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Mapping and Characterizing the Green Belt of Córdoba: Land Dynamics and the Urban-Rural Transformation Process

Nicolás A. Mari[1,3,*], Beatriz Giobellina[2,3], Alejandro Benitez[2,3], Victoria Marinelli[2,3,4]

[1]Instituto Nacional de Tecnología Agropecuaria – Agencia de Extensión Rural Cruz del Eje

[2]Instituto Nacional de Tecnología Agropecuaria – Agencia de Extensión Rural Córdoba

[3]Observatorio de Agricultura Urbana, Periurbana y Agroecología de Córdoba (O-AUPA)

[4]Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)

Abstract

In Córdoba, Argentina, the peri-urban horticulture is in conflict with industrial agriculture and urban development. This problem is partly due to urban expansion to rural areas occurred in the last years and to monoculture farming, which has replaced traditional fruit and vegetable cropping in the region. This transformation process has raised concern about the current and future availability of productive sectors that can sustain food supply within the city boundaries and its immediate surroundings as well as about the loss of ecosystem services associated with peri-urban natural environments. Although these dynamic processes are well known, they have not been described or quantified in Córdoba. Baseline information about land use and its dynamics in productive areas or about number of producers is insufficient and/or out of date. At O-AUPA (Spanish acronym for Observatory of Urban and Peri-urban Agriculture and Agroecology) different mapping strategies are developed to contribute to the understanding of the land dynamics in the Green Belt of Córdoba (GBC) and the rural environments surrounding the city. In this work, we present a method based on the use of remote sensing and geographical information systems to characterize urban, peri-urban and rural areas of Córdoba city with the aim of evaluating the temporal dynamics of urban growth and the current state of land use and cover. We mapped and quantified the urban growth between 1974 and 2014, and evaluated land use in peri-urban and rural areas in 2015. We used satellite information from Landsat TM 5 to map the urban growth via a principal component analysis (PCA) and SPOT 5 imagery to characterize the current land use and land cover with the support vector machine classification algorithm. The results show an urban area growth of 46.5% over almost 40 years within the boundaries of the Capital department. Farm plot size increased, showing a concentration of land ownership, implying a reduced number of producers. Evidence indicates the importance of defining land planning guidelines that limit the advance of the urban frontier to valuable agricultural systems, ensure diversification of productive activities and protect and develop the fresh food production systems at the local level.

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Corresponding author: Nicolás A. Mari, Instituto Nacional de Tecnología Agropecuaria - Agencia de Extensión Rural Cruz delEje

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Introduction

Land use planning, is a crucial process that requires that social actors assemble knowledge of the strategic variables generated by the complex dynamics and changes in the biophysical, socioeconomic, cultural, technological, and political situation in a territory. Awareness of the current situation is not enough; rather, it is also necessary to understand the temporal dynamics: the historical process, the current situation and the trending scenarios. Likewise, there is also a need to articulate the different scales and dimensions operating in a territory, from the local to the global scales, from the microbiological level to scenarios such as climate change, from the rationale of the internal market to decisions made outside the region, in the international markets, which influence the local responses [1].

Among the biophysical variables, land use and land cover type (agricultural and natural) require an accurate analysis of their spatial and temporal distribution, which evidences the production rate in a region and agroecosystem stability and capacity to provide ecosystem services [2]. Land use planning requires generating diverse databases to support relevant decisions about planning and land use management. Land use planning aims at achieving a fairer and more efficient territorial distribution in terms of opportunities for development, shaping the relationships between the territory and its users, and linking human, productive and spatial activities, with the ultimate goal of improving life quality of present and future generations [3]. Urban growth, distribution of the population in the urban and rural settings, the impact of rapid city expansion on the provision of ecosystem goods and services, and the agricultural expansion processes appear to be the dominant factors in land use changes worldwide [4] [5].

Many strategies are well known for the purpose of mapping and analyzing the urban-rural transformation processes. Remote sensing and Geographical information Systems (GIS) are the main tools for providing local, regional and global historical databases. As part of the fast growing computational capabilities and storage, digital image processing is becoming more accessible with the more reliable digital processing techniques [6].

In Argentina, Córdoba was one of the first provinces to exhibit expansion of annual crops in the 90s, as indicated by the agricultural censuses. This phenomenon has caused profound biophysical, socioeconomic and cultural transformations in the territory [7] [8]. The consequences of agricultural and urban expansion in the urban-rural interface of the main cities of Córdoba, however, are still less understood.

The peri-urban area, historically known as the "Green Belt of Córdoba" (GBC), has the typical characteristics of a rapid, uncontrolled and scarcely planned urban growth at the expense of the surrounding agricultural land, neglecting the importance of local food production. That process has been largely promoted by the real estate boom and industrial expansion to areas that had been traditionally used for fruit and vegetable production [9]. Small and medium-sized producers have witnessed the transformation of their environment driven by interests other than food production (great part of that urban and agricultural expansion has been driven by short-term economic benefits, disregarding the associated social, economic and environmental costs).

Urban development has also deteriorated canal irrigation systems, generating a water supply crisis and contamination of productive lands. As a consequence, producers started to migrate to areas more distant from the urban center or to abandon their production activities.

Thus, the GBC area has been reduced due to both the growth of the urban area and the expansion of extensive cropping towards peri-urban areas. Both processes have generated an array of conflicts regarding distribution, availability and type of productive activities in the GBC. As a consequence, new activities are conducted in the GBC that are no longer related to its strategic and historical role, which was the provision of food and raw materials in the area surrounding the city. Given the possible decline of land productive capacity in the area due to land use deregulation and water scarcity), it is crucial to make a comprehensive diagnosis of the area, involving the following aspects: biophysical environment and rural infrastructure, spatial distribution of the population, socioeconomic and cultural levels of the populations, ecosystem service provision (production of commodities, water regulation, carbon fixation, erosion control, etc.), landscape transformation (mapping of types of covers and their temporal dynamics), land tenure and distribution and regulatory framework.

One of the activities conducted at the Observatorio de Agricultura Urbana, Periurbana y Agroecología de Córdoba (O-AUPA, Observatory of Urban and Peri-urban Agriculture and Agroecology) is to assemble knowledge to promote care and preservation of agricultural productive spaces of the GBC. The institution proposes the coordination and articulated actions of stakeholders working and participating in a single region to generate complex, multisector and multidimensional knowledge, and management of information; this emerging discipline is termed territorial intelligence. Therefore, the method proposed by O-AUPA is one that uses Participatory Action Research (PAR), which is based on building knowledge with others (shared knowledge), as well as on the articulation of actors and the generation of networks for sharing the currently fragmented and disarticulated knowledge. Thus, O-AUPA is proposed as a tool encompassing diverse innovative theories, practices and strategies for territory development [9].

Based on data collected from inter-institutional participative workshops, surveys to producers, satellite data, as well as on the use of GIS, we propose 1) characterizing the GBC by mapping the urban area of Córdoba city in 1974 and 2014 and determining the urban growth over that 40-year period and 2) determining the current agricultural land cover and use and the changes in agricultural parceling.

Materials and Methods

Study Area

The work was conducted in an area of approximately 170,000 ha of the metropolitan region of Córdoba city. The limits of the study area were the Sierras Chicas (below 600 m a.s.l.) to the west, the altitude above 350 m a.s.l. to the east; the locality of General Paz to the north and the national Route C-45 to the south. The area covers the historical Green Belt of Córdoba (GBC), including three well-defined sectors: the northern sector, irrigated by Canal Maestro Norte; Villa Retiro, Villa Esquiú, El Quebrachal, part of Colonia Tirolesa; the eastern sector covers the area of Chacras de la Merced, and the southern sector includes the road to San Carlos, Ferreyra, also defined by the irrigation system –Canal Maestro Sur, which is derived from San Roque reservoir–, although they are currently supplied in part by Los Molinos reservoir. (Figure 1)

The analysis was focused both on the peri-urban area surrounding Córdoba city, where small and medium producers of fresh food that supply the local market are concentrated, and on more distant areas characterized by extensive agriculture. The study includes the productive areas to the north and south of the city, which have been characterized as herbaceous graminoids under irrigation [2] in the soil cover classification map of Argentina (Year 2006-2007) performed by INTA.

Mean annual temperature in the study area is 17 ºC, with thermal amplitude of 14 ºC. Frosts occur between May and September, and the frost-free period spans 270 days. Mean annual precipitation is 750 mm, with a monsoonal seasonal distribution. Water deficit varies between 180 mm in the east and 240 mm in the west [10]. Productive activities are characterized by a concentration of leaf vegetable production in the

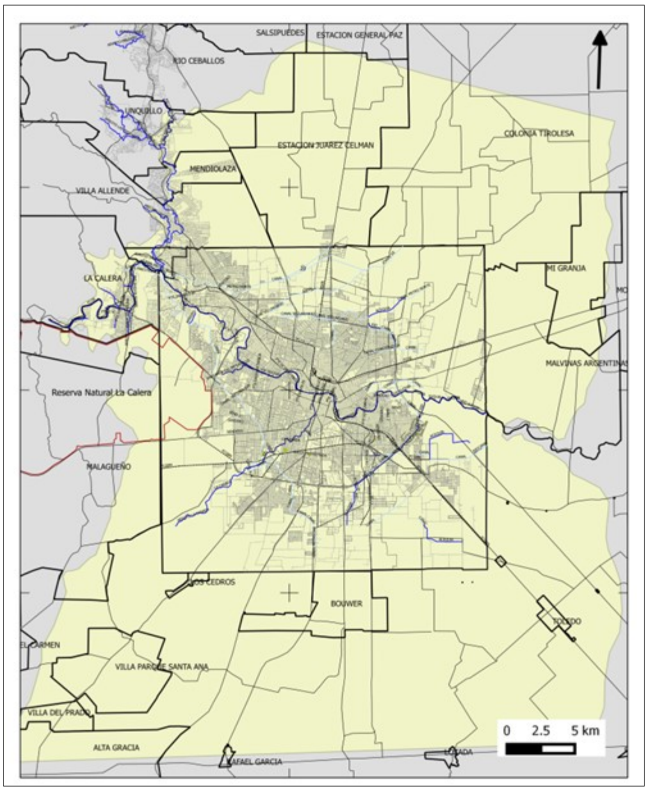

Figure 1. Study area of the GBC.

northern area, whereas the southern zone is dominated by potato and carrot production, with some cases of agroecological businesses [11]. The most important annual crops are soybean and maize, which are mostly distributed outside the Capital department, but with an important participation in the urban-rural interphase.

Strategy of Analysis

The characterization of the GBC consisted of three phases of analysis:

1.urban growth in Córdoba city (delimitation of the historical perimeter of the city and comparison with the current one)

2.present land cover types

3.dynamics of agricultural parceling (determination of the changes in parcel structure).

The historical and present boundaries of Córdoba city were delimited with a multi-temporal principal components analysis (PCA) [12] using Landsat 1 MSS (Multi Spectral Scanner) image of 60 m of spatial resolution acquired on 12/06/1974 and a Landsat 8 OLI (Operational Land Imager) image of 30 m resolution acquired on 24/07/2014. The method consists of combining both images in a single data stack using the set of spectral bands corresponding to each sensor, except for the thermal bands. Since the images have different pixel size, the PCA was performed for each image date separately. The analysis aims at reducing spectral dimensionality of each image and generating new synthetic bands (principal components, PCs) that summarize the greatest variability of the original information. Accordingly, the urban areas were better differentiated by PC2 for 1974 and PC3 for 2014. Thus, discrimination of urban covers for each data was maximized, which allowed us to delimit their spatial distribution with greater accuracy (Figure 2). Urban perimeters were delimited using the ISODATA unsupervised classification algorithm. This type of algorithm is used to partition a spectral image into a given number of classes based on the statistical information of the image; it does not require human supervision for training [13]. The obtained urban covers were monitored by visual inspection using the Landsat images employed in the PCA, as well as Google Earth images. The comparative analysis of the urban area was

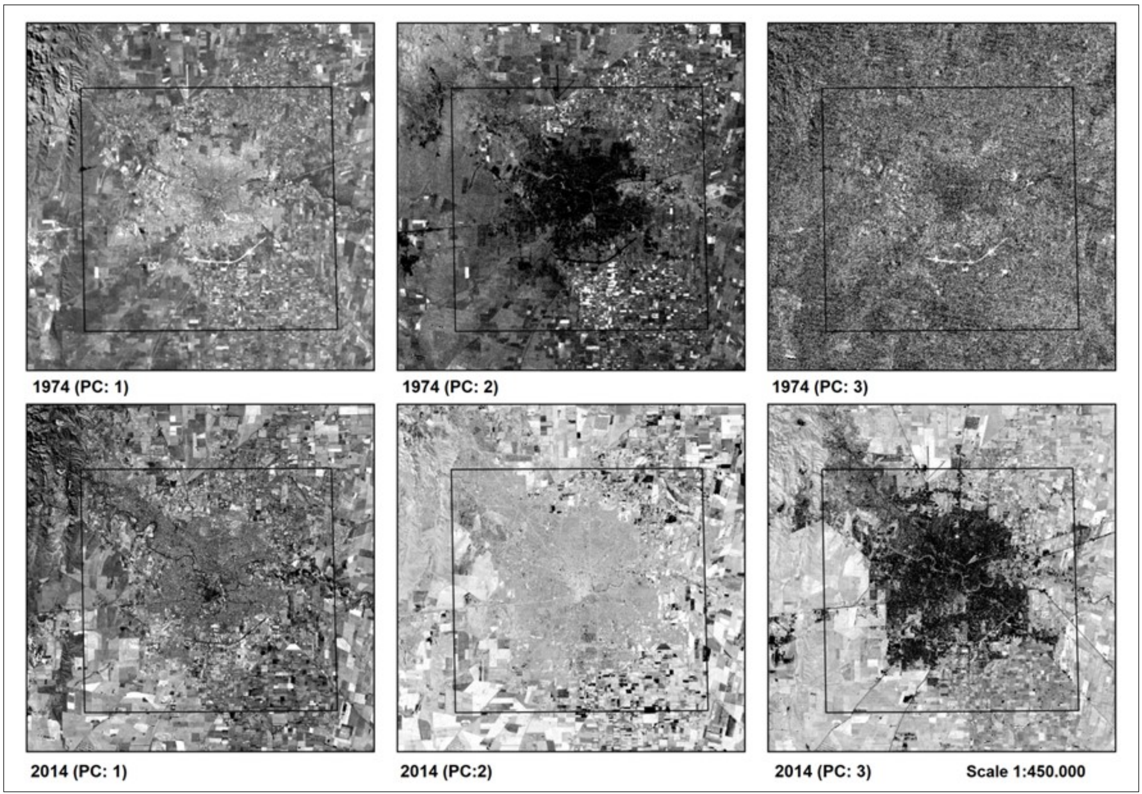

Figure 2. Principal Components Analysis. The first three principal components for each year are shown.

performed within the limits of the Capital department, covering a total of 58 neighborhoods distributed between the northern and southern sectors of the GBC.

Based on the distribution of the limits of the neighborhoods (DGCyE, 2008), we calculated the urbanized proportion within each neighborhood for the two years of study (Equation 1). Then, we used a normalized change index to evaluate the relative change in urban growth (Equation 2).

$$Urban\_develop = \frac{Neighborhood\_area_n}{Urban\_area_{year}} \quad (1)$$

$$Urb_{b,c} = \left(\frac{Urban\_develop_{t2} - Urban\_develop_{t1}}{Urban\_develop_{t2} + Urban\_develop_{t1}}\right) * 100 \quad (2)$$

Urban development is the proportion of urban area within each analyzed neighborhood. $Urb_{b,c}$ is a normalized change index between dates *t1* and *t2* for each neighborhood. This index provides a relative measure of the normalized change for each neighborhood.

Agricultural land use and cover types were characterized and analyzed using a 10-m spatial resolution SPOT 5 image (Satellite pour l'observation de la terre) acquired on March 11 2015 (Table 1). This type of multispectral image has a better spatial resolution than Landsat images, which allowed us to work at a lower detail scale (100 m^2 x pixel). Land use and land cover types were mapped via a supervised classification method using the Support Vector Machine (SVM) algorithm. SVM is a learning algorithm that allows optimal separation of a data set, each one being assigned to a class of interest, depending on the training samples added to the classifier [14].

The date selected for classification coincides with the end of the maturity cycle of summer crops and the future harvest in April/May; in contrast, winter crops cannot be characterized in March, since this in an early date. Intensive agriculture known as "Liviana" is characterized by crops of alternate short cycles of approximately 3 months; thus, production can be characterized on a continuous basis using images over the year. In March, "pesada" extensive agricultural crops (potato, carrot) are ready for harvest and, in general, local producers, particularly of potato, usually leave them in the ground for a maximum period of three months; hence in March plots will be visualized as deprived of or with low plant cover.

The training strategy of SVM was conducted based on geolocation of field samples (direct observation of crops) and by visual interpretation on a SPOT image. Field visits were made to the study area between April and June 2015 (Figure 3). For that purpose, a legend was constructed to define in the field the different land cover and use types present in the region: summer crops (soybean, maize, alfalfa), pesado horticultural crops (potato, sweet potato, carrot), light horticultural crops (lettuce, chard, spinach, etc.), mixed land use (vacant parcels, abandoned fields, roadsides, weedy plots), urban areas, forest areas, bare soil or fallow land and water. Given the small size of horticultural plots (light), very often of smaller size than the resolution of the sensor used, we decided not to include them in the classifier. For their identification, high-resolution Google Earth images were used and polygons were manually digitalized, and then added as a mask to the already classified map. This procedure helps to avoid confusion with other classes of similar phenological cycles and ensures a more accurate fit of the final horticultural area. Location and characteristics of the classes observed in the field were geolocated with GPS (Global Positioning System); a total of 96 locations were recorded, which were then used in the classification assessment phase. The result was evaluated using two indicators: overall accuracy (OA) and Kappa coefficient, both derived from the *confusion matrix* [15].

OA summarizes the overall result of the classification. The Kappa number is an alternative measure of the accuracy of classification that subtracts the effect from random accuracy. Kappa quantifies how much better a given classification is than a random classification. [16] suggests that the use of a subjective scale in which Kappa values <40% are "poor", 40%-55% "fair", 55%-70% "good", 70%-85% "very good" and >85% "excellent". The producer's accuracy is a measure of the omission error and indicates the percentage of pixels of a given class that are correctly classified. The user's accuracy is a measure of the commission errors and indicates the probability that a pixel classified as a particular class really represents that class in the field [15], [16].

The analysis of agricultural parceling consisted of three phases: a) texture filters, b) segmentation and c) unsupervised classification. These techniques are widely used in digital image processing with the aim of

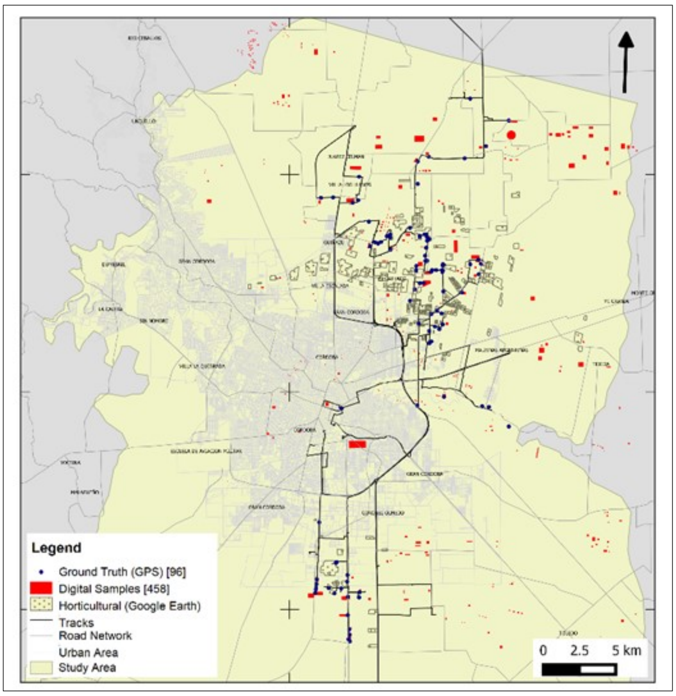

Figure 3. Training and validation sites used in SVM classifier

identifying homogeneous shapes, sizes and edges. Different co-occurrence texture filters were tested on different far off dates (Table 1). A Landsat 5 TM image of 30 m of resolution acquired on 11/04/1988 was used to define the historical parceling, and a Landsat 8 OLI image acquired on 24/07/2014 was used to define the current state of parceling. Texture filters are used to detect edges and shapes that follow defined patterns in an image. We tested 8 filters computed in 3 x 3 pixel moving windows applied only to the nIR bands, with the aim of identifying the maximum discrimination of the parcel borders on each of the processed dates (*mean, variance, homogeneity, contrast, dissimilarity, entropy, second moment, correlation*). By visual inspection of the tests, we determined that the variance filter was the best option. In the following step, we segmented the variance images processed for both dates. Segmentation classifies the images into different segments and requires the definition of thresholds and a minimum pixel population. Here, we determined the thresholds by counting the digital values that represent at least 80% of the data for each one of the dates, which allowed us to establish the parcel borders and agricultural limits that were best represented in the image. At the final step, the segments obtained were classified using the ISODATA unsupervised method (Figure 4 a,b).

Results

Analysis of Urban Growth of Córdoba City

Northern Zone of the Green Belt of Córdoba

Urban growth was evident in all the periphery of Córdoba city. In the northern zone of the GBC, the neighborhoods showed a mean growth of 26.4%, considering the average urban proportion between 1974 and 2014. In 1974, the neigborhoods Ciudad Villa Retiro, Finca la Dorotea, Ciudad de los Cuartetos, Los Chingolos, Nuestro Hogar II, La Dorotea Guiñazu Sud and Los Hornillos were completely rural areas; hence,

Table 1. Methods and satellite information used for the characterization of the Green Belt of Córdoba. The type of sensor used and the spectral bands selected for each analysis are indicated.

	Method	Data	Dates	Bands	Spectral Region	Wavelength (µm)	Spacial Resolution (m)
1) Analysis of urban growth of Córdoba city	Principal Component Analysis (PCA) / Unsupervise Classifier ISODATA	Landsat 1 MSS	12/06/1974	4	Green	0,5-0,6	60
				5	Red	0,6-0,7	
				6	NIR	0,7-0,8	
				7	SWIR	0,8-1,1	
		Landsat 8 OLI	24/07/2014	2	Blue	0,45-0,51	30
				3	Green	0,53-0,59	
				4	Red	0,64-0,67	
				5	NIR	0,85-0,88	
				6	SWIR 1	1,57-1,65	
				7	SWIR 2	2,11-2,29	
2) Analysis of current agricultural land cover and use	Supervise Classifier Support Vector Machine (SVM)	Spot 5 HRG1 - Google Earth	11/03/2015	1	Green	0,5-0,59	10
				2	Red	0,61-0,68	
				3	NIR	0,78-0,89	
				4	SWIR	1,58-1,75	
3) Analysis of the dynamics of agricultural parceling	Texture Filter / Segmentation / Unsupervised classifier ISODATA	Landsat 5 TM	11/04/1988	4	NIR	0,76-0,90	30
		Landsat 8 OLI	24/07/2014	5	NIR	0,85-0,88	30
NIR: Near Infrared							
SWIR: Short Wave Infrared							

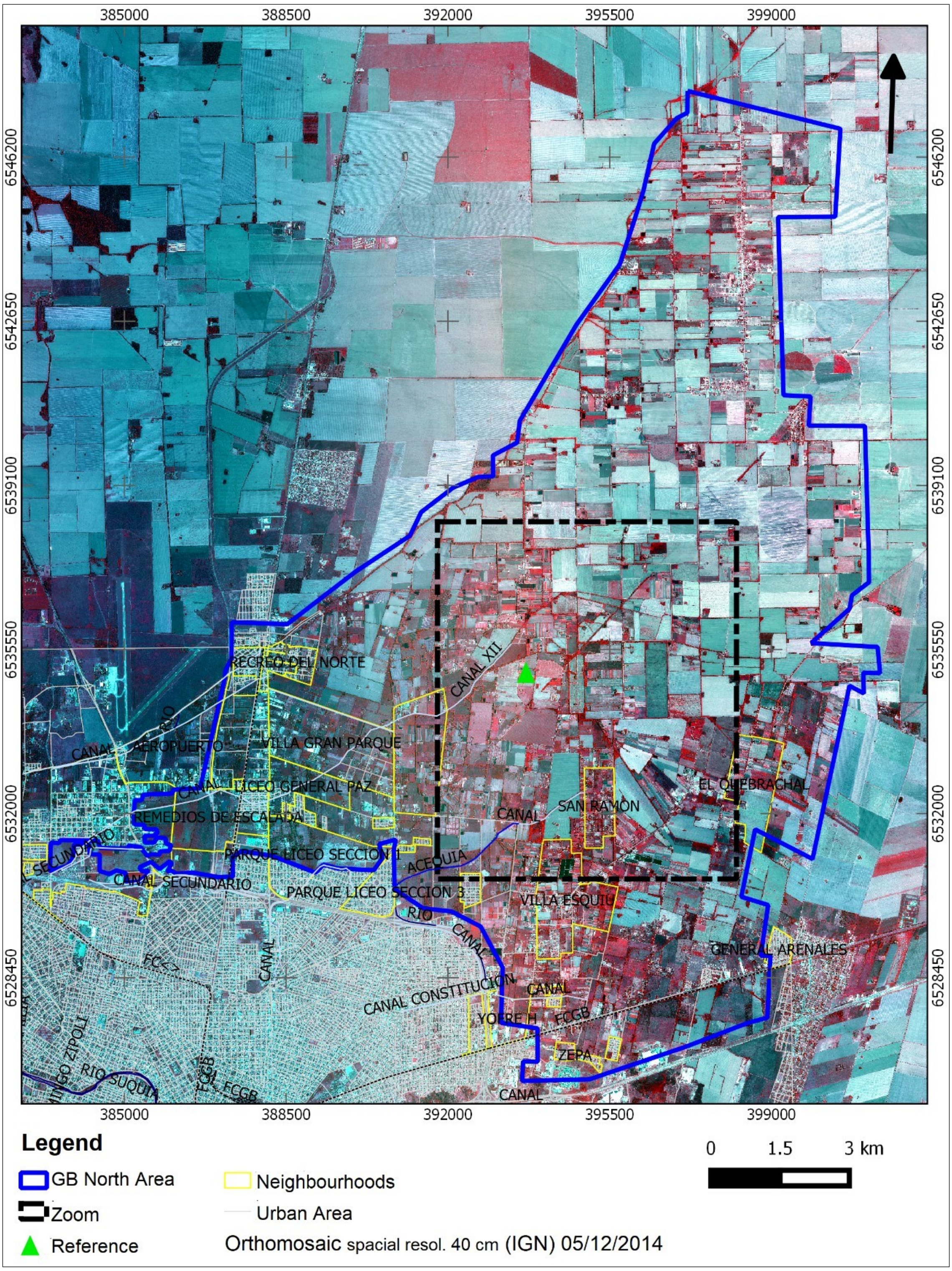

Figure 4a. Northern sector of the Green Belt of Córdoba. The image corresponds to an orthorectified mosaic generated by the Instituto Geográfico Nacional (IGN). RGB: NIR-Red-Green. (Date of aerial photographic flight: 1,2,3,4 and 5/12/14). IGN-Dirección de Sensores Remotos.

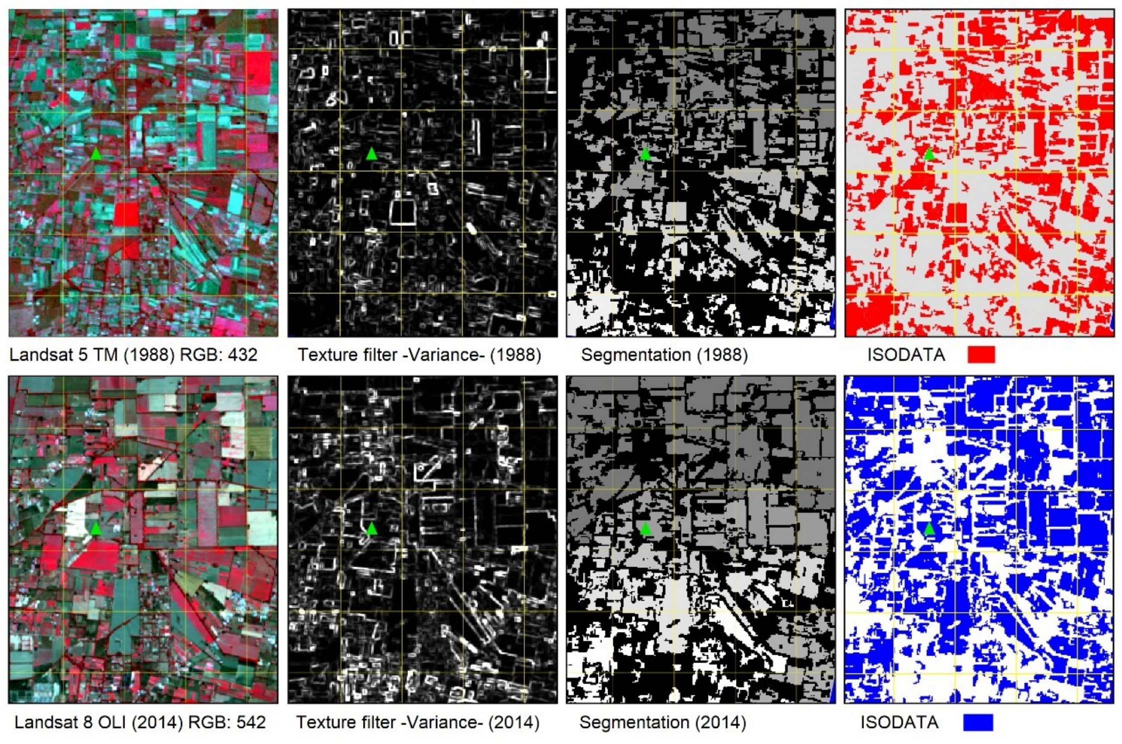

Figure 4b. Scheme of the processing for the identification of the parcel structure of a productive area of the northern sector of the Green Belt of Córdoba. The upper right quadrant (RGB: 421) represents the parceling situation in 1988. Down, the situation corresponding to the same sector in 2014 (RGB: 542).

absolute changes were recorded (Figure 5_a). In 1974, the neighborhoods Villa Esquiu, Villa Retiro, Villa Gran Parque, Zepa, San Ramon, Parque Liceo Seccion 3, Recreo del Norte, Villa Alicia Risler, El Quebrachal, Guiñazu, Aeropuerto, Los Boulevares, Maria Lastenia, Liceo General Paz, General Arenales, Parque Liceo Seccion 1, Remedios de Escalada and Yofre H already exhibited different levels of urban infrastructure given by the presence of streets or buildings, but not necessarily by the provision of services. Although barely developed, these neighborhoods exhibited, in relative terms, different levels of development in 2014.Thus, Parque Liceo Seccion 3 showed the highest change level, whereas El Quebrachal, which is far from the city, presented the lowest change level (Figure 5_b).

An "absolute" change was recorded for those neighborhoods that in 1974 were totally destined to fruit and vegetable production and other productive activities. A 100% change does not indicate that a neighborhood is currently totally urbanized, but that the zone was rural and exhibits urban uses at present. "Relative" changes are attributed to those neighborhoods which, by contrast, already had evidences of urban development in 1974 and that gradually expanded and occupied areas that were rural in the past. For these cases, the percent change explains the relationship between built area in the past and in the present (Figure 5_b).

Figure 6_a presents the historical urban area (in black) for 1974 and the current urban area (in red) for 2014. The area recorded for 1974 was approximately 7700 ha and the present area is about 14400 ha, which indicates an increase of 6700 ha for the entire periphery of the city, within the limits of the Capital department. This increase accounts for a 465 % growth over 40 years.

Land use was disorderly, particularly for the zones outside the Av. de Circunvalación (beltway). The analysis shows that the neighborhoods that exhibited the highest sprawl within Capital department are those distributed in the north-western area, close to the Sierras Chicas; however, this aspect was not quantified in this work because this area is outside the GBC.

Southern Zone of the Green Belt of Córdoba

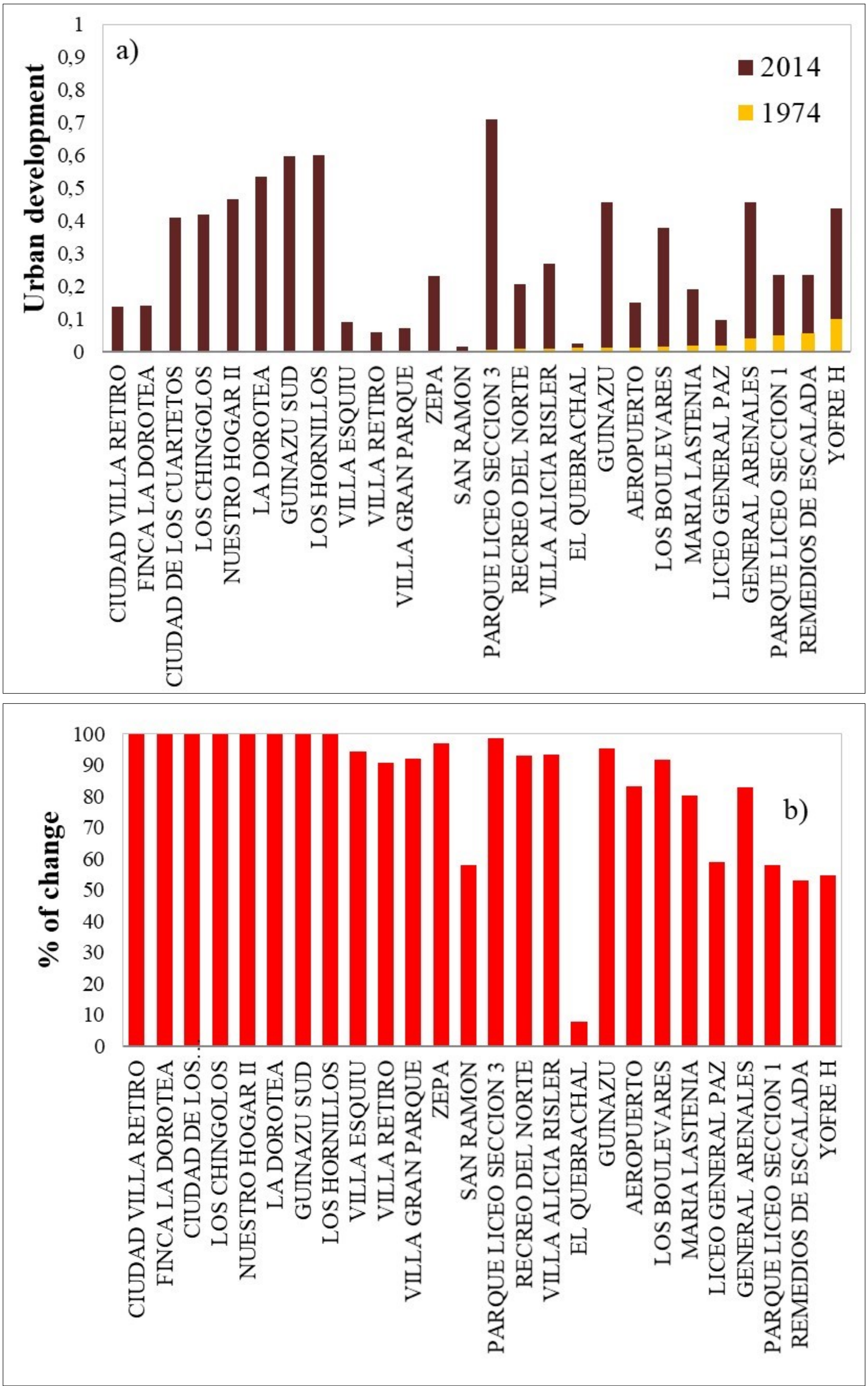

Figure 5a. Average urban development level for the neighborhoods of the Northern Zone. b. Changes (%) of the urban area for each neighborhood between 1974 and 2014.

Growth of the southern zone of the GBC was 33.2 % during the study period, which is a sensitively higher difference from that recorded for the northern zone (▲6.8%). The neighborhoods that did not exhibit urban zones in 1974 were: Ciudad Ampliacion Ferreyra, Quintas de Flores, 25 de Mayo, Country Fortin del Pozo, Quintas de Italia, Country la Santina, Rocio del Sur, Ciudad Obispo Angelelli, Villa Rivadavia, Inaudi, Ferreyra Segunda Seccion, Country Campina Del Sur, Country Los Mimbres, Posta de Vargas, Piedras Blancas and 23 de Abril. In increasing order, the neighborhoods with the greatest urban proportion at present (>50%) are: Tejas II, Nuestro Hogar III, Posta de Vargas, Piedras Blancas, Nuestro Hogar I, Villa Coronel Olmedo and 23 de Abril (Figure 6_a). The relative change with respect to the built area in 1974 was highest for the neighborhoods: Nuestro Hogar I, Villa Coronel Olmedo, Tejas II, Nuestro Hogar III, Las Canuelas, Fincas del Sur (above 90% of change) (Figure7_b). The only neighborhood that did not exhibit urban development over the study period is Ciudad Ampliación Ferreyra.

From a comparative perspective, for both zones, in most of the studied neighborhoods an overall greater urban development is observed in those neighborhoods that were rural areas in the past, whereas in the historically urban areas, the urban process was lower. In other words, urban growth occurred in new areas rather than in already urbanized sectors.

Analysis of Current Agricultural Land Cover and Use

Mapping results are presented in Figure 10. Soybean was the crop covering the greatest cultivated area (59500 ha), followed by maize (17477 ha), alfalfa (9724 ha), potato (6850 ha), and light vegetables (1780 ha) (Figure 8). Soybean was the prevailing crop, covering an area 24.5% greater than that of maize. The "mixed use lands" class (urban, rural and indeterminate zone areas), with an area of 34600 ha, and "urban areas", with 24740 ha, ranked second and third, respectively, in the general land cover ranking in the study area.

Mixed use lands covered 20 % of the total area; These zones are around the city, in which the rural and urban activities are distributed.

Production of intensive crops (light horticulture) covered 1% of the study area, whereas heavy intensive production covered 4% (with dominance of potato) (Figure 9, 10)

Classification Accuracy Assessment

Table 2 presents the summary of the calculated assessment measures, assigning 80 % of accuracy, which indicates an acceptable general result for the aim of this work. The Kappa obtained coefficient value defined the classification result as "very good" (76%). The variation of the results of the Kappa coefficient for each class indicates very good and excellent results for all the classes, except for the potato crops, forest and fallow, which were scarcely or not represented in the field sampling (Table 2).

In comparative terms, the "urban" class had the best classification assessment, without confusion due to loss or overestimation of data. The highest omission error corresponded to maize class, and was due to the confusion recorded with the potato class and "mixed used lands" (data not shown). These results mean that the classifier recorded a smaller maize area than the true area size. Likewise, potato crop had the highest commission value of the classification, since this class was mostly confused with light horticultural crops, i.e. the classifier falsely depicted a potato crop.

Analysis of the Dynamics of Agricultural Parceling (1988-2014)

The approach used to detect changes in size, distribution and number of agricultural parcels present in 1988 and 2014 was based on two procedures: 1) visual interpretation by combining both dates in false color composite (RGB; nIR-Red-Blue), and 2) analysis of size and shapes of segments associated with agricultural parcels using the previously described procedure (see 2.2). Notable differences between parcel distribution and size were visually differentiated for the northern GBC. Although the dates of analysis have a three-month difference for each year, it is evident that parcel distribution and size were reduced at the temporal scale analyzed. To estimate the relationship between size and number of parcels in the years analyzed, we applied the segmentation process, which allowed us to evaluate those differences without the need to classify the land uses of the past. Here, they were used to define the characteristics of the agricultural parceling. Figure $11_{a,b}$ shows a higher number of small farm parcels (in red) in

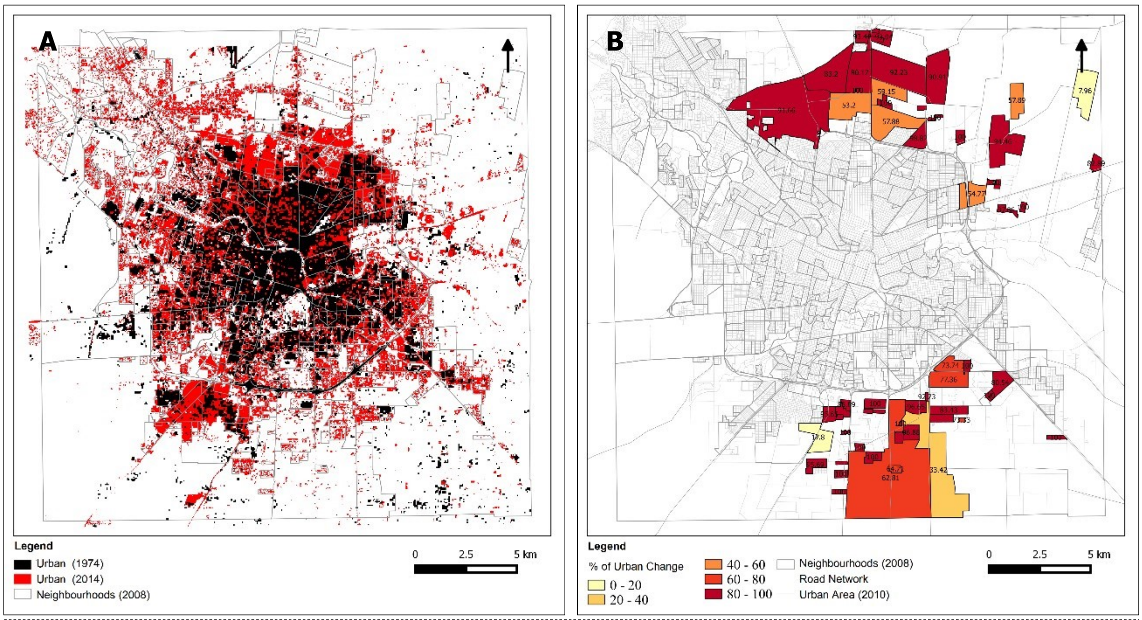

Figure 6a. Map representing the urban area in 1974 (in black), and in 2014 (overlapped in red). B. Percent change in the urban area per neighborhood.

Table 2. Results of the classification assessment based on the confusion matrix.

Class	Total Reference	Total classified	Correct Samples	Producer accuracy	User accurancy	Kappa
Urban	5	5	5	100%	100%	1
Soya	25	23	22	88%	96%	0.9412
Potato	3	8	3	100%	38%	0.3548
Corn	12	8	8	67%	100%	1
Forest	0	6	0	no data	no data	0
Mixed use land	22	17	15	68%	88%	0.8474
Fallow	1	0	0	no data	no data	0
Alfalfa	4	5	4	100%	80%	0.7913
Water	5	6	5	100%	83%	0.8242
Horticulture	19	18	15	79%	83%	0.7922
Total	96	96	77			
Overall Accurancy = 80,21 % - Kappa General=0,76						

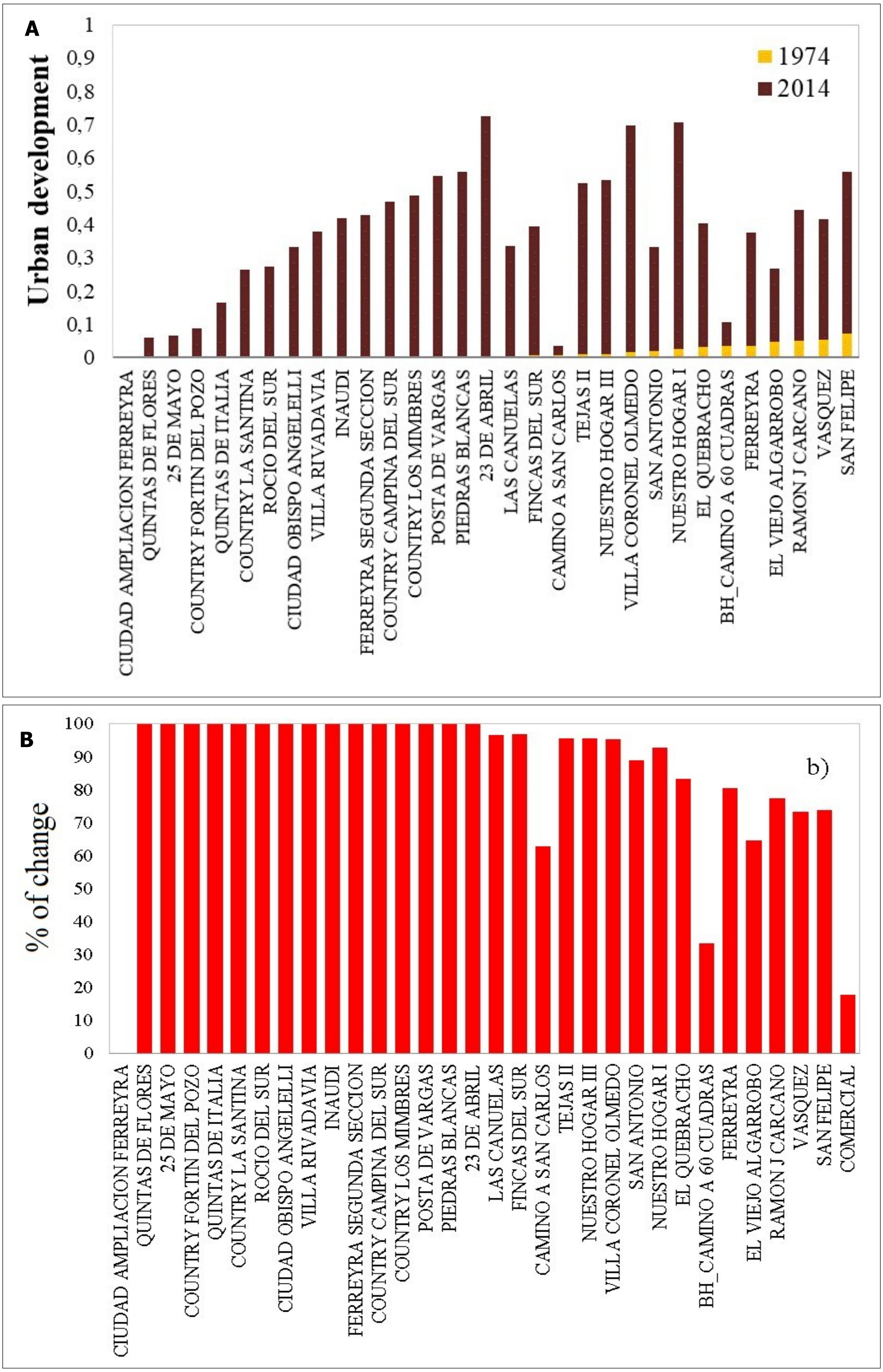

Figure 7a. Average urban development level for the neighborhoods in the southern zone. b) Changes (%) in the urban area per neighborhood between 1974 and 2014.

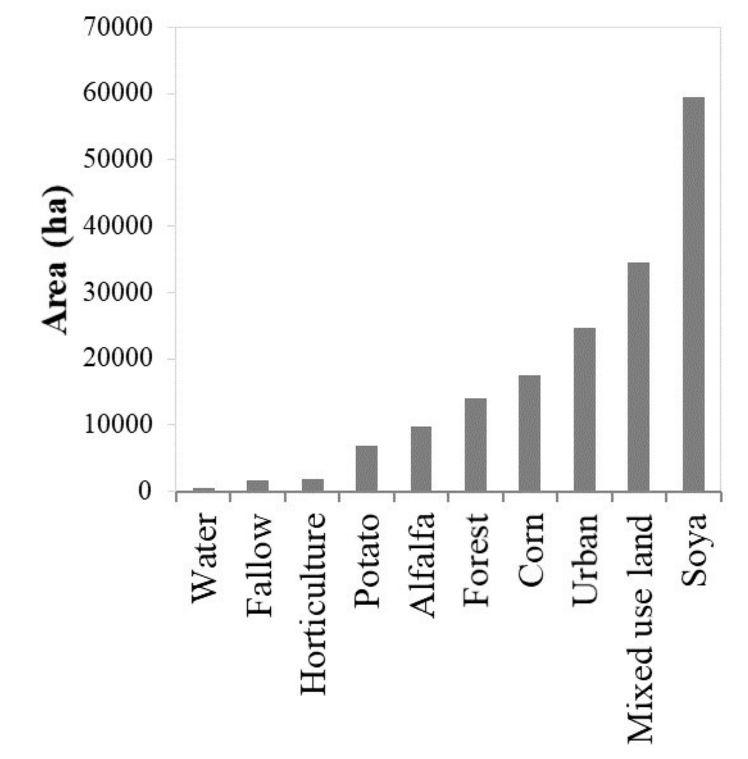

Figure 8. Areas of the mapped land cover and use classes.

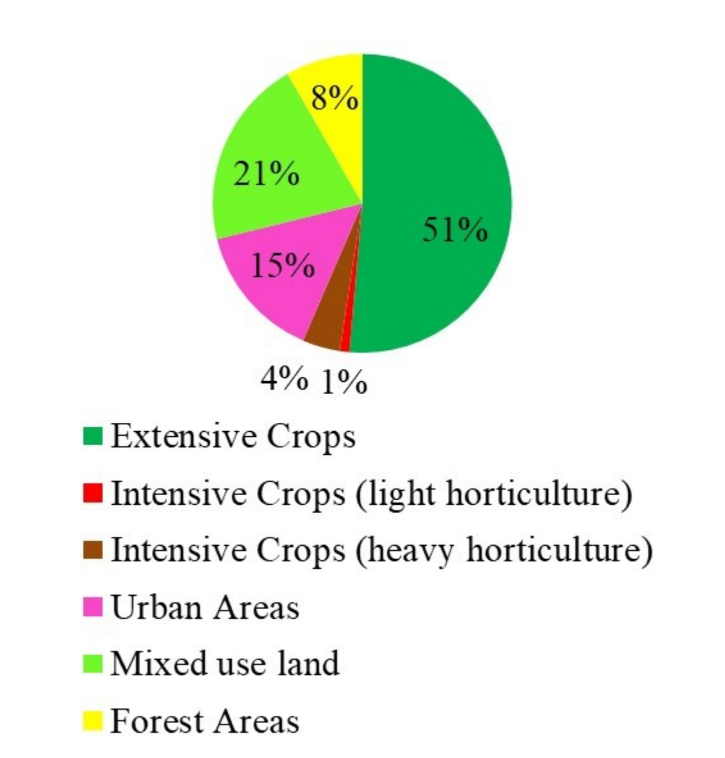

Figure 9. Cover types grouped according to type of crops and land uses in the Green Belt of Córdoba.

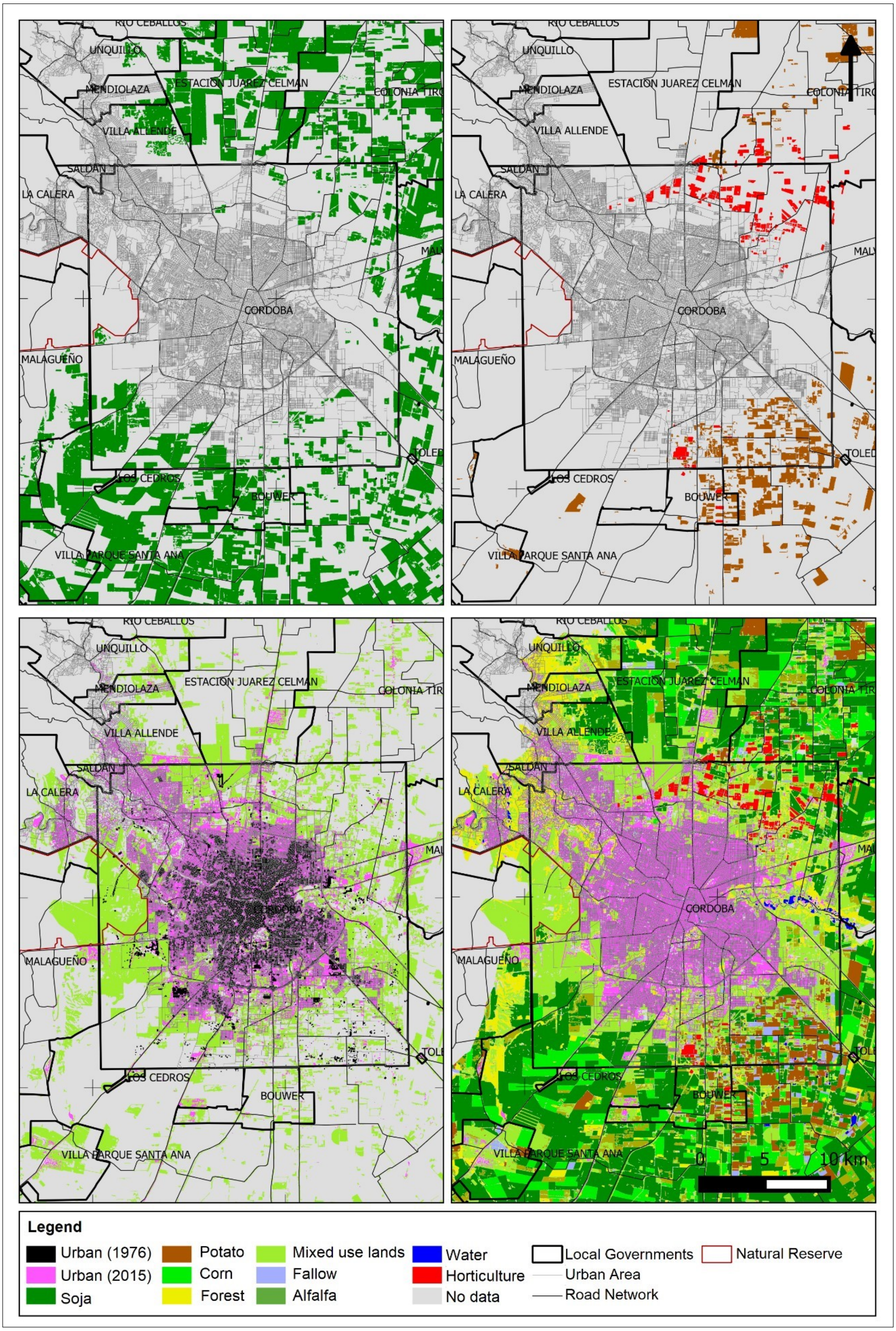

Figure 10. Land cover types and uses: Above (left): Distribution of soybean crops. Above (right): Distribution of intensive production. Below (left): Urban and mixed use zones. Below (left): Complete map of cover types.

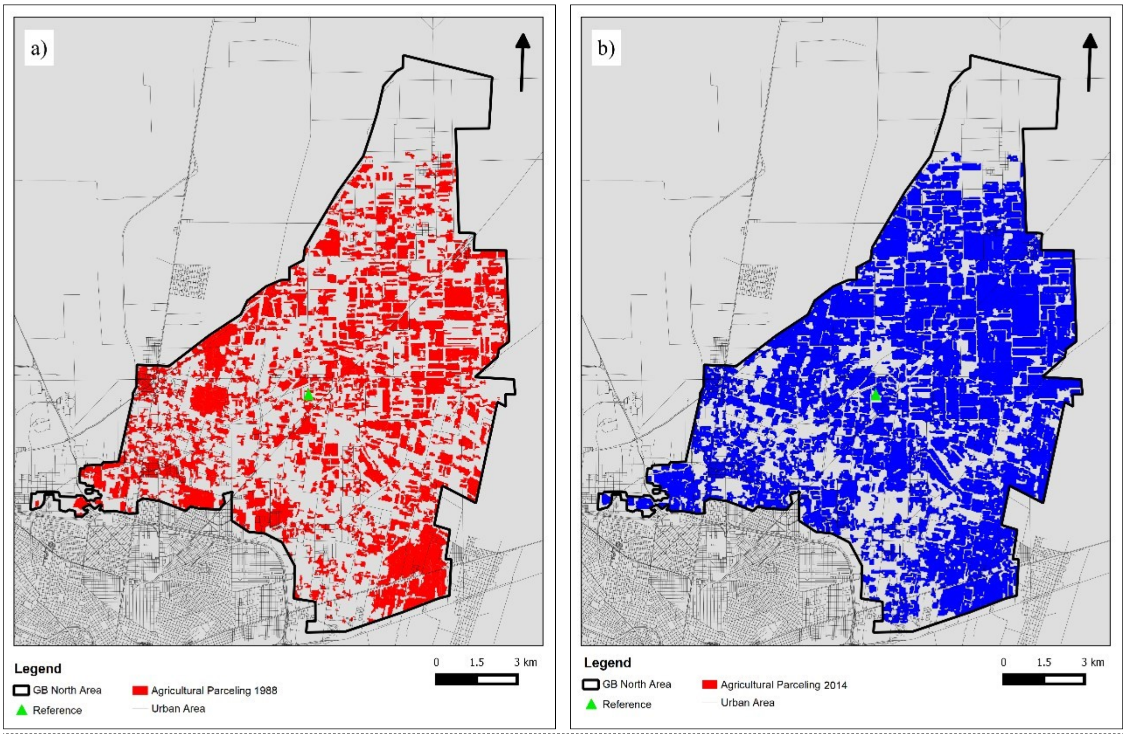

Figure 11. Results of segmentation and classification of agricultural parcels. a) Distribution and size of parcels for 1988 and b) for 2014.

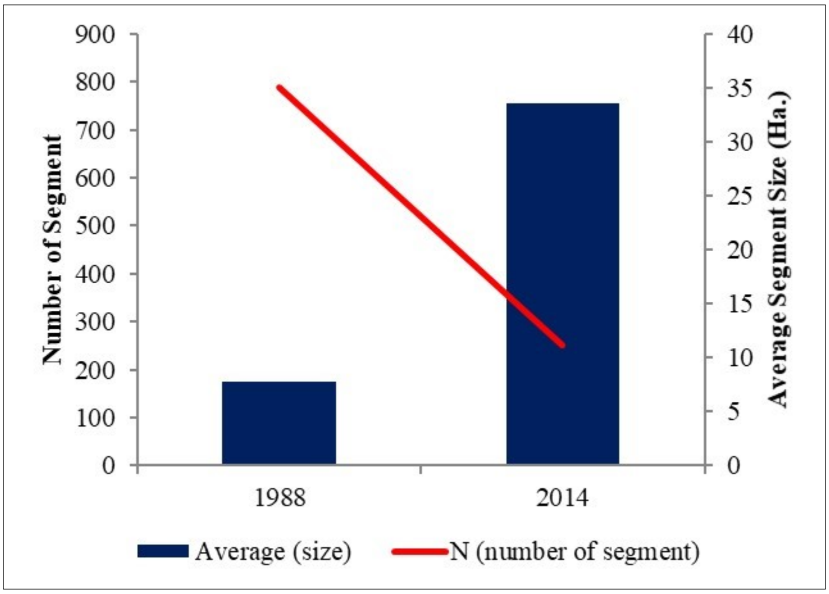

Figure 12. Size and number of agricultural parcels represented by homogeneous segments.

1988; by contrast, in 2014, a smaller number of larger parcels were recorded, which were devoted to extensive production, showing a land tenure concentration process. The reasons behind are related to technological adoption (mainly soybean monoculture) and its related socioeconomic impact. The concentration of land tenure has been the result of free market policies, which have defined the search for bigger production scales to reduce average production costs, implying that the larger the area, the greater the productive competitiveness.

Although the segment size may be over- or underestimated, the results of the analysis conducted provide a basis for making an estimation and support the hypothesis postulating the loss of production spaces devoted to intensive agriculture at the expense of the expansion of extensive agriculture due to soyization. Figure 12 illustrates that relationship based on the segments classified for each year.

Discussion and Final Remarks

In general, society has put an emphasis on the importance of urban green spaces, especially because recreational and landscape aspects are associated with a better quality of life. However, at present there is a new challenge: protecting peri-urban areas to ensure food production near the cities and to enable the continuity of traditional production practices.

This work evidences how the urban growth process in Córdoba city, through the expansion of the urban area, has had direct effects on the reduction of the productive agricultural areas. The urban sprawls and the change processes recorded in the productive systems have displaced small and medium scale productive businesses, which were replaced with residential plots, social housing and gated neighborhoods, as well as agro-industrial businesses. Accordingly, local producers have been forced to sell or rent their lands and migrate to produce in other localities, or to definitively abandon food production, which threatens the continuity of agricultural activity in the Green Belt of Córdoba. Future work is needed in order to assess the quality and continuity of quantification and classification of peri-urban horticulture. More complex procedures are needed to be developed such as machine learning techniques. The information must be immediately available to end users and the institutions who are involved in urban and rural planning.

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