use efficiency (RUE) will have a direct impact on crop biomass, resulting in increased grain growth and output. Due to reduced N competition in maize-bean intercropping systems, maize RUE increased by 7% to 11% when compared to solitary maize, according to MAHALLATI et al. (2015).

Maize-legume intercropping in Southern Mexico

In developing countries, especially in tropical regions, intercropping is considered a standard practice and is typically practiced in low-input or low yield farming systems and performed on small-scale farms with low resources (NGWIRA et al., 2012). In southern Mexico, Intercropping plays an important role in maintaining the food security of the region. For example, VÉLEZ et al. (2007) reported that in the State of Yucatan, Mexico, 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.

In the southern region of Mexico, maize is commonly intercropped with squash and beans (ÁLVAREZ-BUYLLA et al., 2011), and planted at different intervals to avoid competition between crops species. Squash was first integrated into the milpa system (8,025 - 4,360 BC), subsequently maize (4,280 - 2,455 BC) and finally bean (380 BC-730 AD) (ÁLVAREZ-BUYLLA et al., 2011). Different maize-legume intercropping systems used in the southern region of Mexico are shown in table 1. Historically, maize has been the most important crop cultivated under this system in America. Maize production under the milpa system was one of the main sources of plant products for people settled in the Mesoamerican region in the ancient times (TERÁN & RASMUSSEN, 1994). This system provided yield resilience to climat variability, pests and disease pressure, and other agricultural production problems (ZIZUMBO, 1986; TERÁN & RASMUSSEN, 1994).

In Southern Mexico, legume species such as *P. lunatus*, *P. vulgaris* and *Vigna unguiculata* have been commonly used in the milpa system (TERÁN et al., 1998). Additionally, species such as velvet bean (*Mucuna pruriens*, L. DC.) and jack bean (*Canavalia ensiformis*, L. Dc.) have been recently cultivated intercropped with maize in the southern part of Mexico, especially as a cover crop and as a food source for cattle.

Throughout the region, the milpa system has been shown to be more productive with respect to the land equivalent ratio, particularly when crops are handled under organic management. Recent studies from the southern Mexico recorded that maize was able to achieve a range of grain yield between 2.8 and 4 t ha^{-1}, in all the different groups participated in the survey (MARTÍNEZ-AGUILAR, 2020).

Advantages of maize-legume intercropping system

Effect on growth and yield

The yield of the primary crop in the maize-legume intercropping system may vary depending on the spatial arrangement and the time of intercrop planting (HTET et al., 2017). ADDO-QUAYE et al. (2011) reported that the crop spatial arrangement was vital for a higher maize yield when associated with soybean (*Glycine max*). MAITRA et al., (2019) reported that a maize-legume intercropping system increased maize yields. In a monocropping system, maize yield was 5669 kg ha^{-1} while in a legume-intercropping system with groundnut (*Arachis hypogaea*, L.), maize had a yield of 7609 kg ha^{-1}.

Table 1 - Maize-legume intercropping system in the southern Mexico.

Intercropping System	Region	Benefits	Reference
Pineapple *M. deeringiana-C. ensiformis*- maize, beans, Habanero hot pepper	Tabasco, Mexico	*M.deeringiana* + corn yielded 3750 kg ha-1; corn+ bean 3875 kg ha-1. *M.deeringiana*-Pineapple intercropping is a viable and profitable strategy.	DE LA CRUZ et al., 2006
Jamaica (*Stachytarpheta jamaicensis*)-bean-maize	Villaflores, Chiapas, Mexico	Jamaica-bean-maize intercropping increased farm´s profit.	RUIZ-GONZÁLEZ, 2015
Maize-bean-squash	Yucatan Peninsula	Burning in intercropping system decreased the SOM and N content, but increase K, Ca, Mg, salinity, and bulk density.	EBEL & ROLAND, 2018
Maize-bean	Yucatan, Mexico	Maize-bean yielded more in year three, whereas a sole maize yielded more in the fourth years.	GARCÍA & GIL, 2013
Pumpkin, maize and vegetable, *Leucaena leucocephala*, *M. pruriens*	Yucatan, Mexico	A two-years Fallow added higher organic matter, NO_3- and K content and a four-year fallow which added only Mg to the soil.	URIBE-VALLE & PETIT-ALDANA, 2007
M. pruriens or C. *brasiliensis*, maize & *Hibiscus sabdariffa*	Yucatan, Mexico	Both legume and roselle increase maize yield and reduced weed by 24–55%.	FLORES-SANCHEZ et al., 2009
Maize, lima bean, *M. pruriens*	Yucatan, Mexico	A sole Maize and a maize-lime yielded more than *M. pruriens*, but *M. pruriens* reduced more weeds during the third year.	CASTILLO-CAAMAL et al., 2010

PUNYALUE et al. (2018) reported that maize-legume intercropping system enhanced maize yield by 31–53% and increased the rate of dry biomass with a high accumulation of N, which was better than planting the maize after burning the dry biomass residue. WANG et al. (2014) concluded that maize grain yield in an intercropping system is substantially greater than in a monocropping system. Shivay et al. (2001) reported that intercropping of maize, both in standard row planting and paired row planting, with urdbean (*Vigna mungo* L. Hepper.) significantly increased the grain yield of maize. NYASASI & KISETU (2014) reported that maize intercropped with *V. unguiculata* had significantly lower yields when compared to a single maize crop; however, due to legumes ability to add N to the soil, intercropping constitutes a promising strategy to enhance maize yield. The yield benefit that an intercropping system offer is due to a legume's ability to fix N and enhance nutrient cycling, soil fertility and microclimate (WITTWER et al., 2017).

Maize-legume intercropping reduced maize yield when compared to a maize monocrop due to the competition problems that may appear between the cereal and legume crops. For example, CHOUDHARY & CHOUDHURY (2016) reported a maize yield of 4110 kg ha^{-1} in a monocropping system and a lower yield of 3886 kg ha^{-1} in a maize-soybean intercropping system. SOUZA et al. (2019) reported that when sunn hemp (*Crotalaria juncea*, L.) was sown before maize, it reduced the maize yield, but increased its phytomass. The decrease in maize yield when intercropped with legumes has been associated to various factor, among those negative effect of shading on maize growth (ABERA, et al., 2017), increased competition for intercropping (ABERA et al., 2017). The advantages of monocropping yield benefit over the maize-legume intercropping system is mostly due to the interspecific competition that exists among the cereal-legume species for space, nutrient, water, and light.

Intercropping maize with legumes has also been productive for the farming system of the southern Mexico. EBEL & ROLAND (2017) reported that a maize-bean intercropping system can enhance maize yield in a satisfactory way when compared to a monocropping system. Previous studies from a two-year experiment concluded that

C. ensiformis, jumbiebean (*Leucaena leucocephala* Lam.) de Wit], wild tamarind (*Lysiloma latisiliquum* L. Benth.) and *M. deeringiana* helped increase maize yield in a maize-legume intercropping system.

Intercropping maize with *C. ensiformis* increased the grain yield of maize during the second year of intercropping when compared to maize in a monoculture. For example, QUIROGA et al. 2006 reported that a Maize-*C. ensiformis* produced a higher amount of biomass than a maize monocropping system, this biomass production led the Maize-C. *ensiformis* intercrop to produce 12% more grain yield than a sole maize after three consecutive years.

The maize-legume intercropping system reduced maize yield in southern Mexico, when the planting date is not taking into consideration regarding to the type of legume species chosen to be intercropped with the cereal. CASTILLO-CAAMAL & CAAMAL-MALDONADO (2011) reported that when velvet bean is simultaneaously intercroppped with maize or 20 days after the maize planding date, maize grain yield and biomass production decreased by 59% and 25% respectively.

Effect on weed suppression

Weed competition may cause field losses in maize from 20-100% based on the level of weed infestation found in the cropping system (PATEL et al., 2006). Weeds are one of the major problems faced by farmers because weeds compete for water, nutrients, and light with cash crops (MCERLICH & BOYDSTON, 2014).

Legumes have been used as cover crops to suppress weed populations for cash crops (HARKER & O'DONOVAN, 2013; LANGEROODI et al., 2018). Adoption of legume cover crops in agroecological production systems has been widespread globally, and as a result, has allowed for reduced the use of tillage and herbicides, which enhances their agroecosystem's sustainability (SARE/CTIC, 2017). Weed suppression in the maize-legume association is given by smothering weeds physically (HUTCHINSON & MCGIFFEN, 2000) and chemically by releasing allelochemicals (KUNZ et al., 2016). Previous studies have reported that a maize- legume intercropping pattern can have an impact on weed suppression that can be around 0-50% (AKEMO et al., 2000).

When maize is intercropped with legumes, competition for light, nutrients and water is increased, which makes intercropping a more effective alternative to reduce weed growth compared to a monocropping system. NAHER et al. (2019) determined that a maize-legume intercropping system is a promising technique for weed control and increasing maize yields. They found that two lines of pea (*Pisum sativum* L.) intercropped between two rows of maize, with two weeding regimes at 20 and 40 days after emergence (DAE), can reduce weed populations and increase maize yields. JAMSHIDI et al. (2013) reported that a reduction of weed biomass by intercropping of maize-cowpea was between 39.6% to 45.5% when crops were at a density between 7.5 to 9 plants_m^{-2}. SAUDY (2015) also reported that in intercropping systems *V. unguiculata* reduced weed growth by more than 49% when compared to a sole maize crop. ODHIAMBO et al. (2011) reported that intercropping maize with soybean reduced the presence of the weed *Striga hermonthica* (Delile) Benth. HUGAR & PALLED (2008) showed that maize intercropped with cowpea and maize intercropped with frenchbean (*P. vulgaris*) provided the lowest weed population and weed dry weight and highest weed control efficiency. The results of the field study conducted by KHAN et al. (2012) reported that in a maize-soybean intercropping system, weed populations were reduced from 230 plants_m^{-2} in a monocropping maize crop to 50 plants_m^{-2}. BILALIS et al. (2010) recorded that intercropping maize and legumes were able to minimize weed density compared to sole maize. One of the main reasons for weed control under intercropping is due to the covering of the soil surface, which limits the light availability of weeds.

Depending on the type of legume species, intercropping may be more or less effective in suppressing weeds. It can be challenging for farmers to identify which legume species are more effective in reducing weeds population. PANDEY et al. (3003) recorded that maize-forage meth [*Phaseolus aconitifolius* (Jacq) intercropping system presented the highest weed control efficiency; however, maize-pigeonpea [*Cajanus cajan* (L.) Millsp.] intercropping system was not effective in reducing weeds population.

In the southern region of Mexico, the use of legume species has gained popularity for delivering ecosystem services which benefit the agricultural system. Their ability to improve yields, weed control, pest and disease reduction and the like, make the maize-legume intercropping system a valuable resource that farmers could use to improve the sustainability of their farming system. For example, FLORES-SÁNCHEZ et al. (2018) found that *Canavalia brasiliensis* Mart. ex Benth and *M. pruriens* produced positive results on weed control.

For example, intercropping maize and maize-roselle (*Hibiscus sabdariffa* L.) mixtures with the legumes canavalia (*Canavalia brasiliensis* Mart. ex Benth) and *M. pruriens* reduced weeds population by 24–55%; however, *C. brasiliensis* was more effective when compared to M. pruriens in terms of its ability to adapt in marginal environment. Previous studies from the southern region of Mexico reported that *C. ensiformis*, *Leucaena leucocephala* Lam. and *Lysiloma latisiliquum* L. Benth. reduced weed growth when cultivated with maize (CAAMAL-MALDONADO, 2001).

Other studies from QUIROGA, (2000) also reported that Both *C. ensiformis* and *M. deeringiana* contributed to weed suppression when intercropped with maize by the fact that these legume species are resistant to shading from other crops (type C3 plant) and strongly allelopathic to certain weeds. Based on the lack of little scientific information from the southern region of Mexico about the potential of maize-legume intercropping system to control weeds population, there is a need to evaluate new legume species and determine their potential to suppress weeds and reduce the use of herbicides in the cropping system of this region.

Effect on pests

Pest and pathogenic population dynamics can be affected by intercropping systems. GABA et al. (2014) reported that intercropping systems offer primary ecosystem services including pest control. Intercropping of appropriate crops encourages biodiversity by offering a habitat for a range of insects that would not survive in a monocropping system (LULIE, 2017).

Legume intercropping system species can influence insect-pest populations due to the ability of some of these legume species to release odors that displease insects; some of them are repellants to pests and can be a promising option to reduce the use of pesticides in agriculture (MUÑOZ, 2018). In a maize-legume intercropping system, populations of beneficial insects such as parasites and predators are increased and pests which are harmful may remain below the economic threshold because of the great diversity of crops (MAITRA et al., 2019). KINAMA & PIERRE (2018) reported that in a maize-legume intercropping system enhanced the number of beneficial insects and minimized the numbers corn borer (*Ostrinia nubilalis*) and leaf hopper (*Cicadellidae*).

In southern Mexico, little scientific information is available on the potential of legumes to control pest and disease populations. However, some research carried out in Chiapas and Tabasco by various authors showed that, in most cases and consistently, the maize-legume intercropping system can reduce pest and disease incidence in maize. For example, ALVARADO (1994) reported that a Maize-*M. pruriens* intercropping system was able to reduce *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) populations when compared to a sole maize production. Furthermore, VÁZQUEZ (1995), recorded that a Maize-*C. ensiformis* intercropping system produced a higher reduction of various soil insects and Spodoptera spp. JIMÉNEZ (1996) also reported the benefits of a maize-legume intercropping over a sole maize production in reducing *Spodoptera* spp, and *Euetheola humilis* (soil). Finally, studies from GARCIA el al., (1994) also reported that Maize-*M. pruriens* reduced *Pylhium* spp. from the soil when sown in a maize-legume intercropping system. Based on that, there is a need to evaluate new legume species and determine their potential to suppress pests and disease population in the maize-legume intercropping system of the southern Mexico.

Nitrogen fixation

The combination of cereal and legume in intercropping system can boosts soil fertility because legume crops can symbiotically fix atmospheric N_2 in ways available to plants through symbiotic relationships with Rhizobium bacteria and provide substantial N in low-fertility soils, thus supplying additional N to subsequent crops and reducing the crop's N application requirement (BLANCO-CANQUI et al., 2015). Intercropping legumes alters the rhizosphere's microorganism colony dynamics, allowing for greater nutrient mineralization (MOBASSER et al., 2014). According to various studies, the adoption of the legume-based intercropping system can result in changes in physicochemical properties in the rhizosphere soil (ZHANG et al., 2004). These changes in physicochemical properties in the rhizosphere soil may be to ability of the maize-legume intercropping system to add fresh organic matter and enhance the soil microbial population, which can contribute to the availability of organic carbon, N, and phosphorus in the soil (SONG et al., 2006). As legumes share up to 15% of N to cereals in the legume-based intercropping system, atmospheric N is biologically fixed and utilized by legumes as well as allied non-legumes (LI et al., 2009). Legumes generally have large amount of N accumulation in their biomass, which confirms their ability to supply N to the cropping systems. Previous studies have found that *C. ensiformis*, *C. juncea*, pigeon pea (*Cajanus cajan*

L. millsp.) and *M. pruriens* had the ability to provide a large accumulation of N and a large production of dry matter for ground cover in tropical regions such as Brazil and Mexico (PAIVA et al., 2014). ALMEIDA-SANTOS et al. (2019) reported that the average accumulation of dry biomass was between 7.08 and 7.16 t ha^{-1} and the average accumulation of 151.61 and 176.37 kg ha^{-1} of N by *C. juncea*. Other studies have also reported that *C. ensiformis* produced up to 8.55 t ha^{-1} of dry biomass and fixed up to 112.4 kg ha^{-1} of N in marginal environments (PAIVA et al., 2014). Furthermore, studies have shown that *M. pruriens* had a maximum of 201 kg ha^{-1} of N in the soil (REYES et al., 2013). When legumes intercropped with maize, this intercropping system offers greater benefits for the cereal by fixing N. Enhanced N uptake was reported by different researchers under a varied intercropping system where legume was considered as a component, for example, maize + sunn hemp intercropping (CHIEZA et al., 2017) and maize-soybean intercropping system (OWUSU & SADICK, 2016). RAZA et al. (2019) also suggested more N uptake in intercropping which contributed to increase the productivity of maize and soybean, due to the leaf defoliation of legumes which have nutrient accumulation (RAZA et al., 2019). OLUJOBI et al. (2013) also reported that *C. cajan* was able to transfer some of its N content to maize in an intercropping system while at the same time the uptake of this nutrient was enhanced because of the ability of pigeon pea to fix N.

Numerous research studies have also shown that intercropping can help improve the biological N fixation compared to monocrop. For example, DU et al. (2020) reported that intercropping helps preserve soil fertility due to its ability to enhance interspecific N competition. Additionally, the results showed that soybean nodule dry weight and nitrogenase activities were 34.2% and 12.5% higher in intercropping than in monoculture at the initial seed stage. GAO et al. (2010) recorded that intercropping system is biologically more efficient in providing greater amount of soil mass compared to a sole cropping system. WANG & GAO (2014) reported that maize-legume intercropping can ease the inhibition of nitrate on the expression of nitrate on the expression of essential nodulation and N fixation genes, facilitating nodulation and symbiotic N fixation. In the southern region of Mexico, FLORES-SÁNCHEZ et al. (2018) found that *C. brasiliensis* and *M. pruriens* intercropped with maize-roselle could fix N to the system and prevent nutrient leaching in the intercropping system. The intercropping maize-legume increased the uptake of N by 52%, P by 24% and by K by 30%. Furthermore, studies have shown that Maize-*C. ensiformis*-Bradyrhizobium intercropping system produced a range from 70 to 91 kg ha^{-1} without application of fertilizers in Chiapas, Mexico (QUIROGA, 2000).

Conversely, some limiting factors may decrease the process of N fixation in the intercropping system, if some of the following factors become limited for the cropping systems. For example, in a few cases, intercropping can prevent from achieving its potential by a decrease in availability of light, water, oxygen (in waterlogged soils), temperature, or any one of 14 essential mineral elements (MARSCHNER, 2012). In addition, even though legumes can increase the N fixation process when intercropped with cereals, this does not necessarily enhance the cereal crop yields. DANSO et al. (1987) reported that the dry matter yield and total N in intercropped fababeans (*Vicia faba*) were lower, resulting in a small reduction in the amount of N fixed in the presence of barley, when compared to the sole crop. However, the proportion of N in fababeans derived from fixation was significantly higher in the intercropped system, according to the same author.

In this context, as N is one of the limiting factors for the region, the use of legumes in the region´s intercropping system has been effective in promoting the agricultural productivity of the maize-based traditional farming system, even though the legumes species commonly used have not fully been studied in order to explore their potential in fixing N biologically. Little is known about the exact quantity of N these traditional legume species can fix in the system and how these legumes interact with the cereal in order to increase the productivity of the farming whole farming systems. As N is considered as one of the limiting factors for maize growth and yield, selection and management of proper legume species to minimize competition within intercropping systems may improve the region´s farms benefits. ALTIERI et al. (2012) reported that legumes can enhance the agricultural productivity of farming systems where N is restricted.

Effect on soil erosion

Soil erosion is one the main threats facing natural resources essential for global food production. Farmers have been looking for alternatives that could minimize soil erosion impacts. Intercropping maize with leguminous species may play a fundamental role in soil conservation, which results in an increase in crop productivity and farm income. Intercropping prevents soil erosion due to the great land coverage offered by the intercropped species. When the soil is covered, it helps reduce the impacts of raindrops on the soil. A maize-legume intercropping system, for example, can help reduce the raindrops' effects on the soil. In a maize-cowpea intercropping system, intercropping is mostly provided enough land cover to protect the soil, thus, this contributed to the reduction of soil erosion (KARIAGA, 2004). Maize can play a crucial role against wind erosion which favors legumes (KINAMA & PIERRE, 2018), this may be due to the fact that in a cereal-legume intercropping systems, maize plants are considered as the taller crops, which can serve as wind breaks, protecting legumes which have shorter canopy from wind erosion. The maize-lablab (*Lablab purpureus* L. Sweet.) combination of intercropping is known to enhance soil erosion control, soil fertility and also increase maize yields in highlands with no burning practices (PUNYALUE et al., 2018). The soil erosion reduction was also reduced by 26% and soil losses by 43% in maize + cowpea intercropping system compared to a monocropping system with a sole maize crop (SHARMA et al., 2017). This was attributed to the contribution of leaf fall and legume-based biological N fixation.

In southern Mexico, there is a lack of studies based on the effect of maize-legume intercropping to enhance soil erosion control. However, some work in the region indicates that intercropping may increase the soil organic matter content after a few years of being established. Additionally, this practice covers greater ground area compared to monocropping of cereals, thus, it is proven to be more beneficial in terms of erosion management. Among the few studies on that matter, GUEVARA (2000) reported that maize-mucuna intercropping system can increase the region´s amount of soil organic matter (6.1-71%), when compared to a sole maize (> 3.4-5.0%) after 4 years of experiments. Overall, the cereal legume intercropping system can be considered as one of the main factors responsible to increase the southern region´s soil fertility.

Effect on farm income and/or food security

Intercropping can enhance farm income and food and nutritional security in developing countries. Agriculture is mainly practice under subsistence farming practices, thus, maize-legume intercropping systems can play a critical part in the reduction of hunger due to its ability to provide a major portion of the family's calorie intake. A recent study by CHRISTINE et al. (2018) showed that a cereal-legume rotation enhanced the production of calories and protein. Intercropping can also increase farms benefits due to the large diversity of crops that are mostly grown simultaneously. ARSYAD et al. (2020) reported that intercropping farming systems with higher crop diversity greatly increased farmer income. In the southern region of Mexico, little is known about the effect of maize-legume intercropping system on farm income and/or food security; however, a few scientific studies showed that conservation practices can help the small farms confront and adapt to changes and turn the system more resilient. As intercropping is part of the conservation practices, this could lead to improve the well-being of the people and also affect negatively food insecurity risk of the rural families. MARGARITA & ERNESTO (2019) demonstrated that agrobiodiverse landscapes contributed to a reduction in the number of people affected by food insecurity. Conversely, a few studies from the southern region found no significant relation of intercropping on food security. For example, research by CARBAJAL (2019) showed that intercropping had no significant relationship between the nutritional food security, diversity indices, or economic variables; nevertheless, it had a positive effect on the cropping system.

Challenges associated with maize-legume intercropping system

As previously stated, intercropping has some advantages, for example, intercropping can be cheaper for those living in marginal environmenment. It may be practiced by those who cannot afford chemical fertilizers, certified seeds, and other technologies to enhance their crop productivity (MAPHUMO, 2011); however, it also has some limitations when compared to monocropping. Crop species must be chosen based on their ability to offer complementary benefits to each other. If crop species are not chosen wisely, only a negative effect on crop mixture productivity may be observed due to competition (SANTALLA et al., 2001). Intercropping can become very challenging for farmers by making it more difficult for farmers to manage essential agronomic operations, especially when farm mechanization is used or when the component crops grown in intercropping have different fertilizer, water, and plant protection requirements.

In southern Mexico, in recent years, the system has been characterized by an increasing use of pesticides and chemical inputs to deal with the problems of pests and low crop yield of this system. Other major challenges of the intercropping system in southern Mexico are related to water stress, which allow farmers to establish their cropping system only once a year under rainfed conditions (LITHOURGIDIS et al., 2011). Furthermore, little scientific information is available about the type of legumes, seeding rate, and planting date; this information is vital to help farmers reduce competition between crops species (KARIAGA, 2004). Although, Intercropping can be very challenging for farmers, it is advisable to retain a maize-legume intercropping system instead of a monocropping one; a maize-legume intercropping system offers a better option for minimizing farm expenses and maintaining similar farm profits for both (YAP et al., 2017).

Furthermore, the southern farming sector has issues related to hurricanes, which are frequently the primary source of crop loss for farmers. The majority of farmers conduct intercropping in rainfed conditions, which means that the amount of rain that falls each year is mostly determined by the amount of rain that falls. These two characteristics are among the region's biggest concerns when it comes to maize-legume intercropping. When natural disasters strike southern Mexico, those who rely on that practice for a living abandon it in favor of traveling to the nearest towns and tourist destinations, such as Cancun and Merida, to make a living. These issues must be considered in current and future research on maize-legume intercropping in southern Mexico.

CONCLUSION

Intercropping is considered as one of the promising alternative increase sustainability of farming systems compared to intensified monoculture production. This practice has been widely used in marginal environments where farm requires less inputs to maximize productivity. When compared to intensified monoculture production, intercropping is considered as a promising alternative for increasing the sustainability of farming systems. This practice is often employed in marginal conditions where maximizing production demands fewer inputs.

Intercropping is mostly practiced in southern Mexico in low and marginal soil ecological conditions. In this review, we discovered that the region's intercropping is characterized by a lack of information about specific strategies that should be used to avoid interspecific competitions among crop species; additionally, little is known about the choice of legume species, planting dates, and spatial arrangements of cereal and legume crops have created soil nutrients problems and competition proliferating. As a result, the region's productive system faces a threat to its long-term viability. Based on intercropping's capacity to boost farm income, this method can be employed in Mexico's southern region to maintain maize productivity while simultaneously achieving sustainability or reducing negative environmental impacts such as soil erosion or chemical runoff.

Finally, due to the rising demand for human labor, managing the intercropping system is undoubtedly challenging. However, given the multiple benefits as well as agricultural sustainability, an intercropping system may be one of the best options for smallholder farmers' food security. More research into the primary limitations of this agricultural approach should be conducted in southern Mexico. Future research should also focus on evaluating new legume species, finding legume species that are likely to adapt to the region's soils and climate, and determining the best plant features and management circumstances.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare that there is no financial/personal interest or belief that could affect their objectivity.

AUTHORS' CONTRIBUTIONS

J.F.P, E.R.S. and K.J. contributed equally to the conception and writing of the manuscript. All authors contributed to writing, gave feedback. All authors critically revised the manuscript and approved the final version.

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