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Social, economic and production aspects of maize systems in Mexico

Aspectos sociales, económicos y productivos de los sistemas maiceros en México

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Abstract. Mexico, where farms range from subsistence to industrial systems, is a good example of the wide global diversity in farm systems in terms of agricultural technology, economic strategies and socio-cultural characteristics. This paper studies national-scale data to analyse three maize production systems: small-scale (< 2 ha per farm), medium-scale (5-10 ha per farm), and large-scale (>50 ha per farm). Farm-scale data from the Agricultural National Survey of 2014 were used at national and state scale to investigate trends and differences among the systems in relation to (1) socio-cultural characteristics (use of maize for self-sufficiency and sales; land tenure, type of seed and use of family labour), (2) agricultural technology (crop yields, irrigation system, agrochemicals use and labour requirements) and (3) economic characteristics (governmental programmes, insurance, credits and production costs). The results show that some characteristics are intrinsic to the type of system but that others deviate from the trends or patterns reported in the literature. For instance, (1) most farmers from the three systems use agrochemicals and (2) a large share of the crop area of large-scale systems (22%) consists of social land tenure ("*ejido*"). Furthermore, some of these trends show geographical deviations. Farms differ in their response to social, economic and technological aspects, and this emphasizes the need for an interdisciplinary approach in the design of political strategies that are context specific.

Keywords: Agricultural systems; Interdisciplinary analysis; Maize; Mexico; Social, economic and technological characteristics.

Resumen. En México coexiste una diversidad de sistemas de producción agrícolas, desde campesinos basados en autosubsistencia, hasta agronegocios industriales. Esto implica una heterogeneidad de características socioculturales, tecnológicas y económicas. Este artículo analiza tres sistemas de producción de maíz: pequeño (< 2 ha por productor), mediano (5-10 ha), y de gran escala (>50 ha). Con base en los microdatos de la Encuesta Nacional Agropecuaria 2014 y mediante la agregación de información a nivel nacional y estatal, se analizaron tendencias y diferencias entre estos tres sistemas en relación con tres ejes: (1) Características socioeconómicas (uso para venta y subsistencia, tenencia de la tierra, tipo de semilla y trabajo familiar); (2) Tecnología agrícola (rendimientos, irrigación, agroquímicos y tipo mano de obra); (3) Características económicas (programas gubernamentales, seguros, créditos y costos de producción). Los resultados demuestran que algunas de estas característi-

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cas son intrínsecas a cierto tipo de sistema de producción, pero, también, que algunas otras difieren de los patrones descritos en estudios previos. Particularmente destacan dos procesos. (1) El porcentaje del área que usa agroquímicos para los tres sistemas es muy similar, y se esperaba que los grandes productores tuvieran más uso de agroquímicos. (2) Una proporción relativamente grande de los sistemas de gran escala (22%) tienen tenencia social de la tierra (ejidos), aunque estos productores también se relacionan claramente con tenencias de la tierra privada. Asimismo, estas tendencias tienen desviaciones a nivel regional. Los resultados sustentan la necesidad de enfoques interdisciplinarios y multiescalares para diseñar políticas estratégicas destinadas a los sistemas agropecuarios.

Palabras clave: Sistemas agrícolas; Análisis interdisciplinario; Producción de maíz; México; Características sociales, tecnológicas y económicas.

INTRODUCTION: MEXICAN AGRICULTURAL DIVERSITY: A CULTURAL AND POLITICAL LEGACY

Maize is one of the most important crops in the world as a source of food (FAO, 2019). In Mexico, it is the main basic food source in the form of *tortillas* (Paredes-López, Guevara-Lara, & Bello-Pérez, 2008; Aguilar, Illsley, & Marielle, 2003). Both its production and its consumption have a millenary cultural legacy that is still present in peasants' agricultural systems (Warman, 1988, 2001; Appendini, García Barrios, & De la Tejera, 2003).

In the second half of the 20th century, the Food and Agricultural Organization of the United Nations (FAO) launched a global strategy (the so-called Green Revolution) for agricultural development in developing countries. The strategy was to intensify production systems focusing on the main food grains. A large share of the agricultural area was industrialized, global food production doubled although with virtually no change in the area involved, and global hunger was reduced (FAO, 2019). As a result, farm systems changed not only in technological aspects but also in their social and economic characteristics and strategies. However, not all farms industrialized. Nowadays small farms account for one-quarter of the global agricultural area and they produce 30%-34% of the global food supply (Ricciardi, Ramankutty, Mehrabi, Jarvis, & Chookolingo, 2018).

In this paper, Mexico is used as a case study to analyse differences among farms. Mexican agricultural systems range from family subsistence farms with low economic income to industrial farms with high economic income (González-Cambrero, 2014). The main drivers for this diversity are related to the biophysical heterogeneity of the country and the agrarian reforms of the 20th century.

In terms of biophysical heterogeneity, Mexico is a mega-diverse country covering a spectrum of tropical, temperate, semiarid and arid climates (Reyna-Trujillo, Vidal-Zepeda, Hernández-Cerda, Granados-Ramírez, Gómez-Rodríguez, 2013). Maize production systems have developed in all these contexts by adaptation over millennia to all these variant conditions (Toledo & Barrera-Bassols, 2009; Aguilar et al., 2003). As a result, a wide diversity of maize races exists in Mexico, a diversity that did not undergo the major decline that would have been expected with the industrialization of agriculture and the neoliberal policies of recent decades (Perales, 2014).

The 20th century left a strong legacy for the present agricultural sector. One of the main characteristics is the different types of land property, including social, private and federal tenure (López Barcenas, 2017). Social land can be either "*ejidos*" or agrarian communities ("*comunidades*" in Spanish). With the agrarian reform, the government renamed the ancient indigenous towns with the epithet of agrarian communities (López Barcenas, 2017: 25; Morett-Sánchez & Cosío-Ruiz, 2017). Currently, practically the only differences there are between ejidos and agrarian communities are that in the latter the law does not allow for farming plots to be entitled personally (even if they are farmed individually) and farmers cannot sell their lands. In contrast, in the ejidos, farmers have individual plots on land assigned for farming, and they have rights to use natural resources on common lands. However, an agrarian community can change to the ejido system by agreement in assembly of the majority of the members and, thus, gain access to individual plots and, even, to their later sale if it is decided by a qualified assembly (Morett-Sánchez & Cosío-Ruiz, 2017).

The Mexican agrarian reforms of the 20th century included a land distribution process from 1917 to 1994. During this period, more than 100 million hectares were distributed and 30,000 ejidos and agrarian communities were created (Warman, 2003). In addition to the social land, the agrarian reforms resulted in small, medium and large-scale holders of private land. This agricultural transition process has been divided into three periods by some authors (Lara, 1998).

First, low-input agriculture from 1917 to the end of the second world war. Second, intensification from the 1950s to the 1980s, which resulted in mechanization and intensification of cereal production systems, with a consequent reduction in human labour, and including large-scale construction of an irrigation infrastructure. Third, post-1980, globalization in the context of integrating the economic dynamics between Mexico, the United States of America and Canada (Castillo, 2014). In this period, neoliberal structural reforms were implemented in rural Mexico (Puyana and Romero, 2005; Castillo, 2014; Calva, 2000). Maize production systems underwent marked changes due to the following political strategies (Calva 2004): (1) reduction of governmental subsidies for production, distribution and commercialization of crops and livestock products; (2) price liberalization and market opening in the agricultural sector with the North American Free Trade Agreement (NAFTA); and (3) agrarian legislation changes in 1992 that allowed the privatization and concentration of agricultural land. During this period, the government had "cheap staple food" strategies in the maize supply chain which focused on providing cheap maize food for the urban population (Appendini, 2014); these strategies focused on supporting large-scale irrigated systems mainly in Sinaloa state. However, after the food price crises of 2008, the government focused again on supporting medium and small farms in the centre and south of the country (Appendini, 2014).

Nowadays, small and semi-subsistence farms with extensive rainfed systems continue to coexist with market-based large-scale farms with intensive irrigated systems (Eakin, Perales, Appendini, & Sweeney, 2014; Sweeney, Steigerwald, Davenport, & Eakin, 2013). The diversity among farms rests mainly on the social actors involved and the different, and usually opposed, aims of production in rural Mexico.

At one extreme, farmers with a small-scale farm have a peasant's livelihood[1] and few hectares per farmer, usually with social land tenure. Their aims are the self-sufficiency of the family in terms of maize, and the lowering of economic risks by diversifying their economic income-generating activities. By achieving self-sufficiency in maize foods, farmers lower both their dependence on the market, and their economic vulnerability because of price fluctuations. In addition, their sense of community is strong, and their agricultural production relies on unpaid family labour. They usually use low-input agricultural technology and have little governmental support. Crop yields are usually low and are mainly devoted to their own subsistence.

At the other extreme, the large-scale systems are based on market strategies and generally have private land. Their aim is to increase production through agricultural intensification measures that include large economic investments and high economic income. For these farmers, individualism is important to increase income, and the labour force is mainly employed agricultural workers.

Between these extremes, medium-scale farming enterprises vary widely in production aims and livelihood, whether through food self-sufficiency or through market sales. These farmers work a larger expanse of land and employ a more intensive agricultural technology than do small-scale farms.

[1] The concept "peasants' livelihood" or "peasantry" has been used in several studies of rural Mexico (Kearney, 1998; Warman, 2001, 1998; Castillo, 2014, 2018) and refers to agricultural production systems with specific social and economic characteristics such as (1) production focused on family self-sufficiency, (2) social land tenure, with land not necessarily being owned by the farmer, (3) unequal socioeconomic context compared with other social actors such as public institutions, agricultural companies and urban population, and (4) unpaid family labour for the agricultural activities (Kearney, 1998; Castillo, 2018; Chayanov, 1974; Wolf, 1995).

However, economic investments are lower than those of large-scale farms. Their labour source is a mixture of unpaid family labour and agricultural workers receiving a wage (González-Cambrero, 2014).

Some studies have analysed the differences among Mexican farmers in relation to the type and aim of production (self-sufficiency or sales) (Appendini & Liverman 1994; Eakin et al., 2014), and the differences among regions (Appendini 2009; Eakin et al., 2014; Sweeney et al., 2013). Farmers who focus on self-sufficiency achieve lower crop yields than farmers who focus on selling their harvest (Eaking et al., 2014). Harvest losses are larger for farmers with social land and rainfed systems than for farmers with private land and irrigated systems (Appendini & Liverman, 1994). Another study (Sweeney et al., 2013) shows the different dynamics among regions that took place between 1980 and 2010 in the agricultural sector. Irrigation increased largely in the north and west with resultant high crop yields and remained very low in the south where rainfed systems persist with very low crop yields (Sweeney et al., 2013). Buyers of the produce also differ among regions: farmers in the south (Chiapas) sell their harvest to family members or people who come to their community, whereas farmers in the west (Sinaloa) sell their harvest to commercial warehouses (Eakin et al., 2014)

Thus, maize production in Mexico is an example of a strong diversity of agricultural production systems, with multidisciplinary implications and problems due to differences in their social, economic and production characteristics.

The aim of the present paper is to seek insights into the social, economic and technological characteristics and implications of maize production systems in Mexico by means of an integrated and interdisciplinary analysis at a national scale. To do this, we use data from a farm-scale survey of farmers representative of the entire country. We discuss differences among three types of agricultural systems (small-, medium- and large-scale) at a national-scale; and explore whether these characteristics deviate throughout the country at a state scale.

DATA AND METHODS

A national-scale analysis used microdata from the Mexican Agricultural Survey of 2014 (INEGI, 2014); the microdata were accessed and processed at the microdata laboratory of INEGI in Mexico City. The sample comprised 29,329 maize growers who had been included in a nationwide survey of farmers. From this sample, we selected the small-scale, medium-scale and large-scale farms (Table 1). The survey (INEGI, 2014) grouped the farms into 6 strata in relation to the planted cropland per farm. This classification was used to select the farms for the present analysis as follows. The small-scale farms were in stratum 1 (<2 ha per farmer), the medium-scale farms in stratum 3 (5-10 ha per farmer), and the large-scale farms in stratum 6 (>50 ha per farmer). The farms of strata 2, 4 and 5 were excluded from the analysis in order to accentuate the differences among the three scales.

Twelve production variables were selected as proxies for the socio-cultural, the technological,

Table 1. Sample of farms used in this study to characterize the 3 maize production systems: small scale, medium scale and large scale.

Maize production system based on cropland area per farm	Number of farms	Planted area (ha)	Production of maize (ton/year)
Small scale (<2 ha/farm)	11,779 (40%)	14,032 (5%)	27,391 (2%)
Medium scale(5-10 ha/farm)	5,607 (19%)	39,301 (13%)	121,466 (7%)
Large scale (>50 ha/farm)	1,242 (4%)	146,765 (48%)	1,162,596 (66%)

The percentage values refer to the total share of farms, planted area and production of maize respectively of the total sample of farms reported by the survey (INEGI, 2014). Calculations by the authors and the economic characteristics of the production systems (Table 2). These variables were used as proxies to identify and discuss the implications and differences of the three production systems (section 3.1-3.3). The national average value, for each proxy and for each system, was calculated with STATA software using the microdata of the survey in the Microdata Laboratory of INEGI, 2019. These values gave a national overview of the differences among systems. However, note that the sample of farms used to calculate these values included farms from all over the country with very different biophysical, socioeconomic and cultural contexts; these differences are explored in section 3.4.

In section 3.4, a state-scale geographical analysis is performed to discuss deviations throughout the territory of the national production variables of table 2 which were analysed in sections 3.1-3.3. ArcGis software was used to map the main variables of table 2. With this, we explore possible drivers and consequences of the deviations of the national trends.

RESULTS

Socio-cultural characteristics "aims of production"

Farmers use their maize production for their family's food self-sufficiency, or for their livestock, or for sales, or as seed for the following growing season, but a share of the production results as crop losses. The values are shown as a percentage of the total production, and in absolute values in annual tonnes produced per farm (Table 3). Small-scale

Table 2. Production variables as proxies to discuss the social, economic and production characteristics of the maize production systems.

Socio-cultural characteristics "aims of production"	Agricultural technology "production implications"	Economic characteristics "access to technologies and economic risks"
Use of maize: food self-sufficiency, feed for farmer's livestock, sales, seeds and loss	Crop yield (ton/ha)	Governmental programmes
Land tenure: Social (ejido or agrarian community), Private or Public	Rainfed or irrigated systems	Agricultural insurances
Type of seed: native or commercial	Agrochemicals use	Agricultural credits
Family labour	Labour requirement	Production costs

Table 3. National average production variables as proxies for the socio-cultural characteristics of the small-, medium- and large-scale maize production systems of Mexico.

	Use or fate of maize production in percentage [%] and in absolute values [annual tonnes per farm or per harvested area]				
Type of production system	Food self-sufficiency	Farmer's livestock	Sales	Seed	Crop losses
	share of the total production for each production system [%]				
Small scale	31%	23%	35%	2%	9%
Medium scale	5%	26%	63%	1%	5%
Large scale	0.1%	8%	89%	0.3%	2%

Table 3. Continue.

Absolute values of maize production per farmer or per hectare					
	[ton/farmer/year]			[ton/hectare/year]	
Small scale	0.7	0.5	0.8	0.04	0.19
Medium scale	1.1	5.6	13.7	0.08	0.44
Large scale	1.1	74.3	836.4	0.24	2.03
Land tenure [share of cropland with each type of land tenure in relation to the total land of each system]					
	Social (Ejido)	Social (agrarian community)	Social ("*colonia*")	Private	Public (Federal)
Small scale	63%	15%	0.3%	22%	0.4%
Medium scale	70%	5%	1%	23%	0.4%
Large scale	22%	1%	6%	70%	1%
Type of seed and labour					
	Native seed	Commercial seed (certified or "improved" seed)	Family labour (unpaid) from total workers		
	(share of planted area using native or commercial seed)				
Small scale	79%	21%	37%		
Medium scale	57%	43%	27%		
Large scale	8%	92%	3%		

farmers use similar proportions for food, feed and sale (23%-35%); medium-scale farmers use one-third of their production for sales, one-quarter as feed, and only 5% as food. Large-scale farmers use their maize production mainly for sales (89%), 8% as feed and only 0.1% as food.

However, the amount of maize for food self-sufficiency per farm is in the same order of magnitude for the three systems: 0.7-1.1 ton/farm/year, i.e. small-, medium- and large-scale farmers use a similar amount of maize for their family's food supply.

The share of maize used as feed for the farmer's livestock is relatively similar among small- and medium-scale farms, and lower for the large-scale farms. However, the absolute values show that the small-scale systems use only 0.5 ton/farmer/year of maize as feed which is one order of magnitude less than the use by the medium-scale systems (5.6 ton/farm/yr), and 2 orders of magnitude less than the use by the large-scale systems (74.3 ton/farm/yr).

The three systems differ more widely in the maize sold: the amount of maize sold per farm is three orders of magnitude greater in large-scale systems than in small-scale systems.

Farmers use a share of their maize production as seeds for the following growing season. Small-scale farms use as much as 9% of their production, in contrast to large-scale systems which use only 2%. But the differences are greater and opposed when the values are compared in units of seeds per hectare: large-scale systems use six times more seeds per hectare than do small-scale systems, and three times more seeds per hectare than do medium-scale systems.

The tenure can be social, private or public land. In general, small-scale farmers have social land, and large-scale farmers have private land (see introduction). This trend is shown in table 3 where 78% of a small farm's crop area is social land (*ejido,* agrarian community and *colonia*). However, a relatively large share of small-scale farms' cropland is private land (22%), and as much as 29% of large-scale farms' cropland is social land. These deviations from the trends are further discussed in section 3.4 and section 4.

The type of seed is an indication of the aim of production. Native seeds are generally used by peasants who have used it for several generations and have exchanged it with other communities resulting in genetic diversity of the crop (Altieri, 1999). In that way, the native seeds have adapted to the local biophysical characteristics of the region. In contrast, the commercial seeds are developed and sold by companies and are mainly used by large-scale production systems. In accordance with this trend, small-scale systems use mainly native seeds and large-scale systems use mainly commercial seeds (Table 3). However, a relatively large share of the planted area of either system diverts from this trend: 21% of the small-scale systems' cropland uses commercial seeds, and 8% of the large-scale systems' cropland uses native seeds.

The use of unpaid family labour is an indication of a type of "family structure" in which agricultural production strongly depends on the family members (Kearny, 1998). Therefore, the values of unpaid family labour of table 3 indicate strong differences in family structure among the three types of systems. For small- and medium-scale systems a large share of labour is done by unpaid family members (37% and 27% respectively). In contrast, only 3% of the workers in large-scale systems are unpaid family members. The common use of unpaid family labour in small-scale systems can be driven by two reasons. First, these farmers do not have enough money to pay wages. Second, agricultural labour for peasants is conceived as a family obligation associated with self-sufficiency rather than (only) as a paid job (Kearney, 1998).

Agricultural technology "production implications"

In general, small-scale systems use extensive agricultural technology and large-scale systems use intensive agricultural technology. The former includes low use of agricultural resources (irrigation, agrochemicals and machinery) and hence in low crop yields, and the latter includes high use of agricultural resources resulting in high crop yields.

The average national crop yield per hectare of small-scale systems (mainly rainfed) is one-quarter that of large-scale systems (mainly irrigated), and two-thirds that of medium-scale systems (Table 4). However, this trend is not clear in the use of agrochemicals. As expected, 92%, 90% and 86% of the large-scale systems' crop area uses fertilizer, herbicides and insecticides respectively. But small-scale systems use relatively large amounts of agrochemicals: a large share of the land of small-scale

Table 4. National average production variables as proxies for agricultural technology; their implications in the small-, medium- and large-scale maize production systems.

Maize production and agricultural inputs					
	Crop yield (ton/ha)	Rainfed area (% of total planted area)	Share of the total planted area that uses agrochemicals: Fertilizers	Herbicides	Insecticides
Small scale	2.05	85%	62%	56%	38%
Medium scale	3.49	77%	66%	65%	50%
Large scale	8.13	24%	92%	90%	86%

Labour requirements per planted crop area [workers per hectare]				
	None paid family labour	Permanent hired workers	Temporary hired workers	Total workers
Small scale	1.51	0.11	2.40	4.02
Medium scale	0.26	0.07	0.64	0.97
Large scale	0.01	0.07	0.26	0.35

systems uses fertilizers (62%), herbicides (56%) and insecticides (38%). Identification of the specific reasons for these differences is outside the scope of this paper. In general, the use of agrochemicals in these systems is driven by two interconnected processes: the political history of agricultural programmes, which have been changing in recent decades; and the farmers' need to increase crop yields in response to the low productivity of their land. In this paper, we shall focus on the first process: governmental programmes that support farmers. These programmes have generally subsidised the use of chemical fertilizers (either by giving the money to buy them or by distributing them directly to the municipalities). Governmental agricultural programmes change over time and vary by state, by the type of subsidy, and by type of farmer. For instance, in the last decade, the governmental programme PROAGRO was for medium and high productivity farms, whereas the programme PROCAMPO was for subsistence farms (SAGARPA 2019). These programmes give fertilizers or economic incentives to farmers depending on the number of hectares owned.

Low use of labour per hectare indicates that the system is mechanized to a larger extent than a system with a higher use of labour per hectare. Small-scale systems require 11 times more workers per hectare than large-scale systems, and 4 times more workers than medium-scale systems. Therefore, large-scale systems are highly mechanized compared with medium- and small-scale systems.

Economic characteristics "access to technologies and economic risks"

The economic characteristics of farmers are generally driven by their access to certain agricultural technology. Farmers who have access to governmental supports, agricultural credits and agricultural insurances usually have more intensive agricultural technology than do farmers without access to these three items. Also, production costs are an indication of the type of agricultural technology because intensive agriculture usually incurs higher costs for farmers than extensive agriculture, owing to the need for external inputs and management practices. Thus, in this section these variables are used as proxies to discuss the access and type of technology of the three systems and the economic implications.

The share of farmers who benefit from governmental programmes is more similar across the three systems than is the share requesting agricultural insurances and credits (Table 5). Our data source distinguishes between requesting and obtaining a credit or an insurance policy. For the three sys-

Table 5. National average production variables as proxies for the economic characteristics of the small-, medium- and large-scale maize production systems of Mexico.

Access to technologies and financing [share of total crop area of each system]					
	Governmental programmes obtained	Agricultural insurance		Agricultural credit	
		Requested	Obtained	Requested	Obtained
Small scale	58%	2%	93%	10%	77%
Medium scale	75%	10%	97%	22%	86%
Large scale	75%	57%	100%	62%	98%

Investment costs: tillage, sowing, management activities, fertilizer, pest and disease control, irrigation and harvest (labour is not included)			
	Total costs per hectare [MXN$/ha]	Total costs per tonne produced [MXN$/ton]	Selling price per tonne [MXN$/ton]
Small scale	$ 4,059	$ 2,079	$ 3,207
Medium scale	$ 4,660	$ 1,508	$ 3,187
Large scale	$10,774	$ 1,360	$ 3,049

tems, almost all farmers who requested insurance or credit obtained them, but the difference rested on whether the farmers made the request in the first place: only 2% of small-scale farms requested agricultural insurance, and 10% requested an agricultural credit, whereas 57% of large-scale farms requested an insurance policy and 62% requested a credit. This might be related to the different production strategies of the farmers; for the market-based strategy of the large-scale systems, agricultural credits and insurances could reduce the economic risks, whereas the peasant-based strategy of small-scale systems involves the diversification of economic income to reduce economic risk. In addition, governmental agrarian policies in recent decades have prioritised large-scale farming because the goal has been to strengthen agroindustry and focus on the market (Appendini 2014; Eakin et al., 2014).

Small-scale farmers have relatively comprehensive access to governmental programmes (58% in table 5). These programmes usually supply a fixed quantity of agrochemicals or degree of economic incentive based on the number of hectares per farmer (SAGARPA, 2019). Hence, the relatively large use of agrochemicals and commercial seeds (see table 4) could be related to these governmental programs.

Large-scale systems have 2.7- and 2.3-times higher production costs per hectare than small- and medium-scale systems respectively (table 5). However, small-scale systems have 1.5 higher production costs per tonne than large-scale systems. Hence, a tonne of maize produced in a large-scale system is cheaper than a tonne of maize produced in a small-scale system. Also, large-scale systems have a lower selling price (MXN $3,049 per tonne) than medium-scale (MXN $3,187 per tonne) and small-scale systems (MXN $3,207 per tonne). However, owing to the differences in production costs per tonne, large-scale systems earn more money per tonne (MXN $1,689 per tonne) than do systems with medium (MXN $1,679 per tonne) or small scale (MXN $1,128 per tonne). This gives large-scale systems a competitive advantage because they can sell their produce at a lower price and have larger gains than can medium- and small-scale systems. A contributory factor is the link of large-scale farms with large food-processing industries.

The investment costs are incurred at successive stages of the growing season. For each of the three production systems, the highest costs are incurred for fertilizers, land preparation and sowing, and the lowest costs are for irrigation, labour, pest and disease control and harvest (Figure 1).

Regional differences, their correlations and their deviations from national trends

States in the south and east have higher concentrations of small- and medium-scale farmers (Figure 2, yellow and orange), and states in the north and west

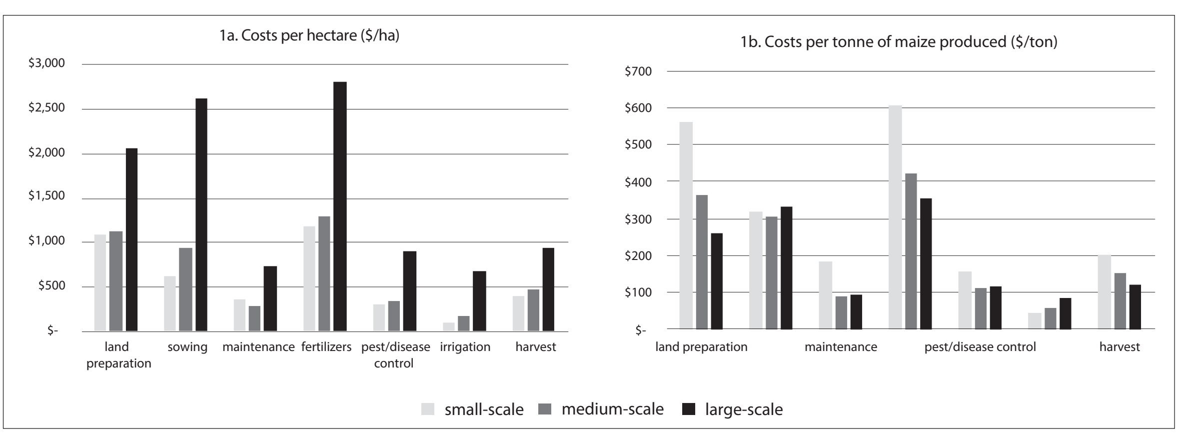

Figure 1. Costs of maize production per system and per management activity: (a) costs per hectare, (b) costs per tonne of maize produced.

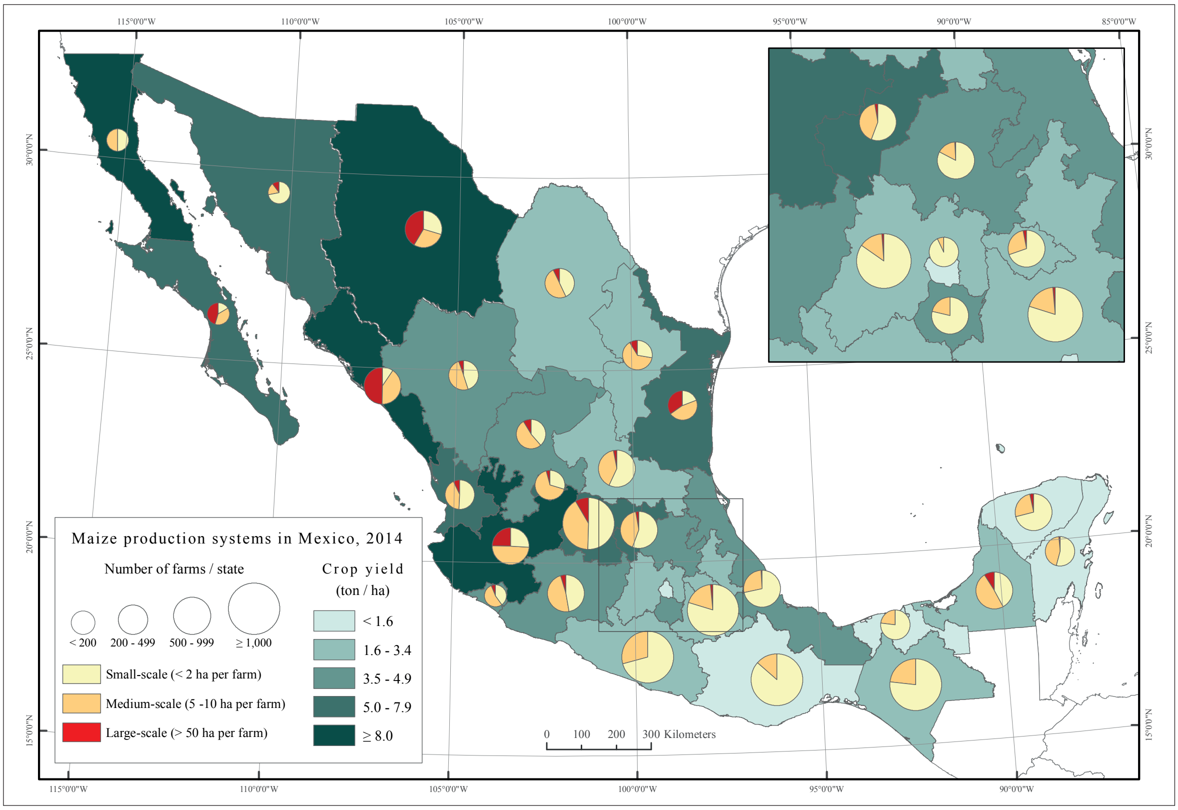

Figure 2. Geographical distribution of maize crop yields and production systems.

have higher concentrations of large-scale farmers (Figure 2, red). There is a clear correlation between crop yield and type of production system: crop yields are higher in states with a larger proportion of large-scale systems, and lower in states with a larger proportion of medium- and small-scale systems.

In small-scale systems the use of a large share of their production for self-sufficiency (54% for food and as feed for their livestock), and only one-third of the production for sale (table 3), is driven by their aims (self-sufficiency and diversification of economic activities) but also by the depression of yields by reliance on low-input rainfed systems (table 4). However, crop yields, degree of self-sufficiency and use of irrigation vary among small-scale systems across the country (Figure 3).

The productivity of small-scale farmers ranges from very low values (<1.6 ton/ha) in the states of the north and south-east, to high values (3.5-6.6 ton/ha) in the states of the centre and west of the country (Figure 3 and Table 6). Allocation of the maize between self-sufficiency and sales also differs: the farmers in the states that achieve high crop yields use a larger share of their production for sales, and the reverse occurs for the states that achieve only low crop yields. This does not mean that farmers retain less maize for self-sufficiency; on the contrary, they use the same or more maize for self-sufficiency, but they can sell a larger share of their production because they produce more maize. For instance, in Jalisco small farms achieve high crop yields (6.6 ton/ha) and the maize they reserve for self-sufficiency is a low proportion (47%) of the yield but a high amount (4.1 tonne per farm) in comparison with the proportions and amounts used in many other states (see table 6). Also, a clear relationship is shown between crop yield and the irrigation system: the states with larger crop yields generally have a larger proportion of irrigated land; note, however, that some states

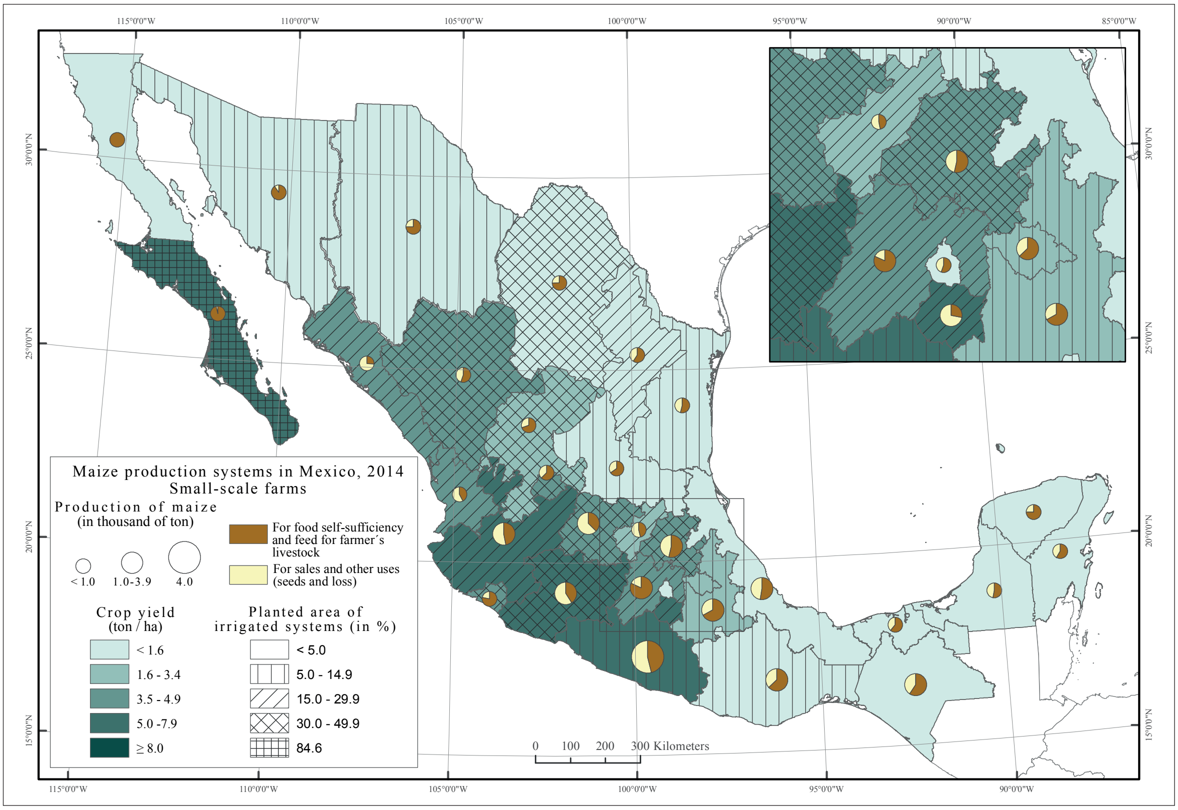

Figure 3. Maize yields, proportion for sale or self-sufficiency, and irrigation systems for small-scale systems. The jump from 49.9% to 84% in the scale of the planted area of irrigated systems is for convenience to show that "Baja California Sur" State has this value.

Table 6. Indicators of agricultural production of small-scale systems linked with average rainfall for each state and with indicators of welfare of the population.

	Crop yield	Self-sufficiency (food & feed)		Irrigation	Annual rainfall	Poverty	Annual Income per Household	
	[ton/ha]	[% of production]	[ton/farm]	[% irrigated cropland]	[mm]	[% of the population]	[MXN $/HH]	
Aguascalientes	2.8	62%	2.03	38%	535	28%	$	101,562
Baja California	0.8	100%	0.80	0%	85	22%	$	115,384
Baja California Sur	7.4	96%	6.41	85%	335	22%	$	110,028
Campeche	1.4	53%	0.90	3%	1,390	44%	$	97,828
Coahuila	1.3	74%	0.94	39%	424	25%	$	107,237
Colima	2.4	79%	2.57	30%	1,920	34%	$	102,373
Chiapas	1.3	59%	0.88	1%	2,056	77%	$	48,947
Chihuahua	1.3	75%	1.41	9%	490	31%	$	87,395

Table 6. Continue.

	Crop yield	Self-sufficiency (food & feed)		Irrigation	Annual rainfall	Poverty	Annual Income per Household
	[ton/ha]	[% of production]	[ton/farm]	[% irrigated cropland]	[mm]	[% of the population]	[MXN $/HH]
Ciudad de México	0.7	55%	0.76	1%	616	28%	$ 145,153
Durango	2.4	56%	1.90	31%	497	36%	$ 75,846
Guanajuato	3.3	37%	1.36	34%	679	42%	$ 77,986
Guerrero	3.6	46%	2.03	10%	1,224	64%	$ 61,068
Hidalgo	2.5	54%	1.25	48%	755	51%	$ 74,504
Jalisco	6.6	47%	4.10	24%	982	32%	$ 102,652
México	2.9	82%	1.75	24%	885	48%	$ 84,285
Michoacán	3.6	41%	1.73	34%	885	55%	$ 67,513
Morelos	4.5	28%	1.16	16%	1,778	50%	$ 76,670
Nayarit	2.9	43%	1.59	19%	1,293	38%	$ 88,073
Nuevo León	1.4	59%	0.95	28%	683	14%	$ 129,551
Oaxaca	1.1	63%	0.76	7%	1,186	70%	$ 54,343
Puebla	1.7	67%	1.02	14%	1,303	59%	$ 63,008
Querétaro	1.8	47%	0.85	23%	773	31%	$ 104,871
Quintana Roo	0.5	58%	0.32	2%	1,358	29%	$ 102,891
San Luis Potosí	0.9	65%	0.52	12%	808	46%	$ 74,597
Sinaloa	2.8	26%	0.97	27%	876	31%	$ 98,426
Sonora	0.6	90%	0.75	6%	481	28%	$ 116,952
Tabasco	1.3	61%	0.81	0%	2,394	51%	$ 78,783
Tamaulipas	1.0	54%	0.70	10%	955	32%	$ 94,930
Tlaxcala	1.7	63%	1.08	7%	885	54%	$ 65,015
Veracruz	1.6	53%	0.82	4%	1,537	62%	$ 65,427
Yucatán	0.8	75%	0.77	3%	1,148	42%	$ 91,887
Zacatecas	1.8	69%	1.47	39%	534	49%	$ 69,480

Source of data: (1) crop yields, self-sufficiency and irrigation: calculations from the authors. (2) Annual rainfall: average annual rainfall per year in 2014 from SMN (2014), (3) Share of the state's population in poverty (values of 2016), and (4) average income per household (HH) per state in 2014, values are given in US dollars constant from 2010 (INEGI, 2016), they were converted to Mexican pesos with an average annual exchange rate of 13.29 MXN per US dollar.

deviate from this pattern (see for instance the Baja California peninsula).

The low crop yields could be associated with climatic and biophysical conditions of the terrains. Table 6 shows the average annual rainfall of the state and two indicators of socioeconomic development and welfare: income per household and share of the state's population who live in poverty.

As expected, in the states with low rainfall farms achieved low crop yields (e.g. Sonora, Chihuahua and Coahuila). However, yields were also low in some states with high rainfall (e.g. Tabasco, Oaxaca and Chiapas); these have the lowest income per capita and high poverty levels. In contrast, some states with low rainfall achieved high crop yields because a large share of their cropland is irrigated; note that these states have high average income and low poverty values (e.g. Baja California). Hence, several environmental and socioeconomic factors drive the differences among small-scale farmers throughout the country.

At a national scale, medium-scale systems show values in between small- and large-scale systems in relation to the use of their harvest (see table 3), which indicates a transition system from self-sufficiency to market-based systems. The differences in production variables between medium-scale systems (Figure 4) and small-scale systems (Figure 3) illustrate the regional diversity of differences between small- and medium-scale systems.

Medium-scale farmers set aside a larger proportion of their harvest for sales than do small-scale farmers, although with regional variations in this trend. Like small-scale farmers, medium-scale farmers achieve higher crop yields in the western states, where a higher proportion of their lands are irrigated. However, in contrast to small-scale farmers, medium-scale farmers also achieve higher crop yields in eastern states, particularly in Veracruz and Tamaulipas. The high yields in Veracruz despite the small proportion of irrigated area might be related to climatic conditions, since Veracruz has a wet climate (table 6). Also, whether medium-scale farmers use their harvest for self-sufficiency or for sale is not directly related with the value of the crop yield, whereas this relationship was a clearer trend for small-scale systems (figure 3). For instance, farmers in Jalisco and Veracruz achieve similar crop yields, but Jalisco farmers use two-thirds of their harvest for sales, and Veracruz farmers use more than three-quarters for self-sufficiency. The maize used to maintain self-sufficiency for the Veracruz

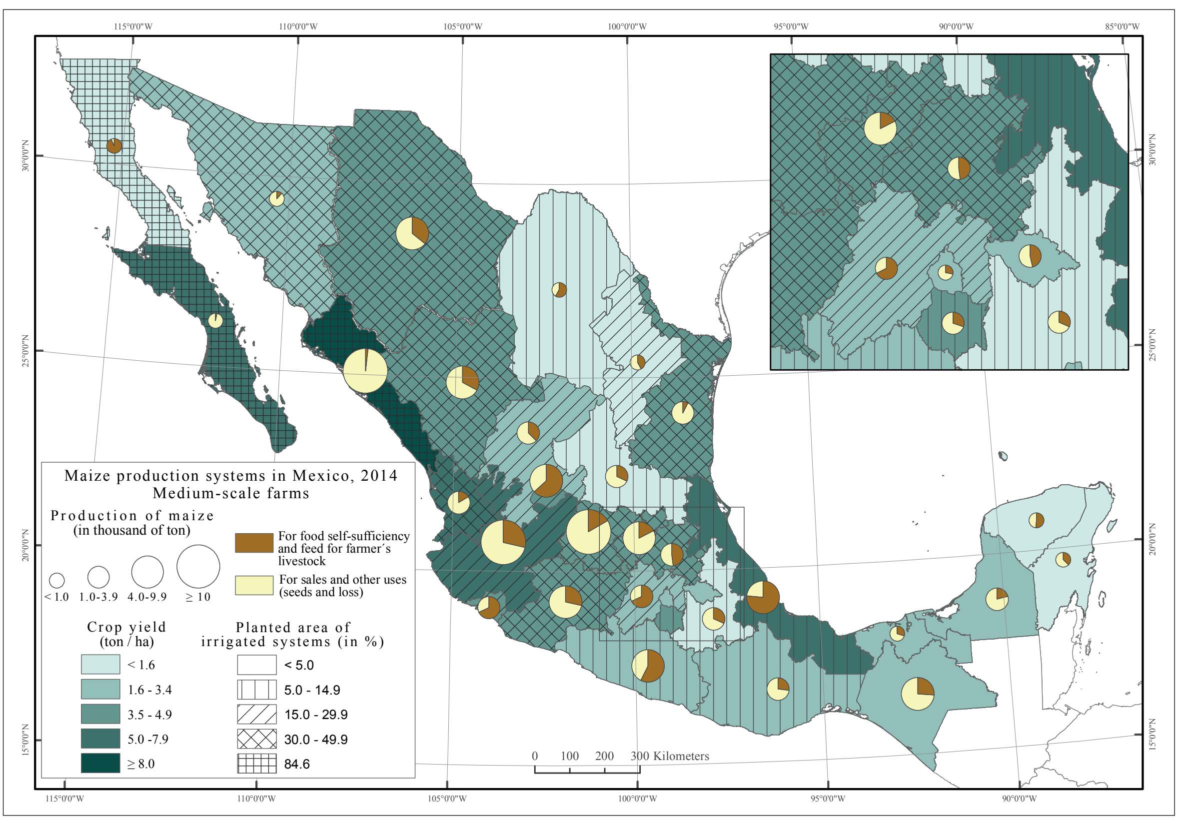

Figure 4. Maize yields, proportion for sale or self-sufficiency, and irrigation systems for medium-scale systems.

farms might be mainly for livestock, reflecting the national trend (Table 3). These different trends suggest a different economic strategy.

Whereas most of the maize land in small-scale systems is under social tenure and is rainfed, most of the maize land in large-scale systems is privately owned and is irrigated (Figure 5, tables 3 and 4). Nevertheless, a relatively large proportion of the large-scale systems is social land (22%) and rainfed (24%). In general, large-scale systems with ejido land tend to have a larger proportion of irrigated land (Tamaulipas, Sinaloa and Chihuahua). This suggests two hypotheses that should be analysed in detail in further research: first, that in the southern states, the relatively large proportion of rainfed systems is driven by their plentiful rainfall (table 6), in comparison with the rainfall in the central and northern states; and second, that social land involves a high degree of participation and collaboration among farmers and that this cooperation can attract more funding or governmental support for irrigation infrastructure than can individual farmers.

The analysis in section 3.3 showed a clear difference in the investment costs among the three systems. Large-scale systems have higher costs per hectare, but lower costs per tonne and lower selling price per tonne of maize compared with medium- and small-scale systems (table 5). We then combined the data for all three systems in each state (Figure 6).

Three patterns can be identified: (1) the states in the south have low crop yields, low costs per hectare and a high selling price per tonne, (2) the states in the north have high crop yields, high costs per hectare and a low selling price per tonne, (3) the states in the west have high crop yields, high costs per hectare and a medium selling price per tonne. The states in the east and west peninsulas are not considered here because the sample size was

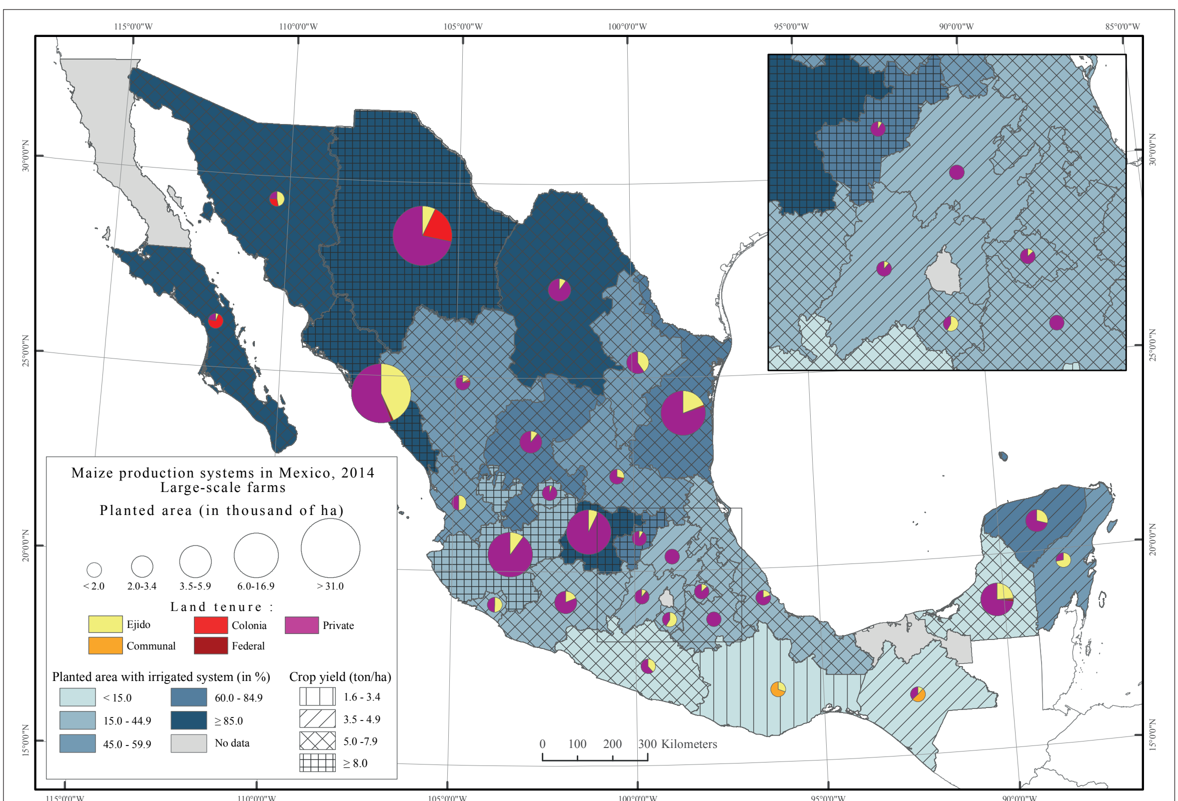

Figure 5. Land tenure, irrigation and productivity of large-scale systems.

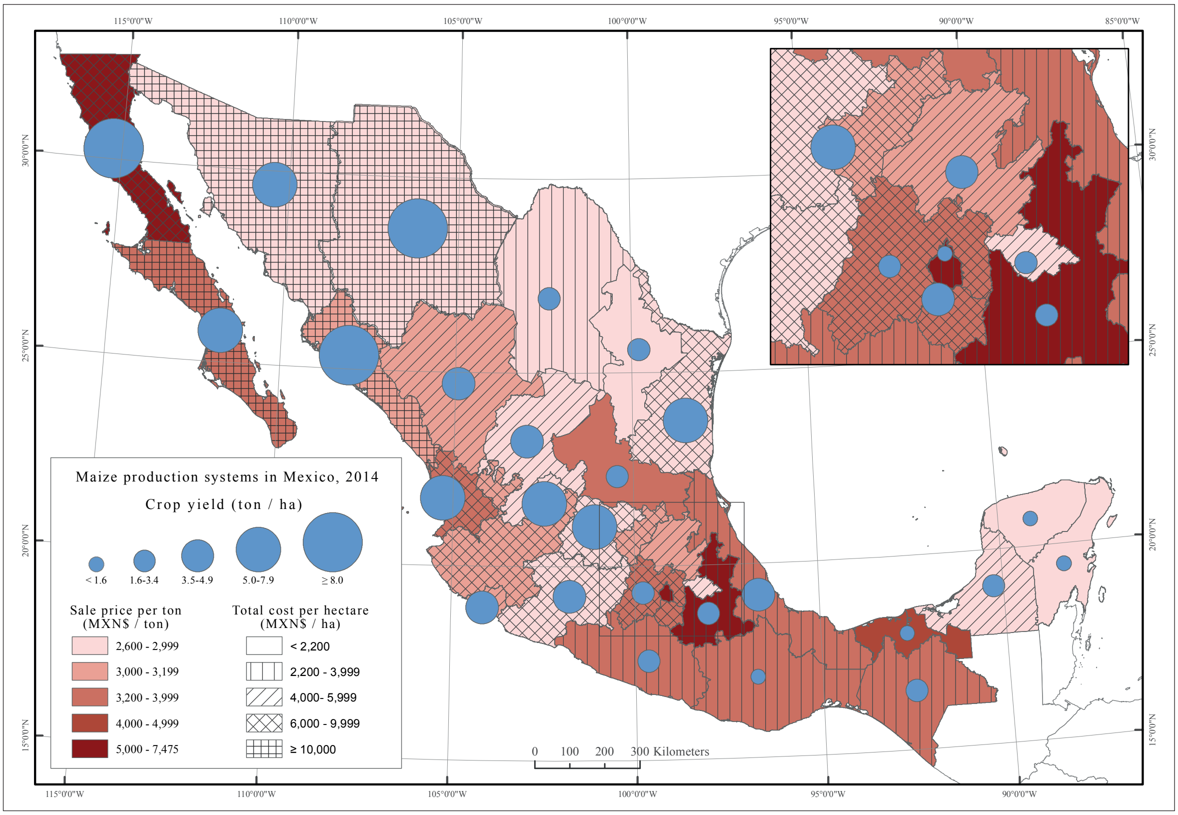

Figure 6. Price per tonne, costs per hectare and crop yields for all maize production systems in each state.

low in these regions (Baja California and Yucatán peninsulas).

DISCUSSION

Small-scale systems reflect the subsistence peasant's aim of production which focuses mainly on food self-sufficiency; family labour is common, native seed is sown, rainfed systems are used, production costs per hectare are low, and social land tenure is common (tables 3-5). In contrast, large-scale systems have a market-based aim of production for which the maize produced is mainly sold in the market, they achieve high crop yields with irrigated systems and agrochemicals, private land tenure is common, and they have high investment costs per hectare, and use agricultural insurance and credits (tables 3-5). The medium-scale systems show values in between the large- and small-scale systems. These differences between small- and large-scale systems support earlier reports on maize growing in Mexico: that self-sufficient farmers achieve lower yields (Eakin et al., 2014), and use rainfed systems and farm social land (Appendini & Liverman, 1994) whereas market-based farmers tend to use irrigated systems on private land.

However, the results also showed deviations from these characteristics which are usually intrinsic of these aims of production. The use of agrochemicals is relatively high for small- and medium-scale systems even though the aim of peasants generally relates production with extensive low-input systems. This might be related to the influence of governmental programmes which include the supply of fertilizers or economic incentives to farmers. No clear distinction among the three systems was found in relation to the receipt of governmental programmes (table 5). However, this study did not distinguish among the types of governmental programme that each system receives. Further research should analyse in detail the type of programme to ascertain the different governmental supports for small-, medium- and large-scale systems.

Irrigation is usually used in intensive agriculture, but in contrast to the use of fertilizers, irrigation needs infrastructure which involves high and long-term investment costs compared with the use of fertilizers which is an investment over a single crop season. The use of irrigation is much lower in small-scale systems than in medium- and, especially, large-scale systems (table 4). This might be driven by two issues: (1) irrigation systems involve high investment costs, (2) government support for irrigation in the last decades has focused on the north and west of the country (Appendini, 2009; Sweeney et al., 2013). Nevertheless, not all small-scale systems have rainfed agriculture: 15% of the land of small-scale systems is irrigated and, surprisingly, as much as 24% of large-scale systems have rainfed crops (table 4). Geographical deviations from this trend (figure 3 and 4, and table 6) showed that several drivers such as climate (rainfall), socioeconomic situation (income and poverty) and governmental support for specific regions (Appendini, 2009) are associated with the crop yields achieved by farmers. Therefore, further research is required at a local scale to identify how these drivers affect agricultural production.

The states with a larger share of social land (figure 5) achieve higher crop yields and have a larger proportion of irrigated agriculture. Possible reasons are: (1) on social land, collaboration and organization among farmers is high and, therefore, they are able to obtain support from the government or other agricultural agencies for irrigated infrastructure; (2) subsidies for irrigation have focused on the states of the north and west (Appendini, 2009), states where there is now the trend for a larger irrigation area; and (3) large-scale farmers rent several parcels of social land and therefore their land tenure is social land.

The states in the south have less potential for commercialization than the states in the west and north because of the higher selling prices (Figure 6), but their economic risks are lower as a result of the lower costs per hectare.

Limitations of the study and needs for further research

This study gives insights into the national trends and differences in the spectrum of maize production systems. However, within each system differences arise through local biophysical, social and cultural contexts. Further studies at a local scale are needed to identify the causes and consequences for the farmers.

Furthermore, in order to characterize the different types of system, we have not used the whole sample of the national survey. Farmers who have 2–5 ha or 10–50 ha were not considered in the analysis. Further studies with a different type of data source are needed to corroborate our results.

CONCLUSIONS

Analysis of the diversity of maize production systems in Mexico has shown the influence not only of geography (e.g. climate) but also of the farm characteristics and contexts. Three main topics were analysed: (1) sociocultural characteristics – land tenure, use of maize (for self-sufficiency or sales), and type of labour; (2) technological characteristics – productivity, irrigation, use of agrochemicals, and requirement of labour, and (3) economic characteristics – governmental programmes, insurance policies, credits and production costs.

Our results give insights into the main drivers and implications of the small-, medium- and large-scale maize farms at a national and state level. The results show the need for an interdisciplinary and multi-scale approach to the interconnections of the biophysical, political, economic and sociocultural conditions that define the agricultural production systems. Furthermore, further studies at a local scale are required to investigate apparent deviations from the trends reported in the literature.

Political strategies and state programmes are critical in the ongoing development of agricultural production systems. Our analysis of data regarding the production of maize in Mexico demonstrates the need, in similar countries and with various crops, to design these programmes with an interdisciplinary approach; this should be context-specific in order to move towards a more sustainable and equitable food system that will produce enough food for everyone and assure the wellbeing of rural areas.

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Access in 2019 to micro-data for analysis with project LM-530 at the Microdata Laboratory of INEGI [Patriotismo 711 torre A-PB, San Juan, 03730 Mexico City]. The conclusions and opinions of this study are the responsibility of the authors and they are not part of the statistics or official positions of INEGI.

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