Article

Potential of legume species as soil fertility enhancers in tropical regions

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Abstract

An alternative to enhance the fertility of agricultural soils in tropical areas of Mexico and the world is through the use of vegetation covers and green manures, mainly of species of the family Leguminosae. The objective of this work was to analyze the potential of legumes as soil fertility enhancers in tropical agricultural areas through the documentary research technique, considering scientific research of the last 20 years, period 2000-2023. Derived from the review, 14 species widely studied and 24 more, with high potential as enhancers of the physical, chemical and biological properties of soils, were determined. The species most used in the tropics are: *Mucuna pruriens* L. (DC) (biomass: 2.6 to 7.9 t ha^{-1} $year^{-1}$, N: 80 to 200 kg ha^{-1} $year^{-1}$), *Canavalia ensiformis* (L.) DC (biomass: 4.6 t ha^{-1} $year^{-1}$; N: 173 kg ha^{-1} $year^{-1}$) and *Centrosema macrocarpum* Benth (biomass: 9.6 t ha^{-1} $year^{-1}$, nitrogen: 311 kg ha^{-1} $year^{-1}$). Production in crops associated with legumes has increased by up to 50%. Despite the benefits to soil and production, the acceptance and adoption of legumes has been limited by different causes, among them: lack of perception of the benefits of legumes, failures in the technology generated and applied, and scarce participatory approach in their selection. With the information generated in this work, 10 recommendations were conceived to facilitate the selection of species, provide information that facilitates their adoption and that serves as a basis for future studies.

Keywords: degradation, nitrogen, organic matter, vegetation cover.

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Introduction

Soil fertility is a broad concept that integrates the chemical, physical and biological attributes associated with its ability to generate benefits to the environment and human societies (Etchevers *et al*., 2022). When these attributes are affected, soil fertility can be reduced and soil can be degraded, Food and Agriculture Organization of the United Nations (FAO) defines soil degradation as the changes in its characteristics that affect its functions and cause the reduction of agroecosystem yields (FAO-ITPS, 2021).

Degradation caused by inadequate management practices generates loss of soil fertility, considered the most serious problem because it limits the purpose of food security and adaptation to climate variability, which influence conditions of poverty and rural migration by preventing soils from providing goods and services in the expected way (Cotler *et al*., 2017; Estrada-Herrera *et al*., 2017). The use of cover crops represents an alternative to enhance the fertility of degraded tropical soils, by incorporating organic matter into the soil (OMS) that enhances its characteristics (Prager *et al*., 2012). The species most used for this purpose belong to the family Leguminosae for their ability to fix atmospheric nitrogen to the soil (Mpai *et al*., 2016).

Although there is ample information on the potential of legumes as enhancers of soil properties, there is a need to collect data on tropical species to make it easier for producers and regional and local programs to select the most appropriate for their use. The objective of this work was to document research conducted in Mexico and other regions of the world on the use of the legume species most frequently used for their potential to enhance soil fertility in tropical agricultural areas.

Methodology

In this review we searched the following repositories; ScienceDirect, Scopus, Scielo, Redalyc and Google Scholar for the period 2000-2023, using keywords such as: tropical legume species, crop association, cover crops, green manures, biomass production, soil fertility, soil degradation. The searches prioritized research of scientific papers, obtaining just over 200 results, from which a total of 65 studies that had greater relevance in the subject were selected.

Results and discussion

Soil fertility associated with vegetation cover in tropical regions

The vegetation cover plays a very important role in the ecosystems of tropical zones because it enhances the level of nutrients of the surface soil, which allows plants to exploit the deepest nutrient reserves, recover leachates, provide organic remains that are deposited on the surface, benefiting microorganisms that contribute to their incorporation (Isaac and Nair, 2006; Alegre *et al*., 2015). The vegetation cover protects the stability of surface aggregates against the destructive action of rain (Matías *et al*., 2020).

The removal and burning of forest cover, a common practice in the soils of the Yucatán Peninsula, decreases the production of organic residues. The problem of soil quality deterioration worsens because an important part of soil fertility is maintained by nutrient recycling (Alegre *et al*., 2015). Given the evident decrease in nutrients observed in tropical soils, there is currently a trend towards more rational use of soil, based on conservation principles that contribute to obtaining maximum yields with minimum degradation.

Use of green covers as soil fertility enhancers

As a consequence of the loss of soil fertility, it is relevant to develop projects that identify and evaluate the factors that govern the process to help to mitigate it. Currently, there are technologies that allow reducing the depletion of soil nutrients, among which are: conservation agriculture, minimum tillage, the use of organic amendments, residue management, agroforestry techniques, crop rotation and the use of green manures and vegetation covers (Halbrendt *et al*., 2014; Delgado, 2017).

'Green covers', a term defined by Anderson *et al*. (1997), are live vegetation covers that cover the soil, temporarily or permanently, grown in association with other plants (intercropped, in relay or in rotation). Their use is a way to increase the productivity of agricultural soils and reduce their degradation. According to Delgado (2017), their use has a positive correlation with soil porosity, moisture content, bulk density, temperature regulation and with keeping soil particles cohesive. Although cover crops can belong to any plant family, most are legumes, as they have a high capacity to enhance soil conditions by recycling nutrients, symbiotic fixation of atmospheric nitrogen, and control of undesirable vegetation (Mpai *et al*., 2016).

Importance of legumes to increase soil fertility

The use of legumes in systems is recognized for their ability to recover soil fertility (Prager *et al*., 2012; Mpai *et al*., 2016). Improvements in the quality of a soil depend on its properties, climatic conditions and management practices adopted (Sánchez *et al*., 2019). In warm regions, legumes have been used because they favor the fixation of atmospheric nitrogen through symbiosis with rhizobia (Wang and Sainju, 2014), an element frequently deficient in them.

In tropical agricultural systems, legumes represent a substantial source of nitrogen (N) product of symbiotic fixation (Douxchamps *et al*., 2014). The N they fix is readily available for associated crops, via residue mineralization, as it contains higher concentration of N and a lower carbon:nitrogen (C:N) ratio than grasses Legumes decompose rapidly, providing N to subsequent crops and when legumes contain tannins, it may be available up to 90 days after incorporation (Mulvaney *et al*., 2009; Wang and Sainju, 2014).

In addition to providing N, legumes incorporate biomass (carbon) into the soil, as well as nutrients such as phosphorus, potassium, calcium and magnesium (Guzmán *et al*., 2008). The legumes here called tropical can develop in various conditions, so it is necessary to select the most suitable species for specific conditions, considering the edaphoclimatic situation of the establishment site, which would help to obtain greater success in their introduction.

Species of tropical legumes most used as green manures

As a result of this research Table 1 was made, which shows 14 species of legumes with significant contributions of biomass and nitrogen to the soil. The species of *Mucuna* sp. and *Canavalia ensiformis* (L.) DC are the most used because they have high biomass yields (Kaizzi *et al*., 2006). Puertas *et al*. (2008) recommend using *Centrosema macrocarpum* Benth to enhance soil fertility due to its ability to provide nutrients to the soil (N 311 kg ha^{-1}, P 25 kg ha^{-1}, K 155 kg ha^{-1}) and to produce a considerable amount of biomass (9.61 t ha^{-1}). Species such as *Leucaena leucocephala* (Lam.) can produce approximately 20 t ha^{-1} $year^{-1}$ of biomass, contributing about 358 kg ha^{-1} of N, 28 kg ha^{-1} of P, 232 kg ha^{-1} of K and 144 kg ha^{-1} of Ca (Bossa *et al*., 2005). The rate of nitrogen fixation is variable depending on the species and management.

Table 1. Biomass (t ha^{-1} $year^{-1}$) and nitrogen fixed to the soil (kg ha^{-1} $year^{-1}$) by legume species in the tropics and subtropics.

Species	Place of establishment	Biomass (t ha^{-1} $year^{-1}$)	Fixed nitrogen (kg ha^{-1} $year^{-1}$)	Source
Leucaena leucocephala (Lam.)	Port-au-Prince, Haiti	20 to 35	388	Bossa *et al*. (2005)
Vigna unguiculata (L.)	Yucatán, Mexico	nd	23.2	Terán *et al*. (1998)
Crotalaria juncea L.	Hawaii, USA	7	150-165	Rotar and Joy (1983)
	Alabama, USA	5.9	126	Reeves *et al*. (1996)
Mucuna pruriens L. (DC)	Eastern Uganda	2.6 to 7.9	80 to 200	Kaizzi *et al*. (2006)
Mucuna sp.	Yucatán, Mexico	5.4	43.4	Castillo *et al*. (2010)
Phaseolus lunatus L. (*long cycle*)	Yucatán, Mexico	5.7	52.9	
Phaseolus lunatus L. (*short cycle*)	Yucatán, Mexico	3.15	31.9	
Phaseolus vulgaris L.	Veracruz, Mexico	2.71 to 8.26	14.72 to 113	Díaz *et al*. (2017)
Canavalia ensiformis (L.) DC.	San Martín, Peru	4.59	173.68	Puertas *et al*. (2008)
Arachis pintoi Krapov. & W.C. Greg	Tabasco, Mexico	5.07	130.38	Vera-Núñez *et al*. (2008)
Calopogonium mucunoides (L.)	Tabasco, Mexico	5.93	189.16	Puertas *et al*. (2008)
Centrosema macrocarpum Benth.	San Martín, Peru	9.61	311.21	
Clitoria ternatea L.	Veracruz, Mexico	nd	26.104	Díaz *et al*. (2017)
Cajanus cajan (L.) Mill sp.	Tabasco, Mexico	nd	230	Vera-Núñez *et al*. (2008)

nd= no data.

Table 2 presents 24 species with potential for use as soil enhancers and that currently have some alternative use, a characteristic that can benefit them and help their use. These species can be useful as a reference for experimental trials in tropical regions of Mexico and other countries.

Table 2. Potential legume species for use as agricultural soil enhancers in the tropical areas of Mexico.

Species	Annual	Perennial	Use				Source
			Edible	Forage	Grass	Live fence	
Aeschynomene americana L.		x		x	x		Díaz-Vergara *et al*. (2020)
Albizia lebbeck (L.) Benth.		x		x			Mireles *et al*. (2020)
Alysicarpus vaginalis (L.)	x			x			Díaz-Vergara *et al*. (2020)
Arachis hypogaea L.	x		x	x			Montero (2020)
Calapogonium sp.		x		x			Díaz-Vergara *et al*. (2020)
Calliandra calothyrsus Meissn.		x		x			Crespo *et al*. (2011)
Canavalia gladiata (Jacq.) DC.		x		x			Chel-Guerrero *et al*. (2016)
Chamaecrista kunthiana (Schltdl. & Cham.) H.S. Irwin & Barneby		x		x			Díaz-Vergara *et al*. (2020)
Desmodium ovalifolium (L.) DC.		x		x	x		Díaz-Vergara *et al*. (2020)
Enterolobium cyclocarpum (Jacq.) Griseb		x		x			Pinto-Ruiz *et al*. (2010)
Erythrina glauca Willd		x				x	Pinto-Ruiz *et al*. (2010)
Leucaena diversifolia Benth		x		x			Pinto-Ruiz *et al*. (2010)
Macroptilium atropurpureum (Moc. & Sesse ex DC.)	x			x	x		Alatorre-Hernández *et al*. (2018)
Macrotyloma uniflorum (Lam.)	x		x	x	x		Echo community (2017)
Mucuna bracteata DC.	x			x			Díaz-Vergara *et al*. (2020)

Species	Annual	Perennial	Use				Source
			Edible	Forage	Grass	Live fence	
Neonotonia wightii (Arn.) J.A. Lackey	x			x	x		López-Vigoa *et al*. (2019)
Phaseolus acutifolius	x			x			Alatorre-Hernández *et al*. (2018)
Pithecellobium dulce (Roxb.) Benth		x	x	x		x	Pinto-Ruiz *et al*. (2010)
Pueraria phaseoloides (Roxb.)	x			x			Ribeiro and Antoniol (2021)
Sesbania rostrata S.		x	x	x	x		Muñiz *et al*. (2012)
Vigna radiata (L.) Wilezek	x		x	x			Miquilena and Higuera (2012)
Vigna subterranea (L.) Verdc.	x		x				Miquilena and Higuera (2012)
Vigna umbellata (Thunb.)	x		x	x			Miquilena and Higuera (2012)
Lablab prurpureus (L). Sweet	x		x	x	x		Beltrán *et al*. (2005)

Effect of the use of legume species as soil enhancers on the production of crops of interest

The introduction of legumes associated with different tropical crops has changed conventional practices, becoming a technology that promotes soil conservation and increases crop yields (Erenstein, 2002). This review collected results of the use of legumes in the production of crops of interest (Table 3). The association of legume crops as soil enhancers increased the production of the associated crop under traditional management up to 50%. In some of these studies, the results were observed in the second or third year after the use of legumes.

Castro-Rincón *et al*. (2018) reported studies conducted in several countries; for example, in studies carried out with rice in Brazil, it was found that, in the treatments with green manures of legumes, they increased the production by 18% to 20% with respect to the control. In the same study, it is reported that, in Uganda, 50 to 60% higher maize grain and bean yields were observed when using green manures. The results suggest that the yields obtained were due to the inclusion of legumes.

Table 3. Effect on the establishment of legumes and different crops.

Legume species	Associated crop	Crop yield	Place of establishment	Source
Mucuna pruriens L.	*Zea mays* L.	1 076 kg ha^{-1} year^{-1}	Oaxaca, Mexico	Serrano *et al*. (2006)
Canavalia ensiformis (L.) and *Mucuna pruriens* L.	*Zea mays* L.	1 477 kg ha^{-1} year^{-1}	Yucatán, Mexico	Ayala *et al*. (2008)
Mucuna pruriens L. and *Crotalaria juncea*	*Zea mays* L.	2 570 kg ha^{-1} year^{-1}	Isabela, Puerto Rico	Martínez-Mera *et al*. (2016)
Mucuna sp.	*Zea mays* L.	1 819 kg ha^{-1} year^{-1}	Yucatán, Mexico	Castillo *et al*. (2010)
Sesbania rostrata S.	*Oryza sativa* L.	Increase of 1 000 kg ha^{-1} year^{-1}	Havana, Cuba	Muñiz *et al*. (2012)
Crotalaria juncea L.	*Manihot esculenta* Crantz	13 026 kg ha^{-1} year^{-1} fresh weight	Tabasco, Mexico	Magaña *et al*. (2020)

Transfer of technologies for the adoption and use of legumes

The studies described in this review show that it is possible to enhance soil fertility and that the benefits of using species of the legume genus are scientifically and clearly demonstrated. Nevertheless, the adoption and use of green manures by producers has not been entirely positive. In the study conducted by Castro-Rincón *et al*. (2018), they found that producers' adoption of the technology has been low due to the following reasons: 1) producers' lack of perception of legume benefits; 2) failures in the technology generated and applied; and 3) lack of a participatory approach in research and dissemination processes. Another limitation is the high cost of seeds and the difficulty of obtaining a synchrony between the release of the nutrients contained in these plants and the demand of the main crop (Resende *et al*., 2001).

The species to be used as soil fertility enhancer must be adapted to the farmer's production system, have low implantation cost, be resistant to pests and fast growing (Sodré *et al*., 2004). Zhang *et al*. (2013) recommend the use of native herbaceous and shrub species that are adaptable to the ecological conditions of the site. Hand in hand with technical recommendations, public policies should be developed for the implementation and development of projects that promote the development and use of technologies aimed at reversing soil degradation, efforts should be aimed at generating technologies or applying existing ones to reverse actions that have degraded the soil (Etchevers *et al*., 2022).

Conclusions

The use of legumes in cultivation systems, in addition to providing N, helps to reduce erosion and enhance the physical (structure, porosity, bulk density, moisture retention), chemical (availability of nitrogen, phosphorus, potassium, calcium and magnesium) and biological (increase in microbial activity) properties of the soil. Due to their high potential, tropical legume species represent an alternative to enhance soil fertility.

It was determined that the species most used for their effectiveness in tropical areas of Mexico and other parts of the world are: *Mucuna pruriens* L. (DC), *Canavalia ensiformis* (L.) DC and *Centrosema macrocarpum* Benth. There are also shrub and tree species that can fix up to 300 kg ha^{-1} $year^{-1}$ of N, such as *Leucaena leucocephala* (Lam.), which can be used within silvopastoral systems or in combination with other species of commercial interest.

Although there is enough scientific information that highlights the benefits of using legumes for the soil, it is necessary to have more studies that focus on the associations of legumes with other crops to avoid competition with the crop of interest, to know in detail the edaphoclimatic requirements of the species to be used for this purpose, to know more about its phenological cycle and its growth habit. The dissemination of the information on the advantages of using legumes aimed at producers in tropical areas in Mexico is scarce, there is a need for dissemination with a participatory approach that considers specific needs. Insufficient information limits the adoption of the use of legumes as soil enhancers in the Mexican tropics.

To achieve the adoption of the use of vegetation covers, it is recommended to highlight the secondary benefits of introducing these species, that it has a low cost of implementation, because they are species of the region and easy to manage. The information obtained in this review may help future research in the selection of legumes because of their high potential to enhance soil fertility in tropical regions.

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