Mapping Indicators of Machinery Utilization predicted by an Artificial Neural Network

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ABSTRACT

A methodology is presented to generate digital maps containing values of Mechanization Indicators (Mechanization Index and Machinery Energy Ratio), predicted without direct calculation, using a multilayered ANN model. The inputs to the ANN model were simple data obtained from local databases.

Complementarily there were processed digital maps related to parameters on land slope, farm size, soil texture, water supply for crop production and distribution of the land productivity potential for the main crops in the region of study.

Overlapping among the generated maps assisted to analyze the mechanization conditions in every production unit of the Mexican State of Guanajuato, in order to estimate the intensity and suitability of mechanization as well as to identify which farms in the region would benefit more from machinery use.

The developed methodology can facilitate the analysis to prioritize areas for the introduction or replacement of agricultural machinery.

It is concluded that the present methodology would be a good tool to assess mechanization sustainability of agricultural activities; this in turn providing policy-makers and planners with tools with which to judge the best use of land in the near future.
Planning the intensity and suitability of mechanization using this approach would contribute to optimize the use of inputs from oil sources.

Keywords: Mechanization indicators, GIS, artificial neural network, Mexico

1. INTRODUCTION

Modern agricultural practices have contributed to increase crop productivity but also rely substantially on direct oil-based inputs, mainly fuels for transport and field operations as well as indirect inputs dominated by chemical fertilizers, as discussed by Chancellor (2001a and 2001b), Stout and Best (2001), Clarke and Bishop (2002), Adams (2006), Pawlak *et al.* (2002) among others.
For example, traditional rice production system in the Philippines has an annual energy requirement of around 0.14 MJ/kg. By comparison, in the United States, even though the modern production system is 4.6 times more productive per hectare, it requires 79 times the energy use per kilogram of product (11.19 MJ/kg). Similarly, for maize production there is a five times increase in productivity but a 33-fold increase in energy use per unit of production.

Collado and Calderón (2000) and Andrade and Jenkins (2003) compared energy intensity and efficiency from a number of agricultural systems found in central and northern Mexico, however, no further similar research appears to have been carried out recently. In those studies it is pointed out that farmers who practice agriculture using tractors in Mexico, rely on relatively high inputs of fossil fuels, not only to power machinery directly but also for the manufacture of artificial fertilizers and agricultural chemicals.

Furthermore, the current Mexican policy for securing food production is eliminating grain import tolls and offering financial support, encouraging mechanizing more as well as for intensifying the application of chemicals, fertilizers and insecticides.

Due to the high contribution of mechanization into the domestic farming system, as pointed out by Collado and Calderón (2000) and Munack (2002), it is considered very important an updated review on the actual conditions as a part of a wider study of opportunities for the adoption of energy efficient technologies.
It is regard as necessary to improve the domestic production system from the point of view of sustainability and competitiveness. Especial consideration should be given to maximize the efficacy while introducing mechanization technology and identifying opportunities for energy conservation taking into account resource constraints (Collado and Calderón, 2000 and Twomlow S. *et al.* 2002).

On the other hand, the Geographic Information System Group of the Institute of Forestry, Agricultural and Animal Research in Guanajuato research station (García *et al.* 2007) has been producing comprehensive information presented in digital maps that shows the most suitable productivity potential sites for selected crops in the entire region. However, this approach takes into account only agronomic aspects and there is no a component related to mechanization, even though machinery represents important contribution into the domestic farming system as determined by Collado and Calderón (2000).

Due the given reasons, the aim of this study is to develop a methodology to generate baseline data from energy indicators which allow categorizing the sustainability of crop production using mechanization.

This proposed methodology is an application of a previous study (Aragón-Ramírez *et al.* 2007) which allows predicting estimates of two Mechanization Indicators using limited data available from the target region, without the need to calculate them directly applying an ANN model.

The resulted data is processed and presented in digital maps. Further analysis based on contrasting the predicted Mechanization Indicators with parameters on crop potential use, soil texture, land slope, irrigated and rain-fed areas, contributed to appraise the mechanization status in the region and better assessment of the sustainability of the farming system.

It is expected that the presented methodology would be a good tool for farmers and policy advisers to assess the overall sustainability of mechanization; to ensure the continued competitiveness of food production, and to provide policy-makers and planners with measures with which to judge the best management of land.

2. DATA SOURCE AND METHOD

A case study was performed in the central Mexican State of Guanajuato (see Figure 1). The total surface area is 3 058 900 ha. Land use is distributed as follows: 829 336 under rain-fed agriculture, 416 726 are irrigated, 1 385 832 are for livestock, 184 070 are dedicated to forestry and 242 936 to other uses.

Figure 1. Location of the region of studied, Guanajuato Mexico.

The prevailing farming system uses tractors as main power source as encouraged by the government in response to the restriction of timeliness of seasonal farm works and labor shortage trends; average fuel consumption is 336 liters/ha per year. Land tenure varies from 1 to 30 ha per farmer. The region presents two peaks of farming activity (during the third week in May and November) and it is a common practice the rotation of crops from season to season exchanging sites; the main crops are: Maize, Beans, Wheat, Sorghum and Barley.

In order to validate the proposed methodology two main sources of information were compiled.

The first was data from in situ interviews with farmers, generated by the Agriculture Information System of the Guanajuato State (2000). This database contains information related to organization, infrastructure and production factors by the farms in the state of Guanajuato.

The second was a database of digitalized information presented in maps. From this database a set of parameters was selected for the present analysis: productivity potential classification for relevant crops, water source (rain-fed or irrigated), and land slope and soil texture. This information was provided by the Productivity Potential System Group of the Guanajuato State (interviewed by author, SICOPOT-GTO group, Celaya Guanajuato México, September 2007).

The unitary area to process all the information was the Basic Geo-statistic Area (AGEB by its letters in Spanish). This farming unit is a subdivision of the political municipalities and was established by the State Ministry of Agriculture in order to administer agricultural policy support in the region. AGEBs size varies between 191 and 26541ha and the Guanajuato state is divided in 337 production units.

2.1. Mechanization Indicators

For each Basic Geo-statistic Area (AGEB unit), two Mechanization Indicators determined by energy flow for crop production were predicted without direct calculation using as inputs to the model simple data selected from the database source. For this purpose an ANN methodology developed by Aragón-Ramírez *et al.* (2007) was applied. The ANN model was calibrated using the Stuttgart Neural Network Simulator (2006, URL: http://www-ra.informatik.uni-tuebingen.de/downloads/SNNS/).

The Mechanization Index (MI) which is an indication of the amount of machinery a given farmer uses for farm work, compared with the average in the region. As defined by Aragón-Ramírez *et al.* (2007) after Andrade and Jenkins (2003).

$$MI = \sum_{i=1}^{n} ((M_{e(a,i)} / M_{av})(L_{(a,i)} / TL_{(a)})) \quad (1)$$

where:
MI = Mechanization Index for the production unit ‘a’
Me(a,i) = Overall input energy due to machinery for crop ‘i’ in the production unit ‘a’
Mav = Regional-average energy due to machinery
L(a,i) = Land area cultivated with crop ‘i’ in the production unit ‘a’
TL(a) = Total farm land ownership of the production unit ‘a’

The Machinery Energy Ratio (MER) which indicates the investment in machinery energy in comparison with the other input energy sources required for crop production, as defined by Aragón-Ramírez *et al.* (2007) after Collado and Calderón (2000).

$$MER = \sum_{i=1}^{n} (M_{e(a,i)} / T_{e(a,i)}) \quad (2)$$

where:
MER = Ratio between machinery energy and total input energy
Te(a,i) = Total input energy (from: labor, machine, seed, fertilizers, agrochemicals, animals) for the production of the crop ‘i’ in the production unit ‘a’.
In particular MER provides an indication of the average effectiveness of energy conversion being achieved by the farming unit.
The inputs and outputs to the ANN model are shown in Table 1.

Table 1. Input and output parameters to the ANN model.

Item	Variable name	Source	Variable type and units
INPUTS			
1	Total farm land ownership	Data-set entry	Continuous (ha)
2	Number of crops	Data-set entry	Discrete (natural number)
3	Tractor units ownership	Data-set entry	Discrete (natural number)
4	Labor intensity	Computed from data-set	Continuous (base on working hours per cropping season)
5	Animal traction intensity	Computed from data-set	
6	Number of tillage operations	Data-set entry	Discrete (natural number)
7	Straw management	Data-set entry	Continuous (base on percentage burned)
8	Benefit / Cost ratio	Computed from data-set	Continuous (unit-less)
9	Technical assistance	Data-set entry	Dichotomy
10	Land tenure	Data-set entry	Ejidos (ownership by government type), Hired, Private
11	Support from migration	Data-set entry	Dichotomy
OUTPUTS			
A	Mechanization Index	Predicted by the ANN model	Continuous (unit-less)
B	Machinery Energy Ratio	Predicted by the ANN model	Continuous (unit-less)

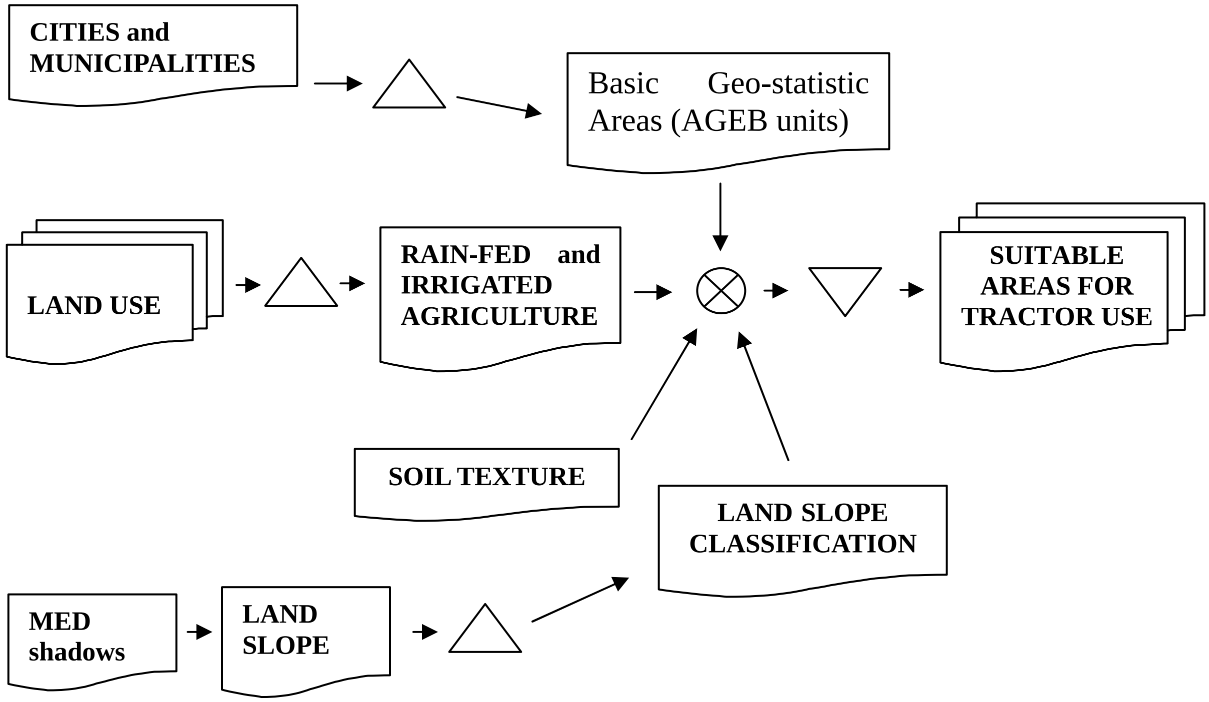
Note: Taken from Aragón-Ramírez *et al.* (2007).

2.2. Mapping Process

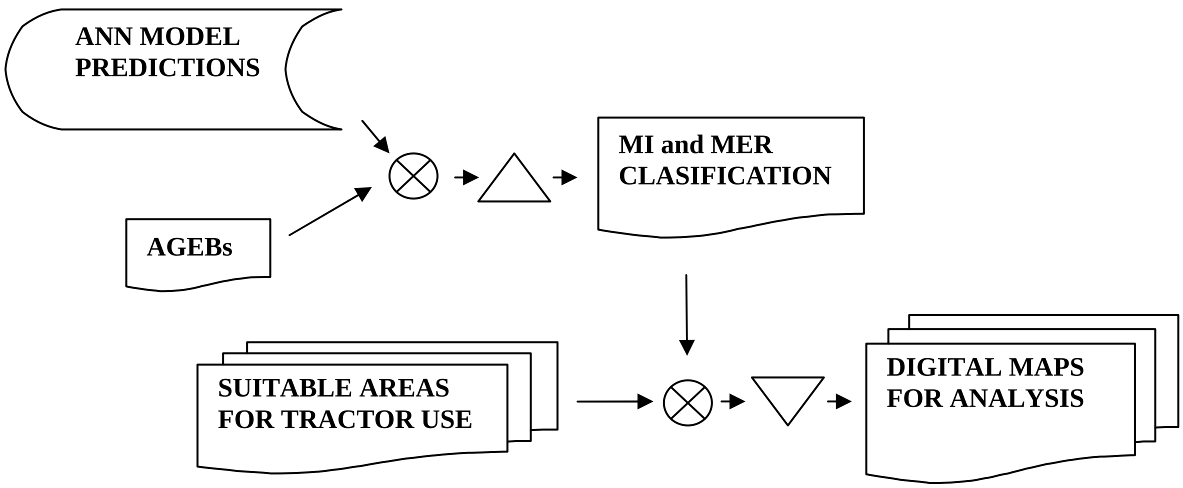
The three stages of the mapping process are shown in Figure 2.

As discussed by García *et al.* (2001 and 2004) and Tortora *et al.* (2006) the procedure basically consisted in processing digital images operations applying ROLL UP GTCO, ARCINFO PC and ARCVIEW's 3D ANALIZE software. The digital images source was the National Statistical, Geographical and Informatics Institute (INEGI) with a resolution 90 m each data frame.

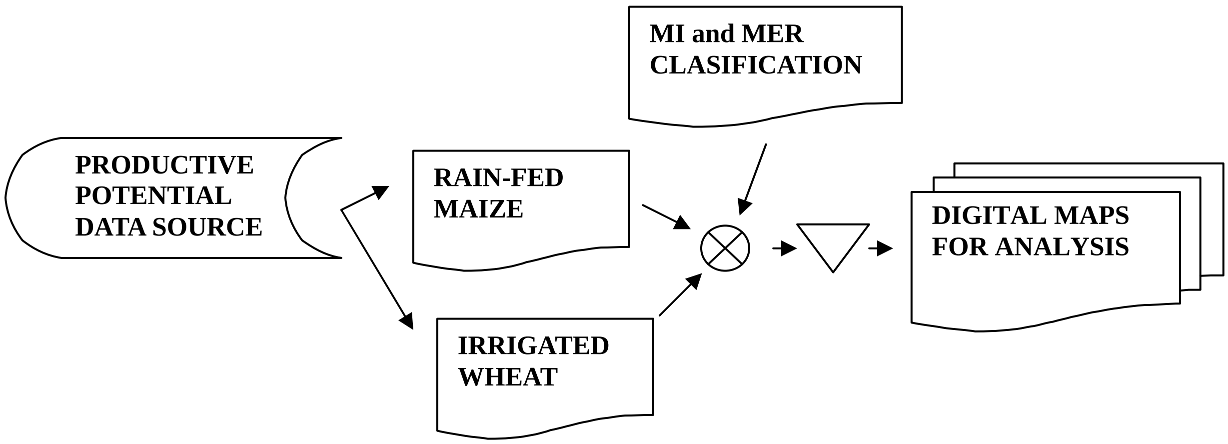
Stage I



Stage II



Stage III



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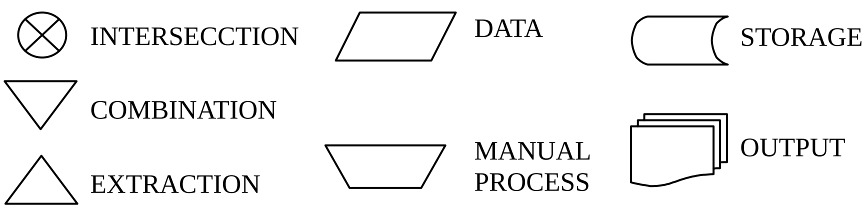

Figure 2. Process flow to generate digital maps for mechanization analysis.

3. DIGITAL MAPS PROCESSING

Stage I

Digital maps were processed in this first stage by the Productivity Potential System Group of the Guanajuato State (INIFAP Bajío Research Station, Celaya Guanajuato México, 2007).
Basically, a Digital Elevation Model (MED) was generated; this MED was in turn processed to produce a shadowed image (sun elevation of 45 deg. azimuth 235 deg.). After that, slopes were derived and classified from MED by ARCVIEW's 3D ANALIZE software.
For cartographic acquisition digitalization the ROLL UP GTCO and ARCINFO PC package was used. For this purpose, soil actual use cartography was processed from the National Forestry Inventory (SEMARNAP 1994). Areas for agricultural use under irrigation and rainfall conditions were segregated, for this purpose ARCVIEW's Maps Generator was used.
In order to determine the different degrees of suitability for mechanizing using the tractor as a main power source, a combining set of variables were selected taken into account the current agronomic conditions as well as land use in the entire region of study. The selected parameters were: land slope, soil texture and water supply for farming.
These three agronomic parameters were classified as presented in Tables 2, 3 and 4.
In case of sandy soils, Table 3, these has been ranked as the lowest because they represent a tiny surface area in the region of study, besides, the famers' preferences for machinery use are directed to fine and medium textures.

The digital images were provided by the Productivity Potential System Group of the Guanajuato State (personal communication, INIFAP Bajío Research Station, Celaya Guanajuato México, 2007).

Table 2. Land slope classification in relation to tractor use suitability.

Land slope	
Lower than 4 %	Preferred
Between 4 and 8 %	Medium
Greater than 8 %	Not suitable

Table 3. Soil texture classification in relation to tractor use.

Soil texture	
Fine	Good
Medium	Preferred
Sandy	Not suitable

Table 4. Irrigation facilities for crop production in relation to tractor use.

Irrigation facilities	
Irrigated	Preferred
Rainfed	Good

Afterwards, three digital maps were produced applying OpenJUMP software package (OpenJUMP Group, 1997). These digital maps were combined and overlapped applying Boolean operations, in order to generate a single map which determines the preferred areas for tractor use.

Stage II

It was generated a set of digital maps containing the geographic distribution of the Mechanization Index and Machinery Energy Ratio categories by linking their values and the geographical locations applying OpenJUMP software (OpenJUMP Group, 1997).

The normalized values of the Mechanization Indicators predicted by the ANN model were grouped according to their frequency of occurrence among the farming units (AGEBs) in the entire region of study. Accordingly the classified value ranges of the Mechanization Indicators (the Mechanization Index and the Machinery Energy Ratio) were combined in order to generate Mechanization Categories as presented in Table 5.

Table 5. Classification of Mechanization Index and Machinery Energy Ratio normalized values.

Mechanization Index		Machinery Energy Ratio		
Value range	Class name	Value range		Class name
Lower or equal to 0.125	**A**. Low mechanization level.	Lower or equal to 0.195		**D**. Little machinery energy use.
Between 0.125 a 0.375	**B**. Representative mechanization level.	Between 0.195 a 0.69		**E**. Representative machinery use.
Higher than 0.375	**C**. Over mechanized level.	Higher than 0.69		**F**. Intensive use of machinery.
Category 1: combination between classes **A** and **D.**	Categories 2, 3, 4: combinations **BD**, **CD** and **CE**; respectively.	Category 5: combination between classes **B** and **E.**	Categories 6, 7: combinations **AE** and **AF** respectively.	Category 8: combination between classes **C** and **F.**

In order facilitate identifying the degree of suitability while introducing mechanization in relation to the prevailing agronomic restrictions, a set of digital maps were obtained by overlapping the Mechanization Categories distribution and the appropriate areas for tractor use. This set of digital maps for analysis were generated using Boolean operations to determine the locations where matching between given conditions were found “true” (operation AND) and where at least one suitable condition was “true” (operation OR). For this purpose OpenJUMP (OpenJUMP Group, 1997) software was applied.

Stage III

Finally with the intention to contrast the prevailing mechanization status in the region of study, there was processed a set of maps containing the combination between the Mechanization Categories and the distribution of productivity potential for selected crops.
The examination of these images could facilitate the decision making intended to harmonize the introduction of a given crop and the mechanization status available in the contrasting production units (AGEBs).
For this purpose, among the most common crops in the region of study, it was selected a traditional crop represented by maize under rain-fed conditions. In addition, wheat under irrigation was selected because represents a well mechanized cropping system in the region.

4. RESULTS AND DISCUSSION

The goal in this section is to illustrate the process to generate recommendations extrapolated after the interpretation of the generated digital images.

The discussion presented in this section was supported by the advice from experts in the local farming system (personal communication, INIFAP Bajío Research Station, Celaya Guanajuato México, March 2008).

In order to simplify this presentation, names and particularities of the locations are omitted because those aspects have relevance only for local analysis which is not the purpose of this study.

4.1. Mechanization Indicators representativeness

Overall representativeness of the Mechanization indicators predicted by the ANN model was discussed and verified with the regional experts from the Productivity Potential System Group of the Guanajuato State (personal communication, INIFAP Bajío Research Station, Celaya Guanajuato México, March 2008).

In order to verify the accuracy of the predicted MI and MER it was decided to estimate their values by direct calculations. This was based on the fact that the source ANN model was developed from the representative farming system in the same region of the present study (Aragón-Ramírez *et al.*, 2007). This process was assumed to be reliable enough because the available data source (Agriculture Information System Group of the Guanajuato State, 2000) provided enough detailed data on the inputs and outputs necessary for the energy flow calculations.

The adopted methodology for the energy flow calculations is described by Chamsing *et al.* (2006), Chaudhary *et al.* (2006) and Jekayinfa (2006). Data was computed applying a database program and then it was linked to a series of spreadsheets for analysis. The spreadsheets contained the energy coefficients and were used to calculate the total energy inputs, outputs and finally the Mechanization Indicators (MI and MER) for each production unit (AGEB).

Further comparison between the predicted and calculated Mechanization Indicators values is shown in Figure 3. The correlation between the ANN model's outputs, i.e. predicted values, and the calculated values of the indicators were quite strong, Pearson's=0.904 and 0.871; R2=0.817 and 0.759 for MI and MER respectively.

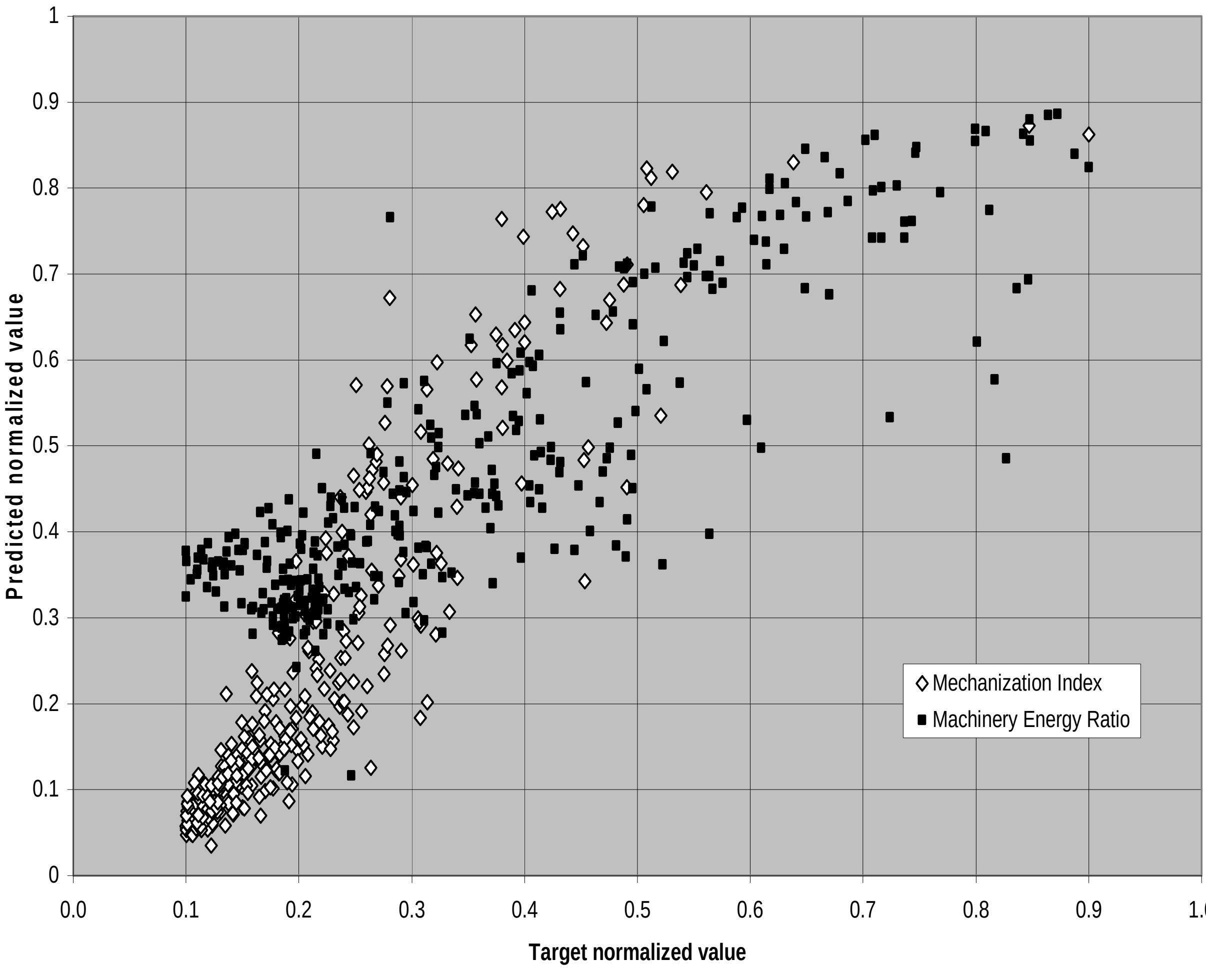

Figure 3. Comparison between predicted and calculated Mechanization Indicators for each production unit**.**

4.2. Preferred Areas for Tractor Use

The digital map which presents the preferred areas for tractor use (obtained in Stage I) is shown in Figure 4.

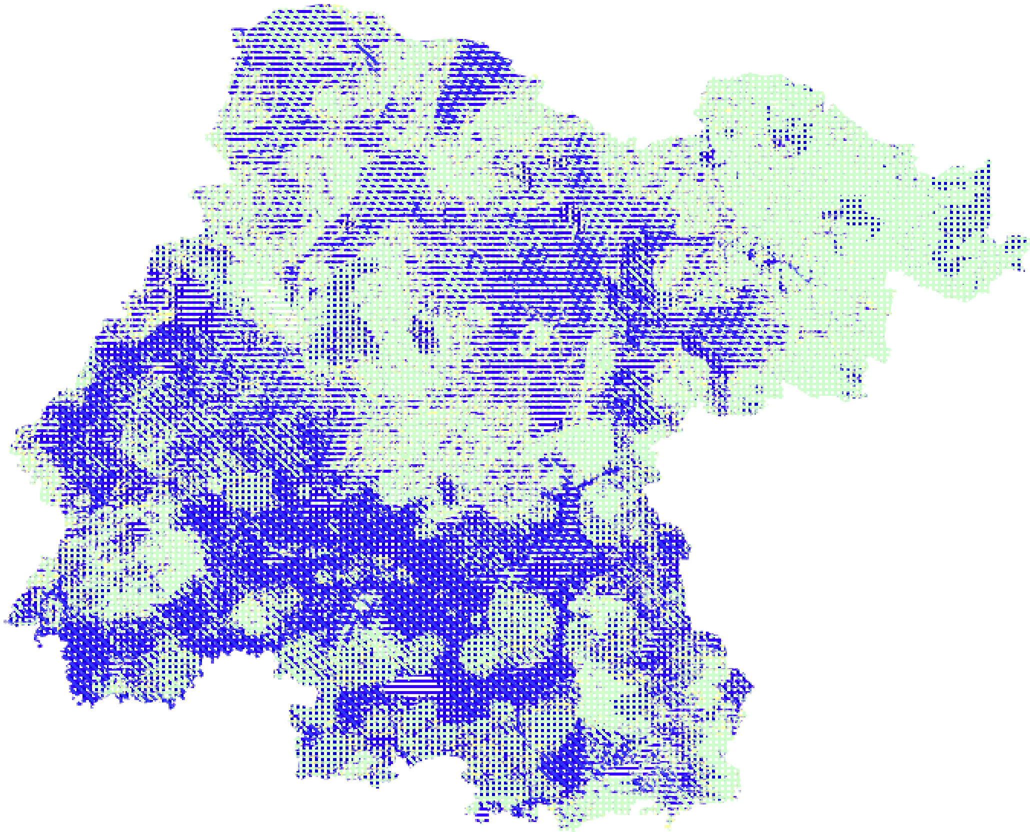

Figure 4. Appropriate areas for tractor use in the State of Guanajuato.
Note: Dashed blue areas represent suitable locations for tractor use.

The geographic distribution of the Mechanization Categories is shown in Figure 5. In Table 6 the interpretation for such categories (defined in Table 5) is presented.

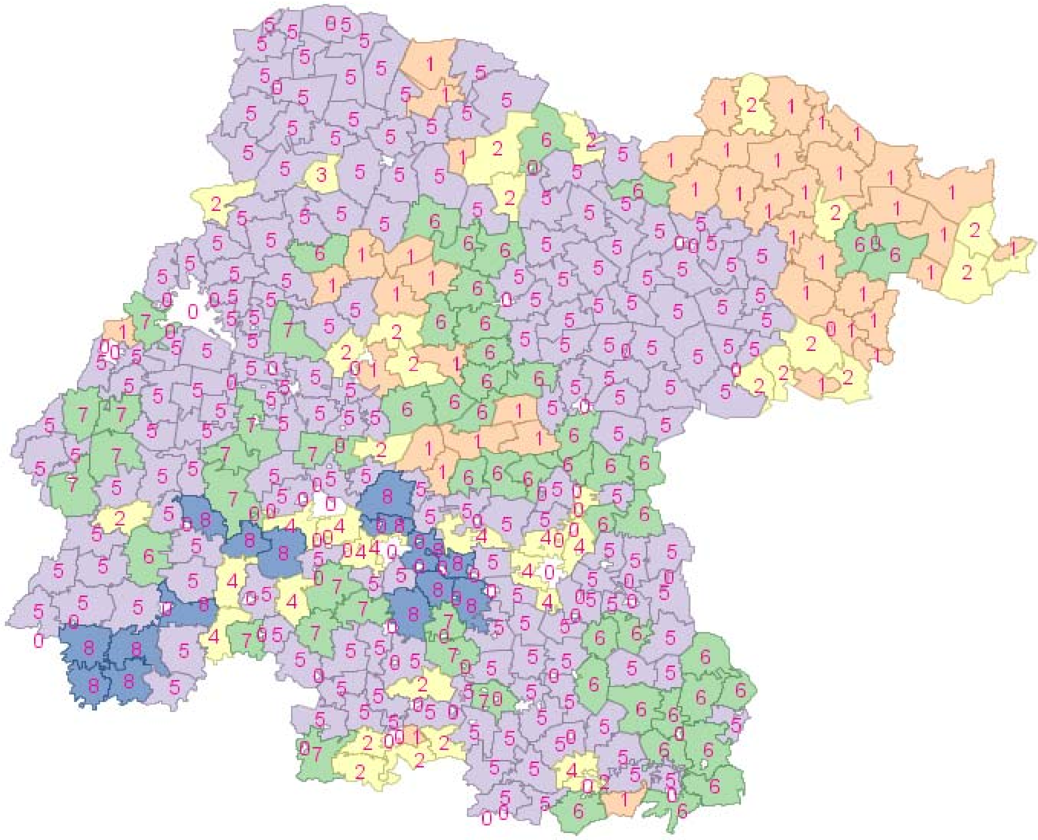

Figure 5. Mechanization Categories distribution in the State of Guanajuato.
Notes: Key numbers interpretation is given in Table 6.
0 notations can be neglected because represent no data available.

Table 6. Mechanization Category values interpretation obtained by combining the Mechanization Indicators.

Category	Interpretation
1 (combination between classes **A** and **D**)	Both, the Mechanization Index and the Machinery Energy Ratio present small values. Machinery availability and use intensity is low in comparison to the prevailing standard situation found in the entire area of study.
2,3 and 4 (combinations **BD**, **CD** and **CE**; respectively)	The normalized value of the Machinery Energy Ratio is larger than Mechanization Index. Machinery availability in these locations is not enough because the insensitivity use is high. Taken into account the combined value of the Mechanization Indicators it can be defined a decreasing rank for introducing machinery more, from category 2 to 4.
5 (combination between classes **B** and **E**)	This represent the most frequent and therefore representative value range predicted for both the Mechanization Index and Machinery Energy Ratio. The normalized values for MI are between 0.125 and 0.375. For MER are between 0.195 and 0.69.
6 and 7 (combinations **AE** and **AF** respectively)	In these cases, Mechanization Index is bigger than Machinery Energy Ratio. This means that in general machinery is available enough however use intensity is low. Taken into account the combined value of the Mechanization Indicators it can be decided a decreasing rank order for introducing machinery more, from category 6 to 7.
8 (combination between classes **C** and **F**)	This category contains highly mechanized areas because it presents quite big and less frequent values for the general trend in both Mechanization Indicators. Given the current situation found in the State of Guanajuato, these areas can classified as either over-tillage or that counts with machinery more than necessary.

4.3. Mechanization Categories Distribution and the Appropriate Areas for Tractor Use

Figure 6 presents the resulting map after combining the actual Mechanization Category and suitable locations for machinery use (maps generated in Stage II). Each production unit of significance was analyzed with the tools provided by the OpenJump software package (OpenJUMP Group, 1997) as well as the data files linked to the images.

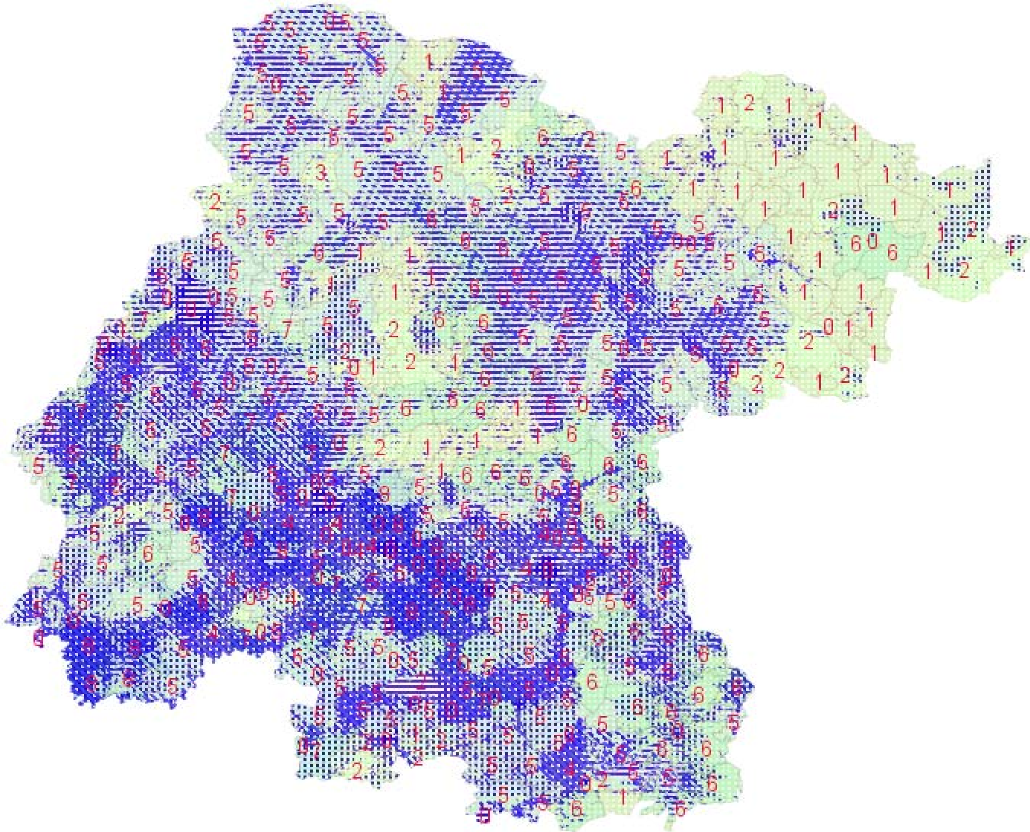

Figure 6. Combination between actual Mechanization Categories and appropriate areas for tractor use.
Notes: Dashed blue areas indicate good conditions for tractor use.
The key numbers are the actual Mechanization Category for each production unit.
0 notations can be neglected because represent no data available.

Table 7 briefly describes recommendations from the case study focusing in the concurrence between Mechanization Categories and good agronomic conditions for tractor use.
It was identified that most production units (AGEBs) with good agronomic conditions for tractor use, correlate well with the availability of irrigation facilities.

Table 7. Combining the actual Mechanization Category with the preferred areas for tractor use

Mechanization Category	Recommendation if concurrence found with preferred areas for tractor use.
1	These locations exhibit the priority for an intensive promotion of mechanization. Farmers in these regions will benefit from machinery more because while favorable agronomic conditions are found, the prevailing mechanization status is low.
2,3 and 4	Introducing new machinery in these locations will improve the mechanization status and will represent a good opportunity to increase the cropping area in view of the demanding machinery trend and favorable agronomic conditions. Regarding the prevailing situation it can be identified that innovations to improve the use of machinery would smoothly adopt. Taking into consideration the given mechanization categories overlay with preferred areas for tractor use, it can be defined a priority order to introduce machinery more which goes from 4 to 2.
5	These areas enclose a representative advantageous mechanization status and good agronomic conditions. Also, these locations exhibit equilibrium between values MI and MER, conditions which are favorable to promote improved farming techniques.
6 and 7	Machinery is available enough, however use intensity is low in comparison to the trend in the region. Also the agronomic conditions represent a great potential. Therefore, it can be recommended that these locations offer good chances to increasing land productivity while no need to introduce machinery more.
8	This category encloses maximum values for the Mechanization Indicators. It is very likely that the farming method in these areas requires especial attention in order to avoid the risk on soil and water degradation provoked by mechanization. Similarly, the contribution of machinery costs for crop production has to be the highest in the entire region. Further analysis would reveal that external input energy for production (chemical fertilizers, agrichemicals, fuel, etc) appears in the upper limit in comparison to the farming management tendency in the region. Therefore, introducing more tractors in these locations is not recommended because would accentuate negative effects related to over-mechanization.

Related analysis was accomplished for the locations that represent the least appropriate conditions for introducing mechanization more (represented by the light dashed blue areas in Figure 6). Assuming the descriptions given in Table 6; Table 8 briefly presents particular interpretations.

Table 8. Combining the actual Mechanization Category with the least suitable areas for tractor use

Mechanization Category	Recommendation if concurrence found with the least suitable areas for tractor use.
1	Bringing more tractors into these locations is not necessary because the agronomic conditions are found not suitable. Besides, the computed Mechanization Category is the lowest in the entire region. These characteristics match the conservative character of the farming status found in these locations.
2,3 and 4	These areas represent the cases were machinery is intensively used while the locations are vulnerable to negative impacts in case of mechanizing more. Consequently it can be suggested that introducing efficient and appropriate tillage techniques are necessary to improve the quality of the farming method.
5	In few cases the typical Mechanization Category 5 correlates with the less favorable areas for tractor use. It can be pointed out that these locations are characterized by a farming status which harmonized tractor use in combination with animal power.
6 and 7	These areas are particularly vulnerable to the negative impacts on intensifying machinery use. In view of the fact that there is enough machinery in these locations (as interpreted in Table 6), it can be suggested that is not necessary introducing more machinery. However if it is decided to increase mechanization intensity, this can be only recommended for promoting conservation tillage.
8	No association was found between Mechanization Category 8 and the lesser suitable agronomic conditions for tractor use. This is a positive indication which confirms the point that vulnerable locations in general do not comprise high mechanization status.

4.4 Mechanization Categories and the Distribution of Selected Crops

In this section the mechanization status is examined in relation to crop productivity potential as well as the actual crop distribution.

The degrees of productivity potential were classified as good, medium and not suitable according to the methodology developed by García *et al.* (2007). The actual (year 2000) crop distribution data was provided by the Productivity Potential System Group of the Guanajuato State (personal communication, INIFAP Bajío Research Station, Celaya Guanajuato México, 2007).

For the present analysis only two main crops were chosen. The first was Maize under rain-fed conditions because it represents the most generalized crop among the farmers in the region. This crop is characterized by a farming method which applies a combination of tractor and animal traction as power sources.

The second selected crop was wheat under irrigated conditions since this is a highly important crop in the region which is top mechanized in the region as discussed by Collado and Calderón (2000).

4.4.1. Irrigated Wheat Cropping and the Mechanization Categories

Figure 7 presents the combination between the Mechanization Categories and the distribution of the production units (AGEBs) which have good potential for introducing irrigated wheat (dashed green). Complementarily in the same figure, it is presented the actual distribution of both: rain-fed wheat (small red squares) as well as under irrigated conditions (red dots).
Accordingly, general observations resulted from evaluating the combinations are summarized in Table 9.

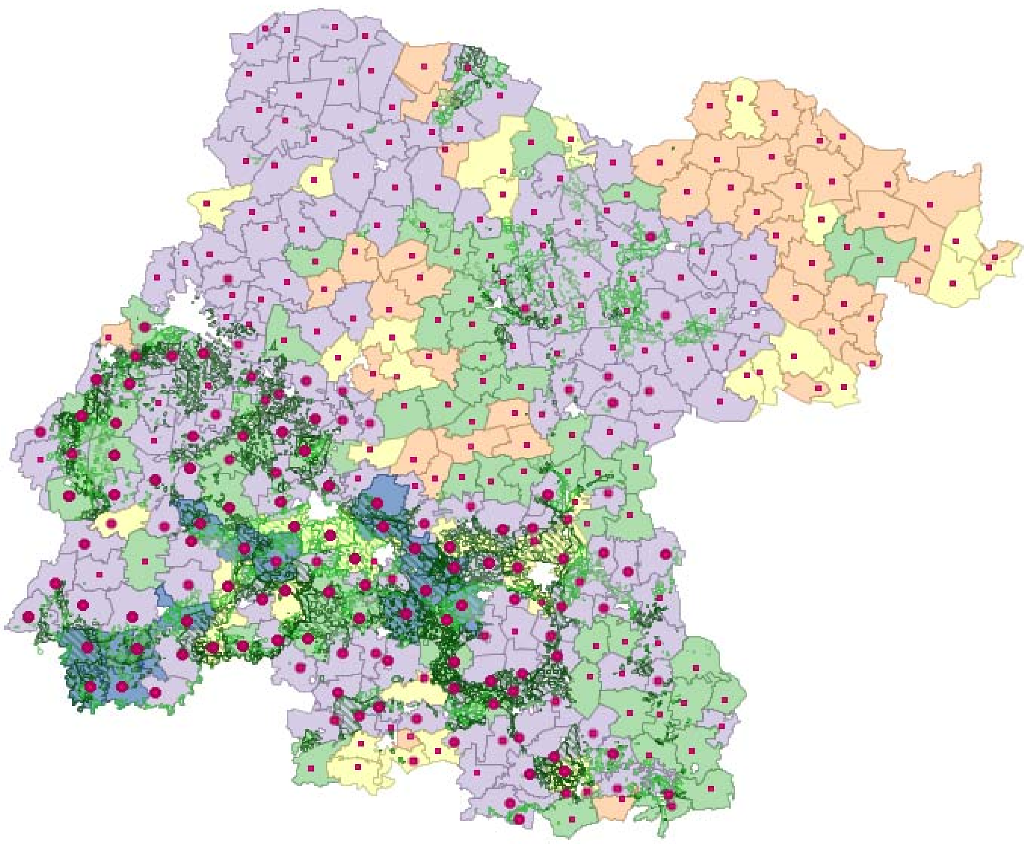

Figure 7. Actual and good potential distribution of wheat under irrigation and rain-fed conditions in comparison to Mechanization Categories.
Notes: Dashed areas represent good potential for wheat under irrigation.
Red dots represent production units actually cultivated with irrigated wheat.
The small red squares are the AGEBs cultivated with rain-fed wheat.

Table 9. Observations derived while overlapping good potential and actual distribution of wheat under irrigation and rain-fed conditions with the Mechanization Categories.

Identified situation	Recommendation
Category 1 overlies with good potential for introducing irrigated wheat.	Introducing such crop can not be recommended in the only one location which presents this condition. This is because of the prevailing low mechanization level (identified by Category 1). As stated before, the conventional trend in the region has established that good mechanization level is required to facilitate the establishment of irrigated wheat.
Category 1 overlies with actual cultivation of rain-fed wheat.	Introducing machinery more in these locations can not be effective because of the agronomic limitations.
Categories 2, 3 and 4 overly with actual cultivation of irrigated wheat.	Most cases (in the centre of the map) with good potential and actual irrigated wheat coincide well. This circumstance confirms the favorable condition in which machinery available in these areas is intensively used. Only one production unit which does not present good potential while irrigated wheat is cultivated. Such situation can be overcome by expanding alternative rain-fed crops.
Categories 5 overlies with good potential for introducing irrigated wheat.	Quite a few locations present this situation. These in turn offer good chances to easily adopt the new crop because of the prevailing suitable mechanization status which is determined by the good balance between values MI and MER.
Categories 6 and 7 overly with good potential for introducing irrigated wheat.	Yet few cases present this condition as a real alternative, these are favourable in order to increase MER value and consequently the mechanization status.
Category 8 intersects actual cultivation of irrigated wheat.	Production units under this condition are characterized by the high demand on external inputs as well as compete for natural resources.

4.4.2. Rain-fed Maize Cropping and the Mechanization Categories

Figure 8 shows the combination between the Mechanization Categories and the distribution of the production units (AGEBs) which have good potential for rain-fed maize (dashed green). Complementarily in the same Figure 8, it is presented the actual distribution of both: rain-fed maize (small red squares) as well as maize under irrigation conditions (red dots).

Accordingly, general observations resulted from evaluating the combinations are summarized in Table 10.

Renewable energy use (such as animal traction) in rain-fed maize locations is particularly important. Under these situations the substitution of available animal power with tractors is not desirable because it may contribute to unbalance the actual cropping method which is more efficient in terms of input/output energy efficiency for crop production.

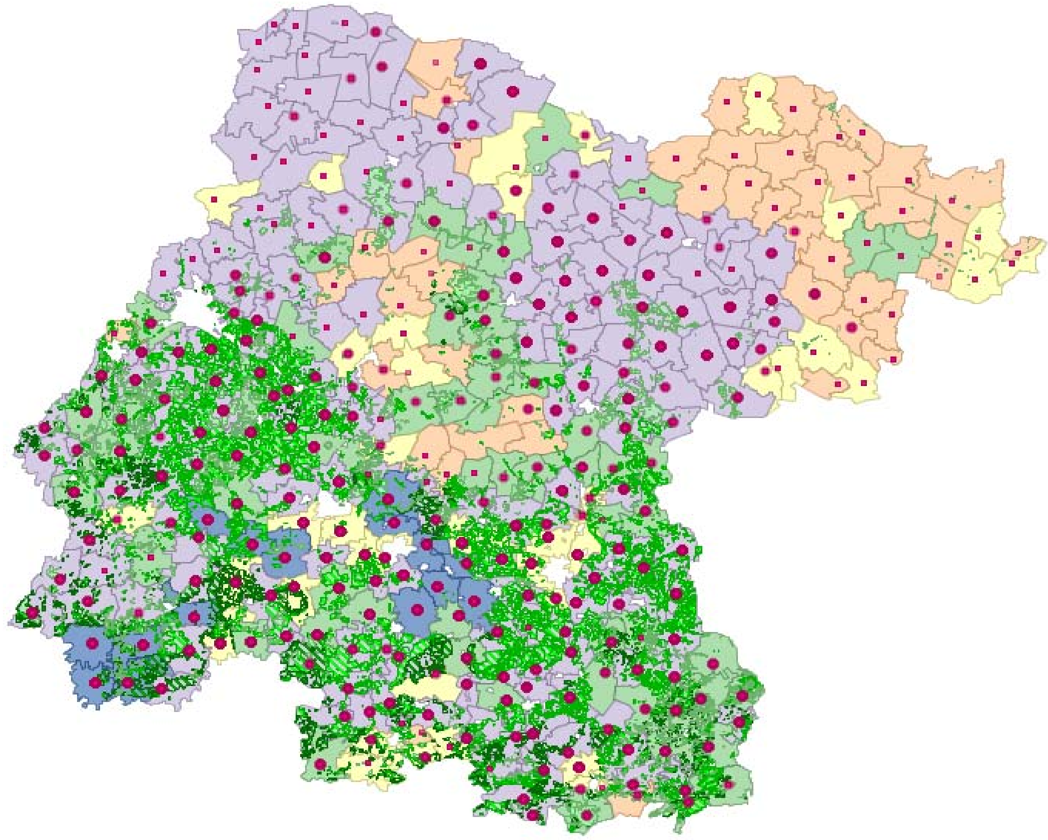

Figure 8. Maize under irrigation and rain-fed conditions; actual and good potential distribution in comparison to Mechanization Categories.
Notes: Dashed areas represent good conditions for maize under irrigation.
Red dots represent cultivated production units with irrigated maize.
The small red squares are the AGEBs cultivated with rain-fed maize.

Table 10. Observations derived while overlapping good potential and actual distribution of maize under irrigation and rain-fed conditions with the Mechanization Categories.

Identified situation	Recommendation
Category 1 overlies with actual cultivation of rain-fed maize.	Locations under these conditions correlate the low Mechanization Category with the prevailing conservative farming system.
Category 1 overlies actual cultivation of irrigated maize.	Production units which does not present good potential but still cultivates irrigated maize. Such situation can be overcome by expanding alternative rain-fed crops.
Category 1 overlies with good potential for introducing rain-fed maize.	In these cases an extensive promotion of rain-fed maize is recommended because the agronomic conditions favour such mechanization strategy.
Categories 2, 3 and 4 intersect actual cultivation of irrigated maize.	These are locations which do not present good potential but still cultivates irrigated maize. In such cases it would be better promoting some other alternatives with suitable crops under rain-fed condition in order to maintain the farming intensity level.
Category 5 overlies with actual rain-fed maize cultivation.	In these cases the substitution of rain-fed maize for higher intensive mechanized crops will have a positive effect on the improvement of mechanization under rain-fed condition.
Categories 6 and 7 overly with good potential for introducing rain-fed maize.	It is not desirable to introduce rain-fed maize in these locations because its characteristic low mechanization demand will adversely affect the established good Mechanization Index level.
Category 8 overlies with good potential for introducing rain-fed maize.	The introduction of rain-fed maize would represent a reduction in mechanization intensity, situation which is not desirable.

5. CONCLUSIONS

5.1. Particular

Areas with low mechanization status do not overlap areas which do presents suitable agronomic conditions for machinery use. Therefore it can be stated that the actual farming system in the State of Guanajuato has been developed well in order to suit the prevailing agronomic restrictions.

High values of the Mechanization Category correlate well with the availability of irrigation facilities. Such locations have the highest energy requirements for crop production in the entire region. In addition those are highly competitive locations for water resources.

It was identified that production units which exhibit innovative tendency, incorporates balanced values of the Mechanization Indicators. These locations offer good conditions to promote improved farming techniques because are very likely that the farmers will adopt them easily.
In contrast, it was observed that conservative farming method - identified by low Mechanization Category - is linked to rain-fed cropping system.

Farmers in rain-fed locations have evolved a farming method which harmonizes the tractor with the renewable power source of animal traction. This study confirmed that in these cases the replacement of animal traction with tractors is not desirable because may contribute to unbalance an available traditional farming system which is more efficient in terms of input/output energy efficiency for crop production.

Values of the most frequent Mechanization Indicators vary widely between individual production units (Mechanization Index between 0.21 and 2.34; Machinery Energy Ratio between 0.436 and 0.61). The main causes of variation are differences in the number of tillage operations and the crop yield per production unit.

5.2. General

The presented methodology can be fully beneficial to analyse mechanization status as far as there is a complementary expertise on the backgrounds and the conditions of the case study farming system.

Applying digital images which introduces the Mechanization Indicators has facilitated the overall appraisal of the farming system.
Associating the Mechanization Categories to the locations and to the corresponding levels of the agronomic productivity potential parameters, provided valuable information to assess the performance and degree of sustainability of each individual faming unit in the region of study.

The limited set of parameters analyzed: MI and MER values; land slope; soil texture; water main source for crop production and degree of productivity potential, allowed fully appraising the mechanization performance of the farming system.

Monitoring Mechanization Indicators should be a continuous process in order to produce a trend over time. Much of the necessary information on the direct and indirect inputs, as defined in this study, can be collected as part of the regular farm monitoring activity.

It is expected that the developed methodology would provide policy-makers and planners with a tool to judge the best use of land, to estimate the intensity and suitability of mechanization as well as to identify which farms in the region would benefit more from machinery use. This in turn can facilitate the analysis to prioritize areas for the introduction or replacement of agricultural machinery.

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