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Soil governance and sustainable agriculture in Mexico

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ABSTRACT

Soils provide multiple ecosystem services fundamental to the continuity of life on the planet. This valuable natural resource is directly and indirectly linked to several Sustainable Development Goals (SDGs), especially through activities related to agri-food systems; however, soils have not been sufficiently valued. In Mexico more than half of the soils present some level of degradation and in a quarter of production units the main problem is the loss of soil fertility. In this context, sustainable soil management (SSM) represents the only way to recover soils. The governance of soils is essential to be implemented them in a locally adaptable framework. In the case of Mexico, the development of national strategies that integrate comprehensive, fair, and effective governance as the axis of actions aimed at the restoration and sustainable management of soil is fundamental to move forward to SSM.

Introduction

Soils produce 95% of the food human populations consume; however, they are so much more than a substrate for growing plants. Historically, the soil concept was linked to food and crop production, but currently soil is also associated with ecosystem services and human health (Lehmann et al., 2020). Soils have not always been seen as a living and complex resource; hence soils are a natural capital that has not been sufficiently valued. Soils around the world have frequently been misused, leading to the degradation of 33% of the earth's soils. if measures to avoid this misused are not taken over 90% could become degraded by 2050 (FAO and ITPS, 2015). Soil degradation requires urgent attention, since soil loss is leading also to the loss of a non-renewable natural resource that provides the necessary elements for sustaining life. Healthy soils constitute the basis of food production and assist in preserving water and air quality while increasing population resilience and reducing its vulnerability in the face of extreme hydro-meteorological events.

Soils are a cross-cutting resource that impact our daily lives and have a great influence on global challenges such as food insecurity and malnutrition, water and air pollution, and biodiversity loss. Soils also contribute to carbon sequestration, and mitigation of greenhouse gas (GHG) emissions, leading to biodiversity conservation, economic decarbonization, and building a sustainable bioeconomy. Hence, appropriate and sustainable soil management (SSM) represents a huge and unique opportunity to address those global challenges. Particularly in agriculture, SSM practices can contribute to revert environmental degradation by efficient nutrient and water use.

Proper soil governance is a vehicle that could drive, accelerate, and streamline proper land management and the co-benefits it entails. Soil governance is the sum of all formal and informal institutions (e.g., legal prescriptions, regulation, market incentives, rules, norms, habits, attitudes, and consumer behaviors) that concern soil-related decision-making processes of state and non-state actors at all levels (Juerges and Hansjürgens, 2018). The collaboration and action of key stakeholders is required for governing soil to ensure implementation of coherent policies that encourage practices and methodologies that regulate the use of soil resources to avoid degradation and conflict among users (FAO, 2021).

In Mexico, more than half of the soils currently present some level of degradation and more than a quarter of production units recently recognized that their main problem for growing crops is the loss of soil

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fertility (INEGI, 2019).

This review presents the minimum elements that a fair and sustainable soil governance should consider in Mexico. It is essential to recognize the diversity of soils and the diversity of peoples' interests that manage them, as well as the need to know the current situation of soils in the country. This knowledge should include soils functionality and how soils are conceptualized in different sectors, as well as the links with national and international policy instruments for soil management.

Current state of soils in Mexico

Mexico is considered a megadiverse country based on its level of endemism, diversity of species, diversity of higher taxonomic levels (genera, families, etc.), and diversity of ecosystems (CONABIO, 2020). Mexico is also considered part of the Mesoamerican center of origin of many crops like maize, *Phaseolus* and Cucurbitaceous species, with spices, fruits, and fiber plants, like cotton. The genetic resources in the native varieties that are still maintained by small farmers and indigenous groups, represent an important source for adaptation to the adverse effects of climate change.

In terms of soil diversity, Mexico includes 25 of the 32 groups recognized by the World Reference Base for Soil Resources. The dominant groups include Leptosols (28.3% of the territory), Regosols (13.7%), Phaeozems (11.7%), Calcisols (10.4%), Luvisols (9%), Vertisols (8.6%), and Andosols (1.2%), which make up more than 82% of the national territory (INEGI, 2013). Such diversity determines the aptitudes the soils possess to perform their different functions as well as the interactions established between biotic and abiotic components.

Mexico's continental area covers almost two million square kilometers, of which 13% has the potential to be used for agriculture (INEGI, 2014). The close link between farmers and land places farmers as the main soil managers in the country. The remaining land shows potential for cultivating perennial crops, forest resource extraction, grazing, or must be preserved along with its original ecosystems as wildlife refuges, which are relevant for biodiversity conservation (Etchevers et al., 2020; INEGI 2020). However, because forestry, livestock, and agricultural activities are integrated in the same production units, the area influenced by farmers is larger than expected.

The arable land surface is 1740 m^2 per inhabitant, yet this value continuously decreases as the population increases. Another factor that reduces the amount of soil per inhabitant is land loss due to urbanization, which frequently occurs on fertile soil. In consequence, the available land will be insufficient to satisfy current demands in the short term, as well as the demands of future generations. Moreover, decreased precipitation and reduction of freshwater availability due to climate change pose a threat to rainfed and irrigated agriculture. Mexico's socioeconomic and geographic characteristics make it highly vulnerable to the adverse impacts of climate change. Mexico is particularly exposed to extreme hydrometeorological events because of its location between two oceans, as well as its latitude and topography (INECC, 2018). In addition, more than 80% of farmers, who account 70% of the agricultural area, are considered within the category of family farming due to the small size of their plots, subsistence production, and with little or no link with the market. Also, many of these farmers have their lands on steep slopes, which accentuates the problems of erosion and low soil fertility. Additionally, poverty of small farmers prevents them from investing in conservation practices and improvement of their lands, which accentuates a vicious circle in which the deterioration of resources generates more poverty and more soil degradation. In this context, SSM is more important than ever to preserve soil health and adapt to climate change more efficiently.

Agricultural soils also have great potential for reducing GHG emissions, increasing capacity to adapt to climate change, and building resilience. The following factors contribute to this potential: (1) agricultural systems represent the third largest net source of GHG emissions at the national level; (2) Mexico is ranked 11th worldwide in food and crop production; (3) soils used for agricultural activities occupy more than half of the national territory, yet around 64% of Mexican soils show a level of degradation (Fig. 1), and roughly 28% of farmers report having problems with the fertility of their soils (INEGI, 2019); and (4) agricultural activities are the direct livelihood of 6.7 million people in an environment where women participate not only as day laborers but also as producers or heads of household business (SIAP, 2019).

The data on soil degradation in Mexican soils are not always clear nor are they up to date, since this demands considerable, costly efforts. Official national sources –the Ministry of Environment and Natural Resources (SEMARNAT) and the National Institute of Geography and Statistics (INEGI)– agree on the seriousness of the situation (Etchevers et al., 2020). At least 12% of the national territory presents severe or extreme soil degradation (CONAFOR -UACh, 2013) and 59% of Mexican land is affected by desertification (Granados-Sánchez et al., 2013), mainly due to overgrazing, land-use change, deforestation, postharvest handling, and poor soil conditions. Moreover, soil loss and soil degradation have occurred on national territory due to climate change.

Soil degradation and climate change are well-defined triggers of human migration not only from rural to urban areas, which entails the development of "urban belts of poverty" in the city suburbs, but also regional migration that exacerbates social conflicts.

Main barriers and challenges for soil governance in Mexico

In Mexico, land regulation has a constitutional and legal foundation that complicates its regulation from a single perspective. In accordance with article 27 of the Political Constitution of United Mexican States, the original property of all land (soil) is vested in the Nation, which has the right to transmit the original national domain of the land to individuals. As a result, we can distinguish the following soil regimes: a) Public property, which includes those soils that the law reserves to the nation (continental shelf and the seabed of the islands; the beaches, maritime areas, and shorelines), whose state domain is inalienable and imprescriptible, and the exploitation, use or development of those resources, be that by individuals or by corporations, shall be through state concessions; b) Social ownership, which is constituted of ejidos (communal village farmlands), and communal land, representing 51% of the national total (CEDRSSA, 2015) and is protected, both for the establishment of human settlements and for the development of productive activities; and c) Private ownership, which arises from transmitting the original national domain of the soil to private persons, so it is an eminently statutory regimen (González and Pacheco, 2021).

The private ownership regime is not absolute, since based on the recognition of the social function of property, it seeks to make both the public and social interests prevail over the individual interest (Anglés, 2010). Thus the Nation shall at all times have the right to impose on private property such restrictions as the public interest may demand, as well as to regulate for social benefit the use of those natural resources that are susceptible of appropriation. The aim of this regime is to achieve an equitable distribution of public wealth, conserve it, achieve a balanced development of the country, and improve the living conditions of rural and urban populations.

The different soil regimes and the diversity of conceptualization for soils have led to a very broad sectorial regulation with different approaches (seeing soils as a natural resource, as a natural element, and from an ownership perspective), (see Table 1), this can generate barriers for sustainable soil governance.

The notion of sustainable development found support in Mexico for the first time in the General Act on Ecological Balance and Environmental Protection, which in 1999 was incorporated into the economic chapter of the federal Constitution (article 25). This is the basis for the sustainable use of natural resources, including land at the three levels of government (federal, state, and municipal).

Which is as mentioned, land and soils are regulated from various approaches in Mexico, as a natural resource, as a natural element, and as

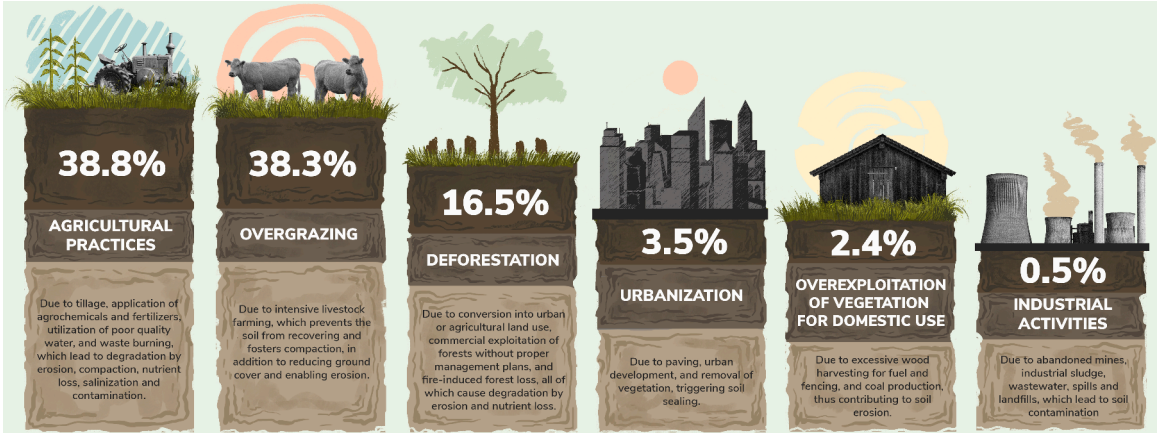


Fig. 1. Main factors that cause soil degradation, and their contribution to the percentage of degraded soil surface.

a private, public or collective good. This has resulted in the issuance of many laws with diverse, even conflicting, objectives that can put land governance at risk. The tension among these competing priorities requires a general land law that comprehensively defines the policy in relation to this resource. Soil governance, understood as the political, economic, and social interactions of actors with an impact on soil management, must be forged taking into account the characteristics of each country. In the case of Mexico, three particularities can be emphasized: 1) the lack of clear boundaries between agricultural and forestry lands, 2) the existence of social property in addition to private property, and 3) the great incidence of rented land for agricultural and livestock use. Moreover, as mentioned, the legislation related to soils in Mexico is fragmented and dispersed in different instruments and responds to various purposes according to the sector that implements it (Table 1).

Historical view of soils

Policies do not develop in a vacuum, but in a historical context that provides opportunities or restrictions to the advocacy of one or another government strategy. Since the late 1940s, Mexico has encouraged an industrialized agriculture that includes the use of agrochemicals, monoculture practices, intensive tillage, and certain irrigation modalities that have contributed to the deterioration of soils and ecosystems (Cotler et al., 2019). Under the paradigm of the green revolution, governments have not recognized the seriousness of the loss of soil ecosystems services and all that it implies.

Land use complexity and land tenure

In Mexicoś rural landscapes, soils are distributed in a dynamic temporal and spatial continuum ranging from agricultural and livestock to forestry use. This relates to the fact that at least 70% of livestock production is practiced extensively without abiding by limits between the agricultural and forestry boundaries. This dynamic is frequent in collectively managed soils, where common-use lands are employed for free grazing (Morret-Sánchez and Cosío-Ruiz; 2017). This situation highlights the need to consider the undeniable link between forestry and agriculture in soil management strategies, which implies a greater effort of inter-institutional coordination. Moreover, private property is not the only form of land tenure in Mexico. Social property systems, also called ejidos or communal properties, constitute half of the territory and 53% of the country's natural vegetation (INEGI, 2008); furthermore, the change of land use from natural vegetation to other uses is the same for common and private property (Bunge-Vivier and Martínez-Ballesté, 2017). In this type of property, part of the land is used for human settlements, another for agriculture, including livestock activities, and another for common use. In addition, social property has specific norms of appropriation of the territory and organizational dynamics that must be considered in the construction of a fair and sustainable governance.

Land rental is another dynamic installed in rural landscapes due to the low income generated by agricultural activity in small areas, which represent 80% of the production units in Mexico. According to a Center for Studies for Sustainable Rural Development and Food Sovereignty (CEDRSSA) report in 2006, between 50 and 60% of ejido lands for irrigation and rainfed crops are leased. In this regard, there is a lack of updated information at the national level. The rental or leasing process, facilitated by changes in the legislation of common property that allowed the commercialization of the land (Pérez Castañeda and Mackinlay, 2015), has generated a carefree attitude from tenants who take advantage of a limited resource unsustainably.

Consequently, in a context with diffuse limits of the agricultural frontier, different types of land tenure and a high proportion of land on lease, production models and public policies have fostered an extractive pattern of agricultural activity, causing severe problems of land degradation in the country. This situation leads to the need to explore contractual arrangements and incentives that encourage SSM from owners and leaseholders.

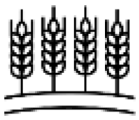
Today, some small and medium farmers still maintain sustainable agricultural and forestry practices. It is up to the government to establish the bases and guidelines to improve agricultural practices in an orderly and sustainable manner (Cotler et al., 2015). To do this, the country must build governance around this resource.

The 2030 agenda in light of sustainable agriculture, and soil governance

The Sustainable Development Goals (SDGs) launched by the United Nations as part of the 2030 Agenda for Sustainable Development (UN, 2015) do not include an SDG to specifically address soils. Nevertheless, this valuable natural resource is directly and indirectly linked to several SDGs, especially through activities, impacts, and opportunity areas related to agri-food systems. In turn, sustainable agriculture simultaneously contributes to the compliance of multiple SDGs. From the soil management and governance perspective, Mexico has the potential to significantly support the achievement of several SDGs (see Fig. 2).

Sustainable agriculture has the potential to contribute to economic growth and decent work, particularly for poor rural populations. SSM practices, especially those aimed at increasing Soil Organic Carbon (SOC) stores, lead to the generation of multiple co-benefits among which are the reduction of CO_2 and non-CO_2 GHG emissions from the agricultural sector, efficiency in the use of agricultural inputs (fertilizers, pesticides), increased and stable crop yields, job creation and poverty reduction by increasing crop production and enabling the capacity of local stakeholders, enhanced inclusion of youth and women farmers,

Table 1
Integrated land perspective in Mexican federal and general legislation.

As a natural element 	From an ownership perspective 	As a natural resource 
POLITICAL CONSTITUTION OF THE UNITED MEXICAN STATES Rights to a healthy environment and water. NATIONAL WATER LAW Receiving body; watershed; wetlands and environmental services. GENERAL WILDLIFE LAW Wildlife habitat. GENERAL LAW ON CLIMATE CHANGE Determination of the natural vocation of the soil. Changes in land use. Expand areas of vegetation cover and organic carbon content in soils. FEDERAL ENVIRONMENTAL LIABILITY LAW Remediation and compensation for soil damage.	POLITICAL CONSTITUTION OF THE UNITED MEXICAN STATES The nation's original ownership of natural resources, social (ejido, communal) and private property. FEDERAL CIVIL CODE Private property (real estate). GENERAL LAW OF HUMAN SETTLEMENTS, LAND MANAGEMENT AND URBAN DEVELOPMENT Land uses; urban resilience, risk prevention and reduction, urban development and territorial reserves. GENERAL LAW OF NATIONAL PROPERTY National property (vacant land, national) GENERAL CIVIL PROTECTION LAW Land use for risk reduction (risk atlas).	POLITICAL CONSTITUTION OF THE UNITED MEXICAN STATES Integral and sustainable national development. GENERAL LAW OF ECOLOGICAL BALANCE AND ENVIRONMENTAL PROTECTION Ecological regulation of the territory, human settlements, protected natural areas, pollution prevention and control. GENERAL LAW FOR THE PREVENTION AND INTEGRATED WASTE MANAGEMENT Prevention and control of soil contamination, responsibility for contamination and site remediation. GENERAL LAW OF SUSTAINABLE FOREST DEVELOPMENT Change of land use in forest lands, protected forest areas. SUSTAINABLE RURAL DEVELOPMENT LAW Land use reorientation when there are high levels of erosion or negative impact on ecosystems; soil conservation works. FEDERAL PENAL CODE Penalizes the offenses of soil contamination and changes in forest land use.

increased soil fertility, and water uptake/infiltration, and soil biodiversity, ultimately reducing soil and land degradation and improved food security. The establishment of traditional agroforestry systems, and conservation agriculture are examples of sustainable practices with a significant potential for improving agricultural production, increasing farmers' income, and maintaining the health of the soil of smallholders' lands, a sector that accounts for more than 80% of producers in Mexico. Therefore, the adoption of SSM practices contributes in multiple ways to the fulfillment of SDG 1 No poverty and SDG 2 Zero hunger. Eradicating hunger and achieving food security remains a challenge, more so in the wake of the COVID-19 crisis. As in many countries, the pandemic has come at devastating economic cost to Mexico, the policies the government implemented to contain the spread of the virus, caused a reduction of activity, a fall in employment and a rise in poverty (Lusting and Martinez, 2021), mostly in cities.

Available data show that the productivity of small-scale producers is systematically lower on average than that of larger-scale producers, and in most countries their incomes are less than half of the incomes of their larger counterparts. In the case of Mexico, with data from 2014, the percentage was 0.9% versus 4.1%, respectively (Naciones Unidas, 2020). Ten percent of children under 5 years of age are affected by stunting, which is higher than average for Latin America and the Caribbean region (9%). In addition, 2% of children under 5 years of age are still affected by wasting, which is higher than average for Latin America and the Caribbean (1.3%) (Development Initiatives, 2021). SSM paired with an efficient governance to support it triggers multiple co-benefits that directly contribute to overcome social barriers such as poverty and marginalization of smallholders and rural populations. This could play a part in the reduction of systemic inequalities by increasing smallholders' competitiveness both at the farm level and along value chains contributing to achieve SDG 10 Reduce inequalities and SDG 8 Decent work, and economic growth. In alignment with SDG 8, and SDG 3 Good health and well-being, the National Development Plan 2019–2024 aims at increasing the production of healthy food in the countryside to achieve the general well-being of the population and, especially, to raise the income of rural producers and improve environmental conditions.

Sustainable agriculture, SSM, and recarbonization practices together with a legal and regulatory framework that effectively addresses local issues can contribute to the achievement of SDG 13, Climate action and SDG 6 Clean water and sanitization. SSM practices centered on SOC conservation and accrual have proven to improve soil quality in Mexico (Cotler et al., 2016) and the uptake and retention of water in soils. This is fundamental to increase resilience to climate change in countries like Mexico where climatic projections (2015 to 2039) indicate temperature increases and reduction in precipitation in the north of the country, where conditions are already dry and hot. One of the most compelling and well-documented co-benefits of recarbonization practices is the increase in water uptake and retention in soils, which would bring along important benefits in agricultural productivity and resilience to climate change, especially for smallholders.

Soil recarbonization supporting soil governance: the RECSOIL initiative in Mexico

Recarbonization of Soils (RECSOIL) is an FAO initiative launched by the Global Soil Partnership as a mechanism for scaling up SSM with a focus on conserving and increasing SOC stores on agricultural and degraded soils. Soil recarbonization is a cross-cutting and transformative solution which proposes a paradigm shift by promoting solutions to global problems such as soil degradation and contamination, climate change, poverty, and food insecurity. This is possible with the implementation of SSM and the derived co-benefits such as the reduction of GHG emissions from the agricultural sector, reduction in the use of agricultural inputs (fertilizers, pesticides), increased and stabilized crop yields, job creation and poverty reduction by increasing crop production and enabling the capacity of local stakeholders, enhancing the inclusion of youth and women farmers, reduced soil and land degradation, increased soil fertility, water uptake/infiltration and soil biodiversity, and increased national capacities for SSM and enabling producers' abilities to take part in climate finance projects among other co-benefits. The mechanism supports the provision of incentives for farmers who agree to implement good practices.

The RECSOILMEX project

Mexico has great potential for the implementation of RECSOIL because of a solid technical feasibility based mainly on the development

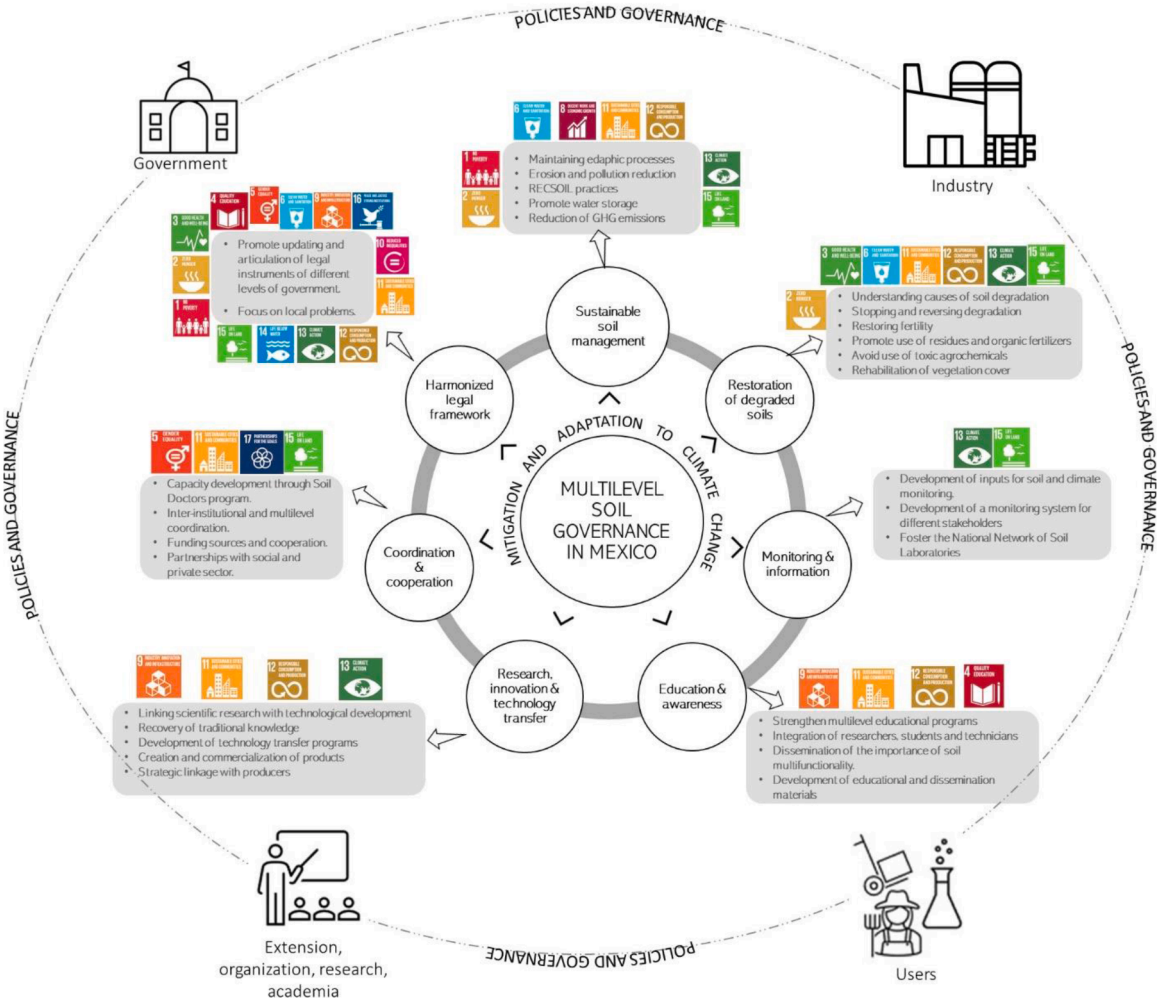


Fig. 2. Synergies between factors related to land governance in Mexico and its relationship with sustainable development goals.

of national capacities, and the updated information and national SOC content maps, and SOC sequestration potential maps. Having this key information has made it possible to identify those areas with the highest SOC sequestration potential, which are ideal areas for RECSOIL implementation. Additionally, through a participatory process and with the support of the governmental sector (Ministry of Agriculture and Rural Development) and FAO, a proposal for the implementation of RECSOIL in Mexico was consolidated and integrated in a Conceptual Note for the Green Climate Found.

The RECSOILMEX project represents a vehicle to strengthen policies, strategies, and decision-making processes with a bottom-up approach since it considers local priorities for the implementation of sustainable SSM, ultimately impacting the strengthening of soil governance. A participatory approach, in which the paradigm shifts in terms of the country's vision of how to use soils, was prioritized during the project planning, and it will drive the implementation of recarbonization practices.

In addition to SOC, the sustainable use of fertilizers is a priority area of focus in terms of both governance and SSM. Due to the low fertility of more than half of Mexico's soils and the growing demand for food, use of fertilizers is high, and in some regions, farmers are applying significantly more nitrogen fertilizer than they need to maximize their yields (Millar et al., 2018). In fact, Mexico is the third largest consumer of fertilizer in Latin America after Brazil and Argentina (FAO, 2015). However, increasing the efficiency of fertilizer use is a challenge due to the socioeconomic and environmental complexity of the country. Agriculture is carried out in a wide array of scenarios, with different types of producers and ways of farming. A gradient prevails in the country, ranging from business-type agriculture with access to natural and economic resources (irrigation systems, land without steep slopes suitable for the establishment of mechanization and technification, production units of up to two thousand hectares, access to services and hydro-agricultural infrastructure), to the other extreme of the peasant agriculture subsector, widely distributed in ~2.7 million production units with working areas of less than five hectares (Cortés et al., 2010) and covering approximately 74% of Mexico's cultivated territory (Instituto Nacional de, 2015). This type of agriculture is rainfed, frequently carried out on hillsides, unprotected from water erosion, and exposed to the effects of global climate change (Turrent et al., 2017). Fertilization strategies and regulatory policies would have to be as varied and dynamic as the different types of agriculture in the country. This is a great area of opportunity as the regulation of fertilizer use is incipient.

SSM and proper regulation could contribute to increased nutrient use efficiency leading to reducing GHG emissions, climate change, and environmental pollution. The restauration of degraded lands, promotion of the use of residues and organic fertilizers, avoidance of use of toxic agrochemicals, and rehabilitation of vegetation cover could play a significant part in the reduction of risks associated with chemical exposure. These actions could positively influence the health of rural workers and consumers (Fig. 2) (CNS-FAO, 2019) contributing to the achievement of SDG 13 Climate action, and SDG 3 Good health and well-being.

Along with environmental challenges other significant barriers persist, such as institutional deficits, especially regarding protections for

smallholder farmers, damaging agricultural practices, losses and waste throughout the food system, and a system of incentives that promotes unhealthy dietary habits (UN, 2020). Sustainable agriculture and a harmonized legal framework in which local priorities are considered is essential to implement and obtain the co-benefits of practices aimed at reducing agriculture externalities.

Soils in the nationally determined contribution

As a signatory to the Paris Agreement, Mexico published at the end of 2020 its update to the Nationally Determined Contribution (NDC, Mexico 2020) in accordance with the General Law on Climate Change (LGCC) and in accordance with the decisions 1 / CMA.2 and 1 / CP.21 and Article 4 of the Agreement.

The publication of the NDC is part of the commitments agreed to in 2015 as part of the United Nations Framework Convention on Climate Change (UNFCCC). The NDC includes, on one hand, Unconditional Commitments, that is, they do not depend on the support of international agencies for their execution. These include reducing 22% of GHG emissions and 51% of black carbon emissions by 2030 with respect to the trend scenario (business-as-usual, BAU). On the other hand, there are the Conditional Commitments, which depend on having external financing and which include reducing GHG emissions by up to 36% and 70% of black carbon emissions by 2030 compared to the BAU scenario.

Additionally, these commitments refer to aspects that emphasize adaptation to climate change or mitigation aspects that contribute to reducing GHG emissions, identifying the synergies that exist between these approaches. The climate change adaptation component within the NDC is grouped in five Axes, with 27 lines of action, of which 18 lines have been identified to have GHG mitigation benefits during their implementation phase. Among the most relevant issues addressed in the adaptation component with mitigation synergies are protection of strategic infrastructure, integrated management of water resources, conservation and restoration of marine ecosystems, soil restoration, restoration and conservation of blue carbon ecosystems and coral reefs, and actions to strengthen the management and conservation of forests and jungles.

Axis C, which corresponds to the Conservation, Restoration, and Sustainable Use of Biodiversity and Ecosystem Services includes a line of action that makes explicit reference to soils: design and implement actions that contribute to combating desertification and conservation of soils. The NDC recognizes that this new line of action has clear synergies with mitigation.

Regarding the mitigation component, two sectors can be identified in which the soil resource is relevant: Agriculture and livestock, and Land use, land use change, and forestry. The NDC recognizes that actions in these sectors contribute to SDG Goals 9, 11, 12, 13, 14, and 15. For the agriculture and livestock sector, the planned actions consider the best agricultural and conservation practices, the promotion of agroforestry and sustainable agriculture practices, the reduction of agricultural burns, and the promotion of biodigesters for the sustainable use of animal waste. In the sector of land use, land use change and forestry, the strategy is maintained and seeks to strengthen the strategy towards a zero rate of net deforestation, which will be achieved under the National Strategy for the Reduction of Emissions from Deforestation and Degradation Forestry (ENAREDD +). Likewise, strategies for the management of Protected Natural Areas are strengthened through concerted actions. Similarly, synergies are recognized in the adaptation component with benefits for sustainable development.

The NDC regarding the five carbon stocks includes the following classes: 1) above-ground biomass, 2) underground biomass, 3) garbage, 4) dead wood, and 5) soil organic matter measures. These contribute to SDGs 2, 13, and 15.

Despite soil carbon's critical role in climate change mitigation and adaptation, according to a recent analysis led by Wiese et al. (2021), only 15% of countries that are part of the Paris Climate Agreement commit to action on soil carbon in Nationally Determined Contributions (NDCs). Mexico is aware of the potential that the re-carbonization of soils has in mitigating climate change, so this activity is a fundamental part of the governance that will be reviewed in the next section. Mexicoś NDC is currently under a judicial suspension.

Developing soil governance for agriculture

Soil governance is a central element of national strategies for sustainable development (Montanarella and Vargas, 2012; Weigelt et al., 2015), considering the essential ecosystem services it provides for the well-being of humanity (Adhikari and Hartemink, 2016; Greiner et al., 2017). The implementation of an effective and fair governance of agricultural soils presents important challenges, particularly in socio-environmental contexts with degraded soils, poverty, asymmetries (e.g., rights, gender and access to training, financing, technologies), food insecurity, marginalization, urban expansion, and high vulnerability to climate change. The complexity increases considering the multi-scale condition related to land management as well as the multi-level and multi-actor nature of governance (Juerges and Hansjürgens, 2018; Weigelt et al., 2015). In scenarios where land governance is partial or has not materialized, the central question is what elements can contribute to achieving it.

i. How to build soil governance

Soil governance must be forged considering the particularities and priorities of each country. In principle, it is relevant to analyze how these institutions work, who implements their mandates, and on which scale they operate. Secondly, it is necessary to know which aspects of the soil are included in the institutional arrangements and, finally, to evaluate their results and impacts on soil health.

In the case of Mexico, the main priorities regarding soil governance revolve around the different land tenure regimes, the diffuse border between agricultural and forest soils, and the rent of land under agreements that are unfavorable for landowners. Also, models with productive dynamics that deplete the resource are still widely implemented in the country's agriculture. In these scenarios, where soil degradation is the common factor in the problems mentioned, soil governance must be strengthened.

Adding to the fragmentation of regulations related to soils, laws concerning agricultural land are broad and also fragmented into multiple instruments with objectives that may be contradictory when implemented (e.g., land tenure, sustainable development, ecological balance and management, climate change). This regulation coexists with the international commitments in instruments where Mexico is a Party, as well as with local regulations, commercial agreements, verbal arrangements, and collective and individual perceptions and behaviors on various aspects of the land. In the case of the conservation of this resource, during the last decade public policies have reflected this purpose. However, efforts have been focused on certain regions and crops, limiting their results (Cotler et al., 2016). Within this framework, instruments are needed that effectively and fairly link the formal and informal institutions associated with decision-making on land, particularly regarding its sustainable management at different levels and scales (Fig. 2).

According to Weigelt et al. (2015), land governance requires shaping social relations, a relevant aspect in territories under a regime of collective use, as is the case of ejidos and local communities in Mexico. These local governance units have been important to implement the ENAREDD +, even though centralizing policies and asymmetries regarding the participation of local actors in decision-making have limited the development of an effective and fair multilevel governance (Trench et al., 2017).

Considering these experiences, it is necessary to develop strategies for the sustainable management of agricultural land where the backbone

is the governance of the soil. In these strategies, the lines of action must be oriented to the restoration of soil health and its sustainable management to preserve its essential functions and to contribute to the SDGs (Fig. 2, restoration of degraded soils). To achieve these objectives, soil recarbonization has a central role, since its operation must necessarily start from local scales that integrate different knowledge systems and positively relate small, medium, and business farmers, input providers, extension agents, researchers, and government authorities at different levels.

The recarbonization of agricultural soils proposes an approach oriented towards the transformation of production systems, where the main purpose is to increase organic carbon reserves through the application of sustainable soil management practices, actions that contribute directly to mitigation and adaptation to climate change. Considering the diversity of agroecosystems, agroclimatic, socioeconomic, and cultural conditions in which the country's agriculture takes place, soil governance represents an articulating axis between different scales and actors belonging to different spheres and levels of government (Fig. 2, SSM).

Moreover, it is necessary to implement strategies to link academia, government, and civil society with multiple objectives. These objectives include generating information for decision-making, providing farmers with indicators on the quality of their soils, developing teams for national soil monitoring, and generating databases. The Soil Doctors Program of the FAO Global Soil Partnership is an example of this type of initiative that is in the process of being implemented.

A General Law for Sustainable Use and Soil Conservation has been proposed in 2018; however, it has not advanced recently. Such an instrument should consider the use and conservation of this resource among several sectors, and with a systemic approach. It would also need to reconcile different interests and respond to diverse needs. Certainly it will take time, coordination, and a very broad dialog.

Conclusions

The existence of institutions, instruments, and norms related to soil management does not imply the existence of a governance for this resource. Linking these elements in a coherent, inclusive, and long-term approach is what Mexico needs to achieve a real, fair, and sustainable management of the country's soils.

The urgency to address the country's soil problems lies in its current situation, where more than 60% of soils present some level of degradation. This reality increases the vulnerability of the agricultural sector to climate change and puts food production, and consequently, food security, at risk.

If current soil practices continue, sustainable development of the country might be compromised in the short, medium, and long term, and along with it, the materialization of multiple human rights that depend on the quality and availability of healthy soils. It must always be remembered that soil health and human well-being are closely linked. In this context, sustainable agriculture becomes relevant since it is one important path to achieving the SDGs and creating inclusive and sustainable agricultural and food systems.

The Covid-19 pandemic caused a striking reduction in economic activity, especially in people with lower incomes, which makes it necessary to take medium and long-term actions to generate structural changes in the organization of productive activity with a view to enhancing sustainable agriculture from a multilevel governance approach. Such a change would promote various co-benefits, both for society and for ecosystems and their resources.

Mexico has an outstanding heterogeneity of landscapes that is reflected not only in a great diversity of soils and climates, but also in production practices, forms of land appropriation, and in the interrelationship between society and nature. These make soil management more complex and compels the government sector to take into consideration these variety of territories.

The challenges for soil governance in Mexico are far from being a reason to discourage the actions of the actors who for one reason or another are involved in the management of this resource. On the contrary, the global context promotes the issue on the international political agenda. At the national level, there is a solid academic platform dedicated to the study of soils, a government awareness to address the problem, and farmers with great interest in reversing the havoc that poor soil management has generated in their productive capacity.

The strengthening of sustainable agriculture and sustainable agriculture policy measures assures policy coherence to allow an advantageous context. It is essential to strive for policy convergence informed by science and with multilevel participation to develop an efficient governance.

Mexico recognizes that it must develop national strategies that integrate fair and effective governance as the key of actions aimed at the restoration and sustainable management of soil, an essential resource for food security, mitigating and adapting to the effects of climate change, maintaining the integrity of ecosystems, and the welfare of society.

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References

Adhikari, K., Hartemink, A.E, 2016. Linking soils to ecosystem services — a global review. Geoderma 262, 101–111.
Anglés-Hernández, M., 2010. La consolidación del derecho ambiental y sus implicaciones prácticas en el derecho de propiedad, Revista de los Tribunales Agrarios, VII. Enero-Abril 21–53. http://www.tribunalesagrarios.gob.mx/ta/docs/pub/rev/50.pdf.
Bunge-Vivier, V., Martínez-Balleste, A., 2017. Factors that influence the success of conservation programs in communal property areas in Mexico. Int. J. Common. 11 (1), 487–507.
CEDRSSA, 2015, La propiedad social rural y su perfil productivo. Centro de Estudios para el Desarrollo Rural Sustentable y la Soberanía Alimentaria. http://www.cedrssa.gob.mx/files/b/13/74Reporte%2030%20La%20Propiedad%20Social%20Rural.pdf.
CNS-FAO, 2019. Sustainable agriculture as a means to achieve the Sustainable Development Goals. A discussion paper. Swiss National FAO Committee.
CONABIO. (2020). México megadiverso. 2021, de Comisión Nacional para el Conocimiento y Uso de la Biodiversidad Sitio web: https://www.biodiversidad.gob.mx/pais/quees.
CONAFOR-UACh, 2013. Línea Base Nacional De Degradación De Tierras y desertificación. Informe final. Comisión Nacional Forestal y Universidad Nacional Autónoma de Chapingo, Zapopan Jalisco, 160pp.
Cotler, H., Cram, S., Martínez-Trinidad, S., Bunge, V., 2015. Evaluación de prácticas de conservación de suelos forestales en México: caso de las zanjas trincheras. Investigaciones Geográficas 88, 6–18. https://doi.org/10.14350/rig.47378.
Cotler, H., Martínez, M., Etchevers, J.D., 2016. Carbono orgánico en suelos agrícolas de México: investigación y políticas públicas. Terra Latinoamericana 34 (1), 125–138.
Cotler, H., Robles, H., Lazos, E., Etchevers, J., 2019. Agricultura, alimentación y suelos (Coord.). In: Merino-Pérez, L. (Ed.), Crisis Ambiental En México. Ruta para El Cambio. UNAM, Secretaría de Desarrollo Institucional, México, pp. 53–84.
Development Initiatives, 2021. 2020 Global Nutrition Report. Bristol, UK. https://globalnutritionreport.org/resources/nutrition-profiles/latin-america-and-caribbean/central-america/mexico/.
Etchevers, J.D., Cotler, H., Hidalgo, C., 2020. Salir de la invisibilidad: nuevos retos para la ciencia del suelo. Terra Latinoamericana 38, 931–938. https://doi.org/10.28940/terra.v38i4.867.
FAO, 2015. World Fertilizer Trends and Outlook to 2018. Food and Agriculture Organization of the United Nations, Rome.
FAO and ITPS, 2015. Status of the World's Soil Resources (SWSR) – Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.
FAO, 2021. Take Urgent Action to Combat Climate Change and Its Impacts. Food and Agriculture Organization of the United Nations.
González Márquez, J.J. & Pacheco Ruiz, A.M., 2021, Soil Law in Mexico, in Harald, G., et al. (eds.), International Yearbook of Soil Law and Policy 2019. 10.1007/978-3-030-52317-6_4.
Granados-Sánchez, D., Hernández-García, M.A., Vázquez-Alarcón, A., Ruíz-Puga, P., 2013. Los procesos de desertificación y las regiones áridas. Revista Chapingo. Serie Ciencias Forestales y del Ambiente. 19 (1), 45–66 [fecha de Consulta 26 de abril de 2021]. https://www.redalyc.org/articulo.oa?id=62926254004.
Greiner, L., Keller, A., Grêt-Regamey, A., Papritz, A., 2017. Soil function assessment: review of methods for quantifying the contributions of soils to ecosystem services. Land Use Policy 69, 224–237.
INECC, 2018. Sexta Comunicación Nacional y Segundo Informe Bienal de Actualización ante La Convención Marco De Las Naciones Unidas Sobre El Cambio Climático. Instituto de Ecología y Cambio Climático, México.

INEGI, 2008. Informe Sobre La Propiedad Social. INEGI, Comunicado Núm, 069/08, 11 abril.
INEGI, 2013. Conjunto De Datos De Perfiles de suelos. Escala 1:250 000. Serie II (Continuo Nacional). INEGI. https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=702825266707.
INEGI, 2014. *Encuesta Nacional Agropecuaria 2014.*México.
INEGI, 2019. Encuesta Nacional Agropecuaria 2019. México.
INEGI, 2020. Actualización de la población a través de la muestra maestra de viviendas y su validación por estimaciones a corto plazo https://www.inegi.org.mx/temas/agricultura/.
Instituto Nacional de, 2015. Ecología y Cambio Climático (INECC) y Secretaría de Medio Ambiente y Recursos. Primer Informe Bienal de Actualización ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático. INECC/Semarnat, México.
Juerges, N., Hansjürgens, B., 2018. Soil governance in the transition towards a sustainable bioeconomy– A review. J. Clean. Prod. 170, 1628–1639.
Lehmann, J., Bossio, D.A., Kögel-Knabner, I., Rillig, M.C., 2020. The concept and future prospects of soil health. Nat. Rev. Earth Environ. 1, 544–553.
Lusting, N., Martinez Pabòn, V., 2021. The impact of COVID-19 on inequality and poverty in Mexico. Estudios Econòmicos 36 (1), 7–25.
Millar, N., Urrea, A., Kahmark, K., Shcherbak, I., Robertson, G.P., Ortiz-Monasterio, I., 2018. Nitrous oxide (N2O) flux responds exponentially to nitrogen fertilizer in irrigated wheat in the Yaqui Valley, Mexico. Agricul. Ecosyst. Environ. https://doi.org/10.1016/j.agee.2018.04.003.
Montanarella, L., Vargas, R., 2012. Global governance of soil resources as a necessary condition for sustainable development. Curr. Opin. Environ. Sustain. 4 (5), 559–564.
Morett, Sanchez, Carlos Cosio-Ruiz, J., Celsa, 2017. Panorama de los ejidos y comunidades agrarias en México. A*gricultura, sociedad y desarrollo* vol.14, 125–152 n.1ISSN 1870-5472.
Naciones Unidas, 2020. Informe de los Objetivos de Desarrollo Sostenible 2020. https://www.bivica.org/files/5967_The-Sustainable-Development-Goals-Report-2020_Spanish.pdf.
NDC México, 2020. Contribución Determinada a nivel Nacional: méxico. Versión actualizada, SEMARNAT. 2020. https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Mexico%20First/NDC-Esp-30Dic.pdf.
Pérez Castañeda, J.C., Mackinlay, H., 2015. ¿Existe aún la propiedad social agraria en México? Polis 11 (1), 45–82.
SIAP, 2019. Panorama Agroalimentario, 2019.
Trench, T., Larson, A.M., Libert Amico, A., 2017. Gobernanza multinivel y uso del suelo en Chiapas y Yucatán (Vol. 188). Cifor.
UN, 2015. The Sustainable Development Agenda. United Nations, Department Economic and Social Affairs.
UN, 2020. Building Better After COVID-19 and Acting Where We Will Have the Greatest Impact On the SDGs Ending hunger and Achieving Food Security. United Nations.
Weigelt, J., Müller, A., Janetschek, H., Töpfer, K., 2015. Land and soil governance towards a transformational post-2015 Development Agenda: an overview. Curr. Opin. Environ. Sustain. 15, 57–65.
Wiese, L., Wollenberg, E., Alcántara-Shivapatham, V., Richards, M., Shelton, S., Hönle, S. E., Heidecke, C., Madari, B.E., Chenu, C., 2021. Countries' commitments to soil organic carbon in Nationally Determined Contributions, Climate Policy. Internet link: https://www.tandfonline.com/doi/full/10.1080/14693062.2021.1969883.
Cortés, J.I., F.A. Turrent., E. Hernández., N. Nicolás., J.P. Torres., A. Zambada. y P. Díaz. 2010. La Milpa intercalada con árboles frutales (MIAF). Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. Subsecretaría de Desarrollo Rural Dirección General de Apoyos para el Desarrollo Rural. México.