Identification of Patterns of Farm Equipment Utilization in Two Agricultural Regions of Central and Northern México

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Abstract. Using a descriptive approach, a study of the dynamics of farm mechanization was performed in the agricultural regions of Delicias, Chihuahua and La Begoña, Guanajuato, México. The study was aimed at identifying patterns of farm equipment utilization through multivariate analyses of relevant data. A total of 135 farmers were interviewed, along with 21 extension agents and 22 farm machinery dealers. A mechanization index was developed to characterize the mechanization level of individual farmers. The methodology used for pattern definition was based on dimensionality reduction through principal component analysis. Three principal components were subjected to hierarchical clustering in order to assemble respondents into groups. Five distinct groups of farmers were identified in Delicias and four in La Begoña. Each group featured a unique combination of characteristics for which the use of farm equipment was well differentiated, including subsistence, and various forms of commercial agriculture.

Results suggest that most farmers in the two regions have access to relatively large amounts of tractor power and other mechanical inputs through a diverse set of mechanisms. The proposed mechanization index relates actual mechanical work expenditure to mean regional values. The index was derived for each farmer from descriptions of farm operations obtained by survey. The mechanization index integrated values for all crops grown during a single season using area-weighted averages. The mechanization index has the potential to be used in establishing optimal levels of mechanical inputs where adequate productivity information is available.

Keywords. México, mechanization, farm equipment, farm power, principal component analysis

Introduction

Starting in the early 1930's, México embarked on a Land Reform project that shaped its agriculture in every imaginable aspect. In a unique way, rural México developed new political and socioeconomic structures that allowed the coexistence of private and communal land ownership. Land reform brought in technological change to a significant extent. Mechanization was the prime national policy meant to

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foster grain production, especially by the recently created Ejido[1] base. The results of such mechanization programs have been deeply criticized but the real issue of the net benefit to México with increased mechanization has not been fully explored.

Better knowledge of the past and present is a key component for the improvement of the planning process that will impact México's agricultural sector in the years to come. Findings from this and similar studies can be used to set new directions for the analysis of the technological status of Mexico's agriculture. This is particularly important in light of recent government policies of deregulation of Mexico's farming sector. In this paper special attention is paid to mechanical inputs.

The biggest challenge for the research work reported here was dealing with the complexities found in the dynamics of farm production in México. In addition, significant regional variation was known to exist. For the purposes of the present study, it was rationalized that there were groups of households that could be segregated according to their demographic, technological, economic, and societal features when farm mechanization is considered a key technological feature.

It is important to point out that this study was focused on establishing an orderly association between mechanization and multiple factors, but it was beyond the objectives to suggest causal relationships among them. Also it should be mentioned that the results of the two regions studied were constantly contrasted but treated separately without a structured analytical comparison.

Analytical Framework

The main framework of the analysis was the transformation made on information from rural households when these data sets were subjected to statistical procedures of dimensionality reduction. The natural association of observations created clusters that were clearly differentiated on this low-dimension representation. Careful examination of the original variables within each cluster provided a way to establish patterns of farm equipment utilization along with similar socio-economic and demographic conditions shared by the member households within each cluster.

At the core of the statistical analysis was a multivariate procedure that yielded artificial variables known as principal components (pc's). A geometric interpretation of pc's comes from visualizing a family of concentric orthogonal ellipsoids centered on the sample center of gravity. The pc scores will be the projections of the observations on the principal axes of this family (Gnanadesikan, 1977). Following is a description of Principal Component Analysis in terms of matrix algebra:

$$[Y] = [X]\,[B]^T + [E] \qquad (1)$$

where:
[Y] is a n X p matrix of raw data with n number of observations and p number of variables
[X] is a n X p matrix of principal components scores (all pc's included)
$[B]^T$ is the transpose of the p X p eigenvector matrix
[E] is a n X p matrix of residuals

[1] Ejido is an agricultural production system with state ownership of land

To decompose [Y] it is necessary to perform eigen analysis of the covariance matrix [Z] :

$$[Z] = [Y]^T [Y] \qquad (2)$$

The following constraint is constructed:

$$[\lambda] = [B]^{-1} [Z] [B] \qquad (3)$$

where:

$[\lambda]$ is a p X p diagonal matrix of eigen values

Principal Component Analysis (PCA) yields a matrix of p number of perfectly independent vectors (pc's). The procedure sets as the first pc that accounting for the most variation, i.e. the axis with the longest range. Dimensionality reduction can be achieved by selecting only the first j number of pc's. This would change the size of the matrices [X] and $[B]^T$ to n X j, and j X p respectively.

Materials and Methods

A questionnaire was prepared to interview samples of households selected at random from two agricultural regions of México. The locations selected were Delicias and La Begoña in Northern and Central México respectively (see Figure 1). Both regions are actual irrigation districts with significant diversity in the crops grown. Soils in the Delicias area are typical of desertic climates whereas in La Begoña the climate is more humid and soils are deep and fertile. The dairy industry is of prime importance in the two regions. Known by their name in Spanish "*Cuencas Lecheras*", these areas have well defined boundaries set by physiographic features.

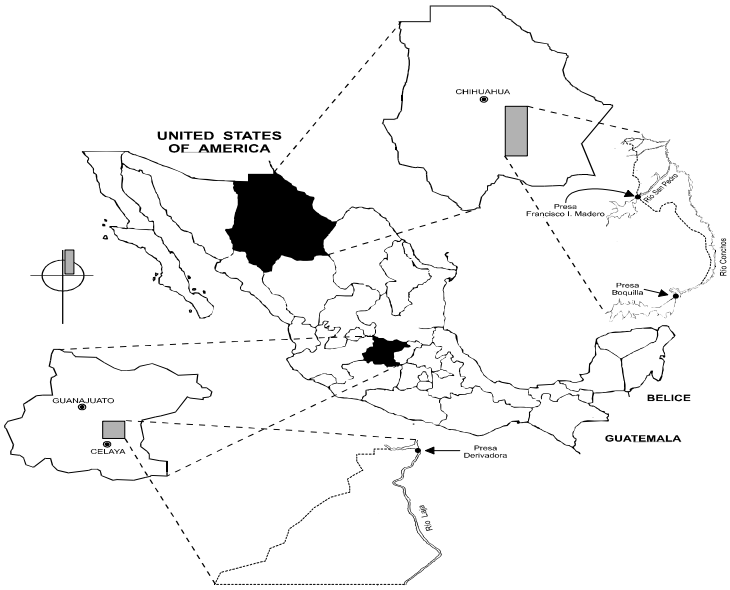


Figure 1. Location of the two regions studied. Delicias, Chih., and La Begoña, Gto. México

Statistical Analysis

Table 1 presents a summary of 27 variables that were generated from the information collected from 60 households in Delicias and 75 households in La Begoña. The interview process also included an inventory of the major pieces of farm machinery that belonged to each household as well as a brief description of the farm soil type and condition. SPSS v. 7.5 (1996) was used to systematically explore the degree of association between mechanization indicators and the rest of variables through one-way ANOVA (Analysis of Variance), linear regression ANOVA and Pearson's Chi-square tests.

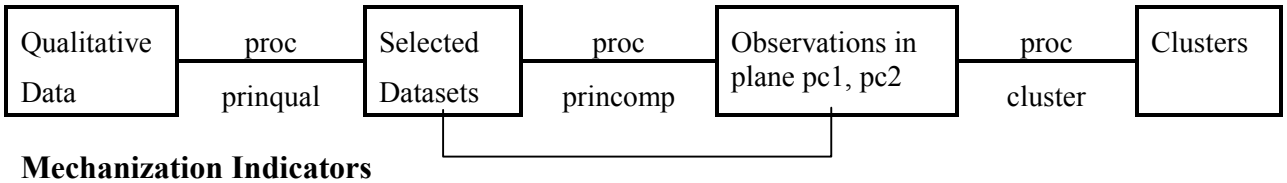
Table 1. Summary of variables incorporated into multivariate analyses.

Variable Description	Variable Type and Units	Source / Computation
Total Farm Land Ownership	continuous (ha)	questionnaire entry
Total Farm Land Leased	"	"
Total Land Cultivated	"	"
Type of Land Ownership	dichotomy (ejido/private)	"
Storie Index of Soil Quality [1]	continuous (0-1 score)	computed from inventory
Crop Diversity Index [2]	continuous (unitless)	"
Total Rated Power Available [3]	continuous (kW)	estimated from inventory
Overall Condition of Tractor(s)	categorical (1-5)	assigned from inventory
Total Weight of Implements [4,5]	continuous (kg·f)	estimated from inventory
Total Number of Implements [5]	continuous (number)	count from inventory
Overall Condition of Implements [5]	categorical (1-5)	assigned from inventory
Number/Weight of Implements Ratio	continuous (number/kg·f)	estimated from inventory
Mechanized/Total Operations Ratio [6]	continuous (unitless)	computed from questionnaire
Share of Contracted Operations [6]	"	"
Mechanization Index [6,7]	"	"
Age of Head of Household	continuous (years)	questionnaire entry
Education of Head of Household	discrete (years)	"
Average Education of Siblings	discrete (years)	"
Family Size of the Household	discrete (number)	"
Diversity of Income-Generating Activities	"	"
Membership to Work-related Associations	"	"
Political Participation of Head Household [8]	categorical (1-3)	"
Mechanism for Machinery Acquisition [9]	categorical (1-3)	"
Head of Household Native to Area	dichotomy (yes/no)	"
US Migration of Members of Household	dichotomy (yes/no)	"
Current Use of Land [10]	categorical (1-3)	"
Source of Finance for Farming Operations [11]	categorical (1-3)	"

[1]Storie, 1959 [2]Strout, 1975 [3]based on advertised rated power [4]based on average weight of implement specifications
[5]data broken in categories of tillage, cultivation, and harvest implements [6]land-weighted values [7]see page 5
[8]community, regional, state level [9]own funds, mechanization program, dealer credit [10]not farmed, rented, sharecropping
[11]own funds, informal credit, formal credit

These data sets were subjected to statistical analysis using different procedures of SAS software v. 6.12. (1990). Qualitative variables were transformed to principal component scores suitable to be

joined with the continuous variables and then be subjected to PCA. This step was systematically repeated several times with the intention of identifying and removing from the analysis variables that showed very low contribution to the total variation in the whole system, i.e. very low correlation with the first three pc's. Once a data set was selected then Cluster Analysis was performed on the scores of the first two principal components. The following flow chart illustrates the process and SAS procedures used:



Mechanization Indicators

A part of the present study was the formulation of an index to measure the mechanization status achieved at the individual level. The Mechanization Index (MI) elaborated here is an expression of the deviation of the actual amount of motorized farm work from the normal values at the regional level. This index is based on the premise that a mechanized farmer is the one that finds a way to utilize amounts of mechanical energy that are higher than the typical values using locally available technology. It is implied that these technologies are mechanized agricultural practices that have been successfully incorporated into the farming systems. During the interview, data was recorded on all the mechanized operations performed by farmers in the sample providing an estimation of the field capacity (hrs of work per unit land). Field capacity was multiplied by rated power so the quantification of energy expenditure was made in work units (kW-h). The regional normal was obtained after compiling a full dataset of all respondents and then it was defined the mode for the number of passes for each operation as well as the mode in tractor size and field capacity. Following is the mathematical description of the MI:

$$MI_a = \sum_{i=1}^{n} \left(ER_{a,i} \times \frac{L_{a,i}}{TL_a} \right) \qquad (4)$$

where:
MI_a = Mechanization Index for farmer, a
$ER_{a,I}$ = Ratio of applied/regional-normal energy ratio of farmer, a; for crop, i
$L_{a,I}$ = land cultivated by farmer a with crop, i
TL_a =Total land cultivated by farmer, a

The present report also includes the computation of several other indicators of mechanization that are useful at a larger scale (from regional to national). Table 2 provides a summary of these.

Table 2. Indicators of mechanization status at the regional and national level

Mechanization Indicator	Description/computation
Rated power per unit land	Computed from survey information in sample of respondents
Number of tractors per unit land	"
Weight of implements per unit land	"
No. of implements per unit land	"
Realized Mechanization Potential (RMP)[1]	Ratio of mechanized / mechanizable operations by crop by region
Machinery Utilization Ratio[2]	Ratio of estimated work units expended / potential energy available
Pawlak's Mechanization Index[3]	Ratio of energy used in manufacture and operation of machinery (E_m) / E_m + energy input to agriculture from animate sources (E_a)
Pawlak's Technical Advance Index[3]	Ratio of E_m + energy embedded in fertilizer (E_f) / $E_m + E_f + E_a$

[1]Chang and Chancellor, 1985 [2]potential work = total rated power * efficiency * average yearly use in hrs. [3]Pawlak and Esmay, 1986

Interview with Dealers and Extensionists

Twenty-two machinery dealers and 21 extension agents were also questioned on issues regarding status of farm mechanization in their regions of influence. No statistical analyses were performed on their responses. These questionnaires were meant to gather knowledge on the prevailing perceptions from influential individuals on topics like: current status of farm mechanization, constraints and mechanization-inducing factors, type and size of most suitable farm equipment, farmer's preferences regarding use of equipment, appraisal of past mechanization programs, future expectations, etc.

Results and Discussion

Statistical Analysis

The selection process indicated that in the Delicias data set only the variable "Land Use" had no significant contribution to the overall variation, while the variables "Political Participation" and "Migration" were removed from the La Begoña data set for the same reason. Figures 2 and 3 show the end result of the multivariate procedures in which there were distinguished five and four groups of households for the data sets of Delicias and La Begoña respectively. By visual inspection of the eigen vectors of the two principal components that form the axes of figures 2 and 3, it was noted that pc1 indicated the degree of capital formation as well as how technically advanced were the households because it was strongly associated with variables such as "Total Land", "Rated Power", and "Number-Weight Implement Indicators". In the same way, it was noted that pc2 was sensitive to variables related to age, size of household, educational levels, and association levels which are mainly socio-demographic components. Table 3 is a summary of the main features found for each group after the membership of all respondents was identified.

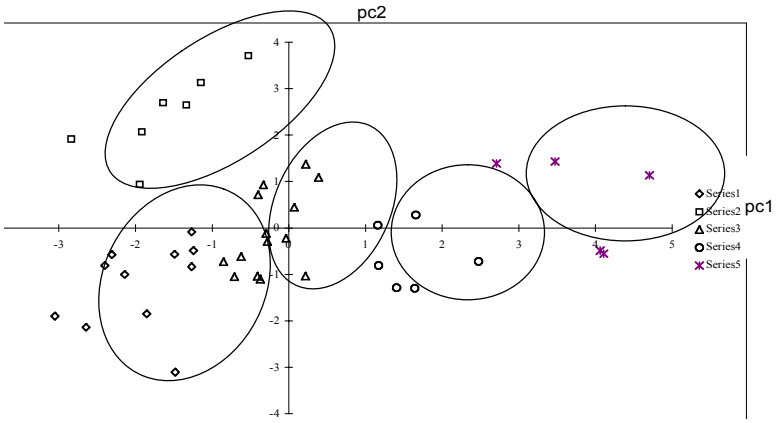


Figure 2. Clustered observations on plane pc1 (horizontal), pc2 (vertical). Delicias data set

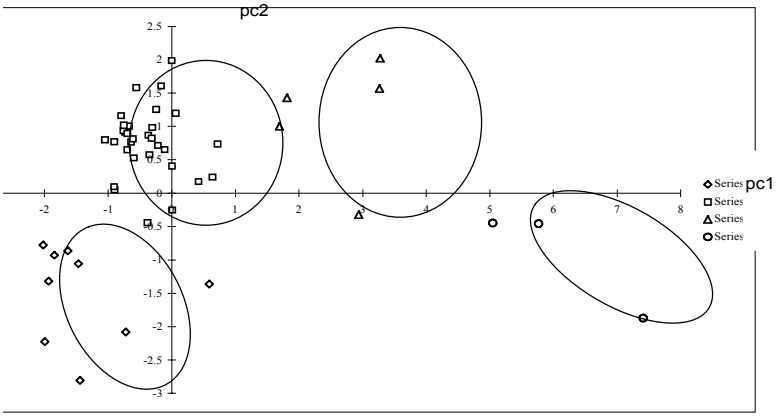


Figure 3. Clustered observations on plane pc1 (horizontal), pc2 (vertical). La Begoña data set

Table 3. Description of main features found in groups of households from survey data.

Group	Technical Component	Economic Component	Socio-Demographic Component	Political Component
Delicias:				
1	Small farm size with soil of regular quality. One crop a year. No farm equipment; 82% c-h dependent. MI = 0.60	Financed with own funds. Farming is the only income generating activity.	Barely literate head of the household; siblings with little education. Medium-size family. 26% of sample	Ejidatario. Not politically involved Not members of collective groups for work purposes.
2	Small farm size with soil of poor quality soil. Two crops a year. Scarce equipment; 59% c-h dependent. MI = 0.70	Financed with informal credits. Two different income generating activities.	Illiterate head of hhd; siblings with little education. Large family w/ US migration. 16% of sample	Ejidatario. Not politically involved Not members of collective groups for work purposes.
3	Medium farm size. Regular quality of soil with multiple crops/year. Usually one medium-size tractor/basic implements; 36% c-h dependent. MI = 0.87	Financed with own funds. Two different income generating activities. (provides forage harvest c-h services)	Medium degree of education; fairly educated siblings. Medium-size family. No US migration 33% of sample	Both ejidatarios and private landholders. Not politically involved Not members of collective groups for work purposes.

4	Larger landholdings. Regular quality of soil Multiple crops a year. Availability of tractors and implements; contracts grain harvesting only. MI = 0.99	Financed with own funds. Two different income generating activities. (net providers of c-h services).	Medium degree of education; fairly educated siblings. Medium size family No US migration 14% of sample	Private landholders. Not politically involved. Members of cooperatives for supply of farming inputs.
5	Largest landholdings. Good soil quality with prominent use on multiple cropping. Availability of all kinds of farm equipment. MI = 0.96	Financed with formal credit. Two different income generating activities (do not provide c-h services).	Medium degree of education; highly educated siblings. Medium-size family. No US migration. 11% of sample	Private landholders. Not politically involved Members of cooperatives for both inputs supply and marketing.

La Begoña:

1	Small farm size. Good soil quality; usually one crop a year with 65% mechanized operations; Customary sharecroppers. No farm equipment at all. 100% c-h dependent. MI = 0.64	Financed with own funds. Farming is the only income generating activity.	Old-age, uneducated head of the household; siblings with primary education. Large family size. Variable US migration. 27% of sample	Ejidatario. Politically active at local level. No membership in collective groups for work purposes.
2	Small farm size with good soil quality; two crops a year with 60% of mechanized operations. Animal draft and few pieces of collectively-owned equipment. 85% c-h dependent. MI = 0.74	Financed with own funds. Two different income generating activities.	Illiterate or little educated head hhd; siblings with elementary education. Large family size. Variable US migration. 58% of sample	Ejidatario. Politically inactive. No membership in collective groups for work purposes.
3	Medium farm size (own and rented out). Very good soil under multiple cropping. Owners of medium-big size tractors and implements. Providers of c-h services. MI = 1.06	Financed with own funds. Either one or two different income generating activities.	Scarcely educated head of the household; siblings with primary education. Large family size. No US migration. 9% of sample	Ejidatario. Politically active at local level. No membership in collective groups for work purposes.
4	Large farm size (owned and rented out). Good soil under intensive cropping. Owners of more than one medium size tractor and corresponding implements. Providers of c-h services. MI = 1.19	Currently financed with own funds, formerly users of bank credits. Two different income generating activities.	Fairly educated head of the household; highly educated siblings. Large family size. No members of the household are engaged in migration to the U.S. 6% of sample	Private landholder. Politically active at local level. No membership in collective groups for work purposes.

Notes: c-h =custom hire, % c-h dependency and % of mechanized operations are calculated on the basis of number of operations.

Table 3 shows that the average Mechanization Index computed at the individual level followed a trend of increasing magnitude as groups of households had accumulated more capital. The proportion of households in the sample decreased with increased capital.

Trends in Mechanization

When statistical analyses were performed to estimate the cross correlation between variables in order to establish meaningful associations, the variables "Soil Quality" and "Crop Diversity" had different degrees of association with measures of farm equipment ownership such as "Total Rated Power" and "Weight-Number Implement Indicator" in the two regions studied. Soil quality and crop diversity were highly significant factors in Delicias where soils are highly heterogeneous and usually with marginal fertility; this has influenced the acquisition of mechanization tools. In contrast La Begoña region has a mild weather that allows multiple cropping on highly productive soils without the need for major investment in mechanization aides. Figures 4 and 5 highlight the magnitude of the difference between regions in terms of types of energy utilization.

Another interesting note is that migration appeared highly associated with the above mentioned measures of farm equipment ownership in Delicias, but in La Begoña the same association had no statistical significance. This fact might be related with the dynamics of México-US migration where farmers in Northern México, due to proximity, can be engaged in a more seasonal mode of migration with higher mobility between the two countries. This theory would account for the introduction of farm equipment of American manufacture that was documented during the survey.

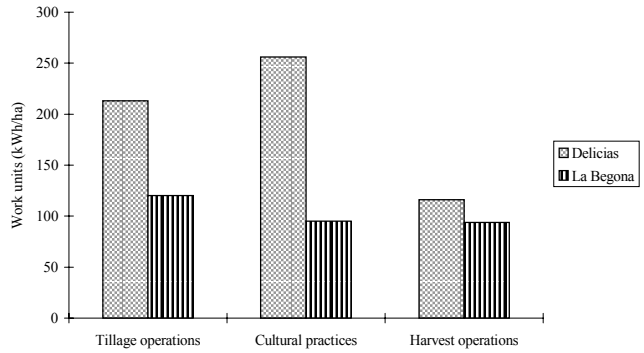


Figure 4. Average work units of mechanized operations according to operations

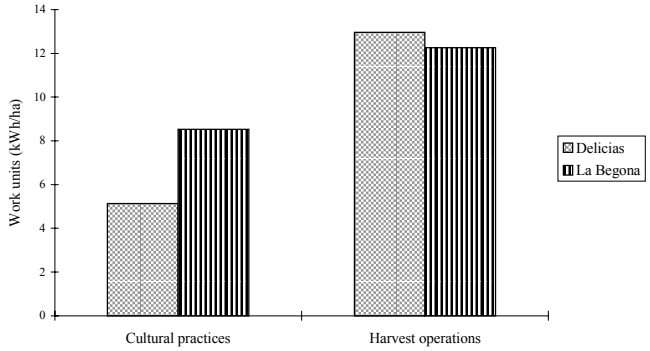


Figure 5. Changes in the number of tractors per 100 ha México and some developed nations

In the same line of comparison, it came as no surprise to find that in both areas, variables "Total Land" and "Land ownership", were highly correlated with the ownership of power units and farm implements. What is interesting to note is that these measurements of mechanization were not correlated with "Family Size" and at the same time were highly correlated with "Income Diversity". The above suggested that farm mechanization in México is articulated with the economics of rural income, i.e. job opportunities and labor availability outside the family nucleus. Some interesting statistics are presented in Table 4 to compare the mechanization status of the two regions.

Table 4. Mechanization parameters found through survey data

Parameter	**Delicias**	**La Begoña**
Rated power per unit land (kW/ha)	2.31	1.43
Number of tractors per unit land (number/100 ha)	5.16	3.11
Draft animals per unit land (number/100 ha)	0.06	4.49
Weight of implements per unit land (kg·f/ha)	189	79

Number of implements per unit land (number/100 ha)	35.8	20.9
Realized Mechanization Potential	0.87	0.61
Machinery Utilization Ratio	0.34	0.36
Mechanization Index	0.85	0.79

Figure 6 show that the two regions have experienced a constant increase in the number of available tractors. Survey data indicated that the overall useful life of these power units extended to at least 30 years. Both regions have developed service systems for the supply of replacement parts as well as technological expertise for repairs and maintenance. Figure 7 extend this line of analysis to the national level. It can be seen in figures 6 and 7 that the two regions have achieved levels of mechanization higher than the national average. Although lower than the values for developed nations, still the scale indicates that México has achieved significant mechanization of its agriculture. This growth has been in part supported by the modernization of the domestic industry in charge of the manufacture of high-energy agricultural inputs such as fertilizers and machinery.

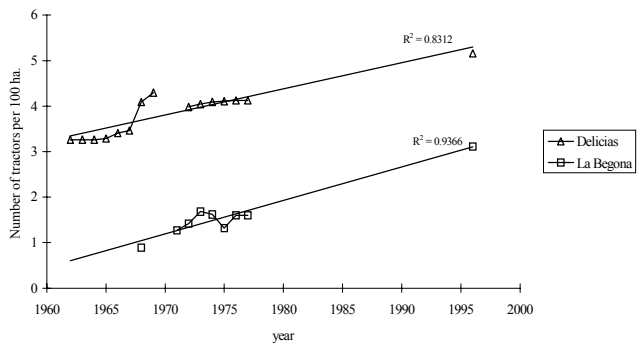


Figure 6. Number of tractors per 100 ha of farm land. Time series data from 1962-1978, 1995

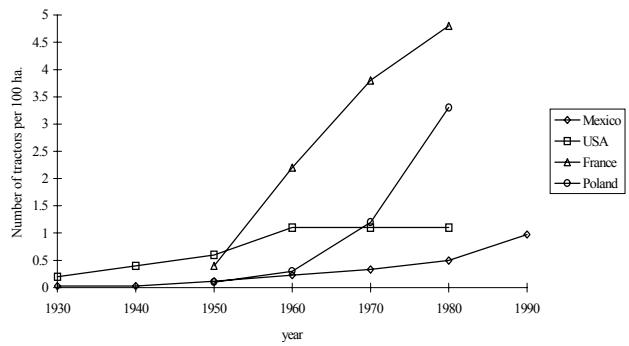


Figure 7. Changes in the number of tractors per 100 ha México and some developed nations

In regards to the responses of machinery dealers and extension personnel. Generally speaking there was good agreement between the two types of interviewees even though dealers had an average of 22 years of experience meanwhile extensionists had only 7. For each type of questionnaire the responses across regions were remarkably similar, except in the case of technically-oriented questions where the regional differences between cropping patterns were clear. One example was the preference of Delicias farmers for four-row implements contrasting with the two-row implements used in La Begoña. Tillage implements were the most sold in Delicias and the least sold in La Begoña.

There was no consensus about the status of farm mechanization achieved in the two regions. Responses ranged uniformly from poor to over-mechanized. On the other hand, there was an absolute agreement that there should be a priority on the increase of the mechanization level. Farm size stood as the factor with the most weight in the introduction of mechanization and land ownership was the least important. The major constraints were events such as currency devaluation and rising cost of fuel. The most important aspects to look for when acquiring farm equipment were those of a financial nature (price and credit availability/terms), followed by technical aspects (work capacity, durability, ease of operation) and with service/maintenance aspects being the least considered.

Conclusions and Recommendations

1. PCA found orderly association between socio-economic, demographic and technical features of households within clusters. Positive values of the first principal component (pc1) indicate self-sufficient households with ample ownership of farm equipment and not requiring contracting of farming operations. The scale of pc2 discriminates the household's levels of education, income diversification, political involvement, and membership in farmer associations for access to information and work-related services.

2. Cluster analysis was able to differentiate patterns of farm equipment utilization in terms of choices among farmers for mechanization through custom-hire, use of their own equipment, or having equipment supplied by owners in the case of sharecropping. For the two regions, about 15% of the population of farmers provided the mechanization services required by the other 85% of households.

3. The distribution of mean values of mechanization index (MI) at the cluster level indicate that there is a pronounced gap between the amounts of mechanized energy used by farmers in the lower and upper socio-economic stratum of La Begoña. Results in Delicias showed a more uniform distribution across clusters. MI can be used to assess the degree of technological inequality within a rural area.

4. The economics of rural communities have played a prime role in the mechanization of farmers in Northern and Central México. More diversified sources of income in the household were linked to higher levels of farm equipment acquisition and/or energy expenditure. Especially in Delicias, migration to the US has helped to finance mechanization costs as well as to introduce mechanized technologies and farm equipment.

5. Climate and soil factors in the two regions have determined regional cropping patterns with different requirements for mechanization. During tillage, the calcareous soils in Delicias used 56% more mechanical work than the deep vertisoils in La Begoña. Also, the high frequency of the summer rains in Central México causes the utilization of mechanical work for cultural practices to be 66% lower than in the Northern region.

6. The two regions surveyed have become more mechanized in the following ways: a) inanimate sources of power provide 95 and 88% of the energy used during cultivation and harvest operations respectively; b) tillage and grain harvest operations are fully mechanized; and c) the number of pieces of farm equipment has increased with a consequent increase in the number of dealers and repair services. This scenario is due mainly to the existing distribution of power where the 15% mechanized fraction of households had control over 65 and 46% of the total land farmed in Delicias and La Begoña respectively.

7. Currently there is inadequate information to relate MI to farm productivity. Further survey work is recommended to establish the relationship between them. This will enhance the usefulness of MI as a tool in formulating mechanization strategies and policies if increasing farm production is an objective.

8. The two regions have realized different levels of potential mechanization (RMP). La Begoña lags Delicias with RMP values of 0.61 and 0.87 in respectively. It is recommended that authorities at all levels should promote research and development of mechanized technologies. Although attention should be paid to regional potentialities and competitive advantages, resource allocation must be balanced to encourage both regional and national development.

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