Assessment of the potential enhancement of rural food security in Mexico using decision tree land use classification on medium resolution satellite imagery

A Bermeo and S Couturier*
Laboratory for Geospatial Analysis (LAGE), Geography Institute, National Autonomous University of Mexico (UNAM)
Circuito Exterior s/n, Del. Coyoacán, CP:04510, Mexico City, Mexico
E-mail: stephcamelo@mailcity.com

Abstract. Because of its renewed importance in international agendas, food security in subtropical countries has been the object of studies at different scales, although the spatial components of food security are still largely undocumented. Among other aspects, food security can be assessed using a food selfsufficiency index. We propose a spatial representation of this assessment in the densely populated rural area of the Huasteca Poblana, Mexico, where there is a known tendency towards the loss of selfsufficiency of basic grains. The main agricultural systems in this area are the traditional milpa (a multicrop practice with maize as the main basic crop) system, coffee plantations and grazing land for bovine livestock. We estimate a potential additional milpa - based maize production by smallholders identifying the presence of extensive coffee and pasture systems in the production data of the agricultural census. The surface of extensive coffee plantations and pasture land were estimated using the detailed coffee agricultural census data, and a decision tree combining unsupervised and supervised spectral classification techniques of medium scale (Landsat) satellite imagery. We find that 30% of the territory would benefit more than 50% increment in food security and 13% could theoretically become maize self-sufficient from the conversion of extensive systems to the traditional multicrop milpa system.

1. Introduction
Because of its importance in international agendas (e.g. the Zero Hunger Challenge by the United Nations), assessing food security has been the object of increased focus in many countries. A vibrant debate exists as to the contribution to food security of agroindustrial and capital intensive agricultural systems with respect to smallholder and traditional cultivation systems. To the advantage of the latter, it is claimed that environmentally harmful production practices are counterproductive since production in the long run decreases in marginalized areas [1, 2]. In this sense, production of food for future demand is a great international challenge since it should be constrained to existing farming systems without expanding extensive agriculture and grazing lands [3].

Following the hypothesis that smallholder agricultural systems are more sustainable than extensive agricultural systems and monoculture lands, research has recently emerged on the spatial characterization and analysis of smallholder rural territories. For example in Mexico, spatially explicit studies have focused on the extent of indigenous territories as fundamental biocultural entities [4], on the compatibility or not of smallholder agriculture with surrounding forest conservation [5], and on the availability, or lack of availability of land for traditional cultivation systems [6].
Food security is defined by FAO [7] as “the access to sufficient and nutritious food by all people at all times to lead a healthy and active life”. We suggest that an innovating insight on the problem of food security in marginalized rural areas could be to estimate its potential improvement by intensifying traditional cultivation systems. Specifically we propose to assess food security benefits as a consequence of (re)establishing the milpa system on the land currently under extensive agriculture and grazing systems in Mexico. The balance between availability of food and population intake needs is an approach [7] involving food self-sufficiency, employed for example to build the Global Food Security Index of The Economist Intelligence Unit [8].

In this research, food security is approximated as self-sufficiency of basic foods (balance between basic food production and its consumption) in a typical, densely populated, rural area in Mexico. The area pertaining to capital intensive agricultural systems is first derived from landscape scale classification of satellite imagery and fine scale analysis of the agrarian structure. Then, the Potential Increment of Food Security (PIFS) is presented as a spatially explicit index, based on the hypothesis that this area is converted to the traditional milpa cultivation.

2. Study area and available spatial data
The study area covers approximately 1337 km$^2$ of the Sierra Madre Oriental eastern mountain range. It corresponds to the Xicotepec Rural Subdistrict (see figure 1) which is the tropical portion of the Rural Development District 01 of the Puebla State, in the United States of Mexico.

![Figure 1. Location of the study area (area in red color)](image)

The Sierra Madre Oriental is one of the main densely populated indigenous regions of Mexico. Maize cultivation was traditionally the main agricultural system in the region, however it was reported with a steadily decreasing production in the last century, while coffee and pasture based systems arose and developed till occupying the major portion of the landscape nowadays, namely the largest coffee region in the State of Puebla. Most livestock estates as well as large coffee plantations are clearly related to capital intensive agricultural activities. Original vegetation ranges from oak forests upland to medium tropical forest and include a rich set of cloud forest ecotones.

196 rural settlements are distributed throughout the study area, each of which received a coffee census detailed at the level of production units in 2004 [9]. Production data from most crops is also reported in the agricultural and pasture activity census ("Censo Agropecuario", [10]. The pasture land component of the landscape can be estimated from the land use national cartography (e.g. [11]) or in medium scale satellite imagery (Landsat, ASTER) available online from the GloVis USGS global viewer, for example.

3. Method
The method consisted in three steps, detailed in the following subsections: 1) assessment of the areas of capital intensive production systems, 2) estimation of the potential maize production using traditional cultivation systems in this area, and 3) calculation of the potential of food self sufficiency increment (the PIFS spatial index).
3.1. Assessing the areas of capital intensive production systems

Capital intensive production systems in the Sierra are grazing lands and coffee large plantations. The 2004 coffee census contains the surface distribution of agricultural production units, allowing to distinguish between smallholder cultivated surface (< 5ha) and large plantation surface. More recently, a polygon-based (parcel clusters) spatial representation with agricultural production data have been released (rural Geostatistical Units: [10]), however, this data does not discriminate small from large estates, which is a high limitation to smallholder agriculture studies such as ours; we could not make use of this recent database for this reason and instead, the large coffee plantation surface was derived on a locality point basis using the 2004 detailed coffee census, as plotted in figure 2.

Figure 2. Land distribution among coffee Production Units (PU) in the Xicotepec Subdistrict (derived from [9])

Official land use cartography may be useful for vast pasture surface estimation, as has been done in a previous study by Bermeo et al. [6]. With the food security focus of this study, an attempt was made to estimate not only large surfaces of grazing systems (>100ha), but instead a more exhaustive account of surfaces pertaining to medium (>10ha) and large land owners. Landsat imagery (year 2003, at the time of the coffee census) was acquired for the study area and geo-referenced to the INEGI 1:50,000 scale official Mexican topographic maps via the national database of ground control points by Mas et al. [12]. A decision tree, based on the combination of unsupervised spectral cluster detection and supervised Maximum Likelihood class assignation was applied to the Landsat corrected imagery, building on the hybrid classification scheme of Couturier et al. [13]; in a first step, ISODATA clustering algorithm was applied to the 7 bands of the Landsat imagery (with 40 to 60 clusters). Next, empirical "pure" spectral classes (representing a gradient of vegetation densities, grazing land, mixed land uses, rainfed agriculture, and forested land, with differing sun expositions and shadowed areas) were selected from the imagery. Then, a supervised ML classifier was applied and each pixel was assigned to the "grazing land" and other classes. Finally, a majority filter was applied to reduce the dispersion of the results, and patches of less than 10 ha were left out of the "grazing land" class, under the assumption that these patches pertained to smallholders.

The classification suffered from some omission of pasture parcels in the shadowed areas due to the reduced contrast. A simplified set of classes was attempted on topographically corrected Landsat imagery, however, because of the extreme topographic gradient of the study area, no significant improvement was obtained.

3.2. Potential milpa production in capital intensive areas

The calculations derived from the earlier subsection (point-based coffee area $A_{coffee}$ and polygon-based grazing land area $A_{pasture}$) were assimilated and synthetized in hexagonal spatial units (HSU), because village spatial limits are largely undocumented. Hectagonal cells were preferred over square cells because the connectivity between cells is greater (one to six neighbors rather than one to four neighbors), and better suited to intercommunity-scale analysis (see [6]). The extent of each HSU was selected with
an average of 4 localities per spatial unit according to point distribution analysis by Mitchell et al. [14] adapted by Bermeo et al. [6]. A preliminary analysis of $A_{\text{coffee}}$ and $A_{\text{pasture}}$ was necessary to handle outlier values (unrealistically high areas of coffee due to the spatial uncertainty of the location of coffee plantations, for example), after mapping these variables over the entire study area (figure 4); a threshold of 70% of the HSU area was applied to constrain these outlier values.

Next, the potential production of maize ($\text{Prod}_{\text{maize add}}$) in these capital intensive areas was calculated according to the following equation:

$$\text{Prod}_{\text{maize add}} = (A_{\text{coffee}} + A_{\text{pasture}}) \times \text{Productivity}_{\text{milpa}} \quad (1)$$

Where \text{Productivity}_{\text{milpa}} (ton/ha), conceived as the productivity of the traditional practice of the milpa system, was estimated on the grounds of field interviews with elder indigenous inhabitants that practice traditional milpa in three localities of the study area. Accordingly, a 1 ha milpa plot typically yields 1.8 tons of maize (among yields of other crops in the plot), but implies 4 ha associated plots under fallow to maintain land fertility. Therefore, \text{Productivity}_{\text{milpa}} = 0.36 \text{ tons/ha}.

3.3. Calculating and mapping the Potential Increment in Food Security (PIFS)

Current Food Selfsufficiency (CFS) can be evaluated on the basis of the balance between local food production and food consumption [15]:

$$\text{CFS} \% = \frac{\text{Prod}_{\text{maize}}}{\text{Cons}_{\text{maize}}} \quad (2)$$

$\text{Prod}_{\text{maize}}$ was estimated at locality level according to the Agricultural Census [10] and $\text{Cons}_{\text{maize}}$ was estimated to 0.274 tons/year, according to a set of interviews in the field.

Finally, the Potential Increment of Food Security (PIFS) was estimated using the following equation:

$$\text{PIFS} \% = \frac{\text{Prod}_{\text{maize add}}}{\text{Cons}_{\text{maize}}} \quad (3)$$

Figure 3. Mapped proportion of land occupied for capital intensive agricultural activities.
4. Results

A \( A_{\text{coffee}} \) and \( A_{\text{pasture}} \) were illustrated for preliminary analysis (figure 3). HSUs with very high surface proportion of coffee plantation (outlier values >70%) were probably affected by a saturation effect caused by the spatial uncertainty of the location of coffee plantations registered in the census.

| Class                        | Description                      | Nº cells |
|------------------------------|----------------------------------|----------|
| No population                | Land occupied by large estates   | 11       |
| Small increment               | PIFS < 25%                       | 27       |
| Medium increment              | 25% < PIFS < 50%                 | 16       |
| Large increment               | 50% < PIFS < 100%                | 13       |
| Very large incr. (over self sufficiency) | PIFS > 100%                    | 11       |

Indeed, most of these HSUs contained small urban centers (head towns of municipios) where many plantations are registered, although their location is in nearby HSUs. To tackle these unrealistic data, it was assumed than no more than 70% of the HSU area could be assigned to coffee plantations.

Next, CFS and PIFS distributions were mapped using the HSU representation (figure 4). Table 1 reports an increment of food self-sufficiency of more than 50% for 24 HSUs out of a total of 77 (30% of the study area), and an increment of more than 100% for 11 HSUs (13% of the study area).

To the East of the study area (towards the coast), several HSUs registered null population because of the absence of localities (low altitude, easily accessible land occupied by very large coffee plantations). A set of HSUs with small PIFS values was detected in the Southern part of the study area, with a high density of indigenous localities and sharper relief. In contrast, a clear pattern of high PIFS values exists near to a circuit of roads in the vicinity of Xicotepex (center North of the study area), the main town of the region, where cattle breeders or coffee plantation farmers could establish easily in spite of the relatively sharp relief. Finally, to the North, a “mestizo” densely populated area, the pattern is more heterogeneous.

![Figure 5](image_url)  
**Figure 5.** Mapped Potential Increment of Food Security (PIFS) through additional milpa activity in the study area.
5. Conclusions
In the context of increasing concerns for massive migration and environmental impacts of the agro-industry in rural territories, the resilience of traditional cultivation systems retains the attention of urban citizens and the scientific community; this situation in turn appeals for a renewal of spatial analysis tools to better grasp the role of these territories in the national and global food security issues.

The proposed approach provides a means of handling smallholder activities and livelihood strategies in spite of highly uncertain statistical data or poor documentation on agrarian structure in subtropical rural areas. Our approximation to food security to the Xicotepec Subdistrict suggests great potential towards more sufficient and more nutritious maize supply in these rural areas (increment of food self-sufficiency of more than 50% for 30% of the territory) if milpa cultivation were to be massively implemented back in the region. Because of the key role of the coffee detailed census of 2004 in our analysis, we recommend the Ministry for Agriculture (SAGARPA) and INEGI to adopt the design of the 2004 census for future census in rural areas.

The mentioned improvement of food self-sufficiency ignores many factors including cash income needs of smallholders, migration induced neglect of cultivation practices, effects from losses of interregional exchange of products from large farms, as well as the possible loss of agricultural production because of non-traditional practices, all of which should be studied further with a regional perspective.

Acknowledgments
This research was developed in the context of the academic PAPIIT project (DGAPA – UNAM financed) number IA300515, entitled “A multiscale territorial characterization of the Mexican society to global environmental change”.

References
[1] Verburg P, Mertz O, Erb K, Haberl H and Wu Wenbin 2013 Land system change and food security: towards multi-scale land system solutions Current Opinion in Environmental Sustainability. 5 494-502
[2] Knoke T, Calvas B, Ochoa S, Onyekwelu J and Griess V 2013 Food production and climate protection- What abandoned lands can do to preserve natural forest Global Environmental Change. 23 1064-1072
[3] Perfecto, Ivette, John V and Angus Wright 2009 Nature’s Matrix: Linking Agriculture, Conservation and Food Sovereignty (London: Earthscan) pp. 40-43.
[4] Boege E 2008 El patrimonio biocultural de los pueblos indígenas de México: hacia la conservación in situ de la biodiversidad y agrodiversidad en los territorios indígenas (Mexico City: INAH/CNDPI) 342p.
[5] Roy Chowdhury R 2006 Landscape change in the Calakmul Biosphere Reserve, Mexico: Modeling the driving forces of smallholder deforestation in land parcels Applied Geography. 26 129-152
[6] Bermeo A, Couturier S and M. Galeana-Pizaña 2014 Conservation of smallholder traditional cultivation systems in indigenous territories: mapping land availability for milpa cultivation in the Huasteca Poblanca, Mexico Applied Geography. 53 299-310.
[7] FAO (Food and Agriculture Organization) 2006 Food Security Policy Brief Issue No. 2. FAO Food Security Program, Rome.
[8] The Economist Intelligence Unit 2015 Global Food Security Index. Retrieved from: http://foodsecurityindex. eiu.com/Index (last access February 2015).
[9] SAGARPA 2005 Padrón cafetalero del Estado de Puebla. Consejo Poblano del Café. SAGARPA, Xicotepec de Juárez, Puebla, Mexico. Digital documents on CD ROM in Excel Format (56395 items). Individual items available at: http://www.spcafe.org.mx/wb3/wb/spc/spc_reportes_pnc
[10] INEGI 2014 Censo Agropecuario 2007. Sistema de Consulta de Información Geoestadística
Agropecuaria (SCIGA). Accessed at http://gaia.inegi.org.mx/sciga/viewer.html

[11] INEGI 2012 Cartografía de Usos de Suelo y Vegetación, Serie V, in: Series históricas del INEGI. INEGI, Aguascalientes, Aguascalientes, Mexico.

[12] Mas J.-F, Velázquez A, Palacio-Prieto JL, Bocco G, Peralta A and Prado J 2002 Assessing forest resources in Mexico: Wall-to-wall land use/cover mapping Photogrammetric Engineering and Remote Sensing. 68 966-969.

[13] Couturier S, Ricárdez M, Osorno J, y López-Martínez R 2011 Morpho-spatial extraction of urban nuclei in diffusely urbanized metropolitan areas Landscape and Urban Planning. 101 338-348

[14] Mitchell A 2005 The ESRI guide to GIS analysis, Volume 2: Spatial Measurements and Statistics. Redlands, (CA: ESRI Press) 238 p.

[15] FAO, IFAD 2014 The State of Food Insecurity in the World: Strengthening the Enabling Environment for Food Security and Nutrition. (Rome: Food and Agriculture Organization of the United Nations)