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Comparative analysis of the production levels in the traditional and the expanding sugarcane planted areas in Tucumán province, Argentina

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ABSTRACT

In recent years, different factors have combined to create a favourable scenario for the expansion of sugarcane in Tucumán province, R. Argentina. This expansion implied the replacement of other plantations, especially grain crops, which are located mainly to the east and south of the area traditionally used for sugarcane crops, in regions with a higher probability of frost and lower rainfall. The zoning of agricultural areas allows for differential treatments depending on the variables that limit production potential. It requires information from different years, which can be obtained quickly through remote sensing and GIS. This paper aimed to distinguish the traditionally sugarcane planted area from the expansion area in Tucumán province, and to differentiate the production zones (low, intermediate and high) in both regions. A multi-temporal analysis of categorized images was conducted using GIS techniques. The thematic layers showing sugarcane crops by levels production for different years and the productive zoning generated from these layers were used as a baseline. Thematic coverages of the agrological regions were also used. The expansion of sugarcane plantations took place to the north, east and south of the traditional sugarcane area, covering mostly the agrological region of the Chacopampeana plain and, to a lesser extent, the Deprimida plain and the Pedemonte.

The environmental conditions in the expansion area led to the assumption of lower yields than in the traditional sugarcane area. However, higher percentages of intermediate and high production zones were found than in the traditional sugarcane area, which showed that proper management of the sugarcane crop is a major factor influencing the yield of sugarcane fields in Tucumán.

GIS analysis produced numerical and geographic information that is useful for crop statistics and serves as the basis for several studies of agronomic and economic nature.

Key words: Zoning, Remote sensing, GIS.

RESUMEN

Análisis comparativo del nivel productivo en el área cañera tradicional y en el área de expansión en la provincia de Tucumán, Argentina

En los últimos años, una serie de factores se conjugaron para crear un escenario propicio a la expansión del cultivo de caña de azúcar en la provincia de Tucumán.

La ampliación del área con cañaverales implicó la sustitución de otros cultivos, especialmente de los cultivos de granos, los cuales se localizan principalmente al este y sur del área tradicionalmente destinada a cultivos de caña de azúcar, en zonas con mayores probabilidades de ocurrencia de heladas y menores milimetrajes de lluvia.

La zonificación de las áreas agrícolas posibilita el tratamiento diferencial de cada zona de acuerdo a las variables que limitan el potencial productivo. Requiere de la información de distintas campañas, la cual puede ser obtenida rápidamente mediante el uso de la teledetección y los SIG.

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Los objetivos del presente trabajo fueron distinguir el área tradicionalmente destinada al cultivo de caña de azúcar del área de expansión en la provincia de Tucumán, y diferenciar las zonas de producción (baja, intermedia y alta) en ambas regiones.

El trabajo se realizó mediante un análisis multitemporal de imágenes categorizadas, empleando técnicas de SIG. Las coberturas temáticas utilizadas como base fueron las imágenes categorizadas surgidas de las clasificaciones digitales de caña de azúcar, la zonificación productiva generada a partir de dichas capas y las coberturas correspondientes a las regiones agrológicas de la provincia de Tucumán.

La expansión de los cañaverales se realizó hacia el norte, este y sur del área cañera tradicional, abarcando mayormente la región agrológica de la Llanura chacopampeana y en menor medida, la Llanura deprimida y el Pedemonte.

Las condiciones ambientales en la zona de expansión, caracterizadas por mayor probabilidad de ocurrencia de heladas severas, menores precipitaciones y cultivos de secano, permitían presuponer menores rendimientos que en el área cañera tradicional. Sin embargo se constataron mayores porcentuales de zonas de producción intermedia y alta que en el área cañera tradicional, lo que puso de manifiesto que el manejo adecuado del cultivo de caña de azúcar es un factor de gran incidencia en los rindes de los cañaverales tucumanos.

Los mapas temáticos generados constituyen una herramienta de gran utilidad para la elección de las prácticas agrícolas más adecuadas que aporten a la sustentabilidad del sistema productivo cañero. Por otra parte, sirven de base para análisis posteriores que incluyan otras variables de tipo ambiental, agronómico o económico.

Palabras clave: Zonificación, Teledetección, SIG.

INTRODUCTION

The sugarcane planted area in the Tucumán province comprises the agro-ecological regions of Pedemonte, Deprimida and Chacopampena plains (Zuccardi and Fadda, 1985). In each of these regions, the climatic, physiographic and edaphic characteristics are different, strongly influenced by the mountain range that runs from south to north, which generates different conditions and aptitudes for sugarcane crops. One of the most important variables is water resources: rainfall volumes, number of rainy days and relative humidity generally decrease from the west (Pedemonte) to the east (Fernández de Ullivarri *et al.*, 2015). In some localities of the Pedemonte, annual rainfall reaches 1,500 mm, while in the east of the Tucumán province it averages 700-800 mm (Romero *et al.*, 2015), which in principle would mean a lower productive potential, especially in drought years.

Another very important factor for sugarcane production is the occurrence of frost, which can cause sugar losses of up to 25%, as a result of a reduction in the quantity, and mainly the quality, of the raw material. The level of sugar loss is notably different between the Pedemonte, where even areas with a low probability of frost can be found, and the east, where they occur every year and with high degrees of severity (Leggio Neme *et al.*, 2015).

Both the importance of water for sugarcane growth, and the intensity of cold spells for defining sugar losses, mark in principle a differential in the productive capacity between the west and the east, which led the sugarcane planted area of Tucumán to lean preferentially towards the west, over in its 200 years of activity as an attempt to avoid the negative effects of periods of water deficit and intense cold spells.

The constant changes in crop production scenarios, mainly of an economic and productive nature, determine not only variations in the planted area but also rotations with other agricultural species.

Statistics on the sugarcane planted area in Tucumán show that in 1965 there were 210,000 ha. Between 1966 and 1968, 11 of the 27 sugar mills in the province were closed down. As a result of the deteriorating economic situation, the planted area was reduced to 135,600 ha in 1968 (Osatinsky, 2012).

There was then a period of stability between 1974 and 1992, with around 250,000 ha planted, until the last of these years when sugar activity was deregulated at the national level, causing a new economic crisis, which led to a reduction in the cultivated area to 183,390 ha by 2001 (Pérez *et al.*, 2019).

In recent years, the implementation of a national biofuels programme has been a decisive factor in the expansion of sugarcane crops in the Tucumán province. The opportunity for growth in sugarcane agro-industrial activity generated important investments in the fields, such as modern harvesting machinery, a notable increase in transport capacity, agrochemical applications, cultivation and soil preparation equipment, all of which resulted in a significant improvement in the productivity of the sugarcane fields by lowering costs and improving the quality and quantity of material per unit of surface area.

In addition, equipment was incorporated in the factories to reduce the cost of sugar production and technology, and capacity for alcohol production was acquired. It could be said that, as a whole, the agro-industry undertook a structural change in production that allowed it to advance in terms of efficiency and sustainability.

The result of these important changes was an improvement in the crop's profitability, associated with favourable prices, and the possibility of its use for biofuel production, backed by national law 26.093/06, which regulates and promotes the production and sustainable use of biofuels, and law 26.334/08, which promotes bioethanol production (Molina *et al.*, 2010; Fossati *et al.*, 2021).

In this process, sugar cane recovered and surpassed the 250,000 ha cultivated area that it had for many decades in the 20th century, before the abrupt fall from 1990 onwards. Thus, in 2021, the net harvestable area under sugarcane in Tucumán reached 276,400 ha (Fandos *et al.*, 2021).

The expansion of the area with sugarcane fields and the replacement of other crops, generated a process of expansion of sugarcane crops in Tucumán's grain-growing area in the last two decades, but mainly in the periods 2012-2014 and 2018-2020 (Fandos *et al.*, 2020).

It is worth mentioning that the displaced grain-growing area of the Tucumán province is located mainly to the east and south of the area traditionally used for sugarcane crops and generally has a higher probability of frost occurrence and lower rainfall millimeters. Figure 1 shows the average annual rainfall between the 2012/2013 and 2020/2021 growing seasons in localities belonging to the traditional sugarcane area (1A) and the traditional grain area (1B). The overall average for each area is also added. In both areas, the localities are situated from west to east and there is a negative gradient towards the east. If we also take into account that in practically the entire expansion area sugarcane crops are rainfed (Sanzano, 2014), it can be inferred that the environmental conditions in the expansion area are not the most appropriate for achieving high sugarcane yields.

The zoning of agricultural areas enables the differential treatment of each zone according to the variables that limit productive potential. It requires information from different growing seasons, which can be obtained quickly through the use of remote sensing and GIS. At the local level, Fandos *et al.* (2022) carried out a zoning of the sugarcane area of Tucumán, according to production levels, using a multi-temporal analysis of categorised images applying GIS techniques.

This work aimed to differentiate the area traditionally devoted to sugarcane crops from the expansion area in the Tucumán province, and to differentiate the production zones (low, intermediate and high) in both regions.

MATERIALS AND METHODS

The scope of this study includes the area cultivated with sugarcane in the Tucumán province, Argentina (Figure 2). It comprises the agro-ecologic al regions of Pedemonte, Deprimida and Chacopampeana plains (Zuccardi and Fadda 1985). The climate is subtropical with a distinct dry season and is characterized by warm temperate climatic conditions, hot and humid summers, and dry winters. The rainfall regime is monsoonal, with 50% to 60% of the total rainfall recorded between December and March.

The study was carried out by a multitemporal analysis of categorised images (Chuvieco, 2008), using GIS techniques. These categorized images are digital thematic maps in raster format generated from classifications of the images acquired by remote sensors. Thematic layers of sugarcane crops for the 2001 and 2021 growing seasons, analysed in Fandos *et al.* (2012) and Fandos *et al.* (2021) were used as a baseline. Thematic layers were generated from multispectral classifications of Landsat 8 OLI and Sentinel 2A and 2B MSI satellite images, obtained from

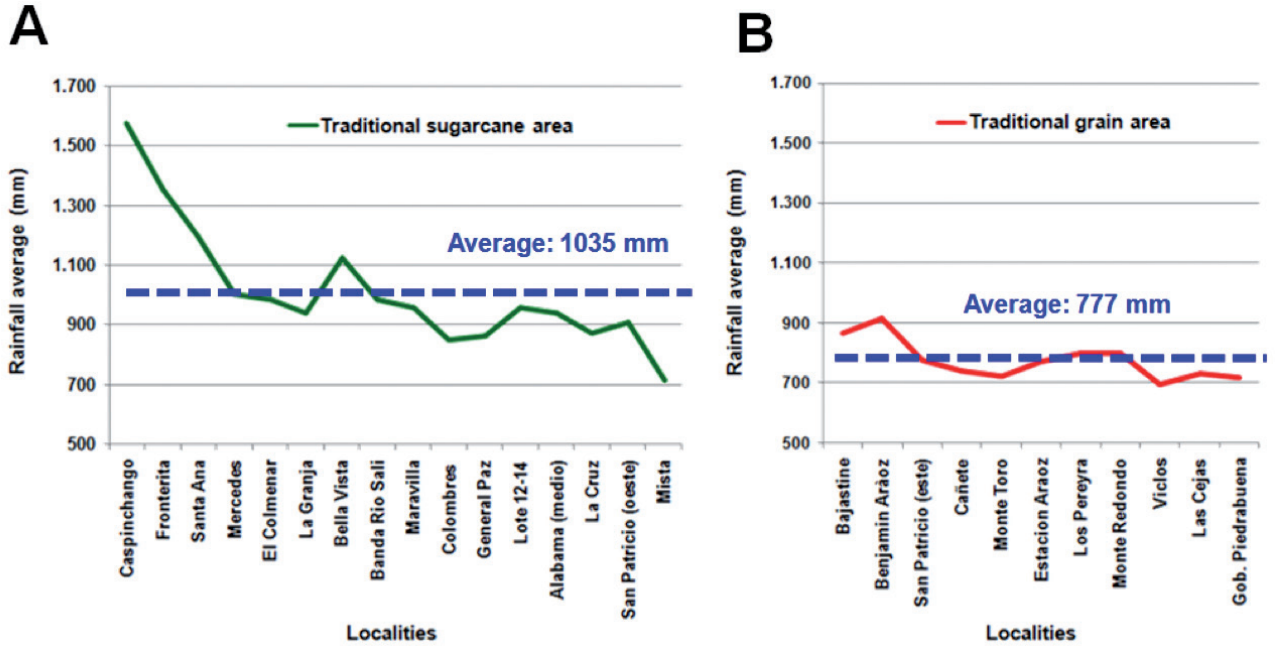

Figure 1. Average annual rainfall between the 2012/2013 and 2020/2021 growing seasons in localities of the traditional sugarcane planted area (1A) and the traditional grain planted area (1B). Tucumán, Argentina. Source: own elaboration with data taken from https://agromet.eeaoc.gob.ar

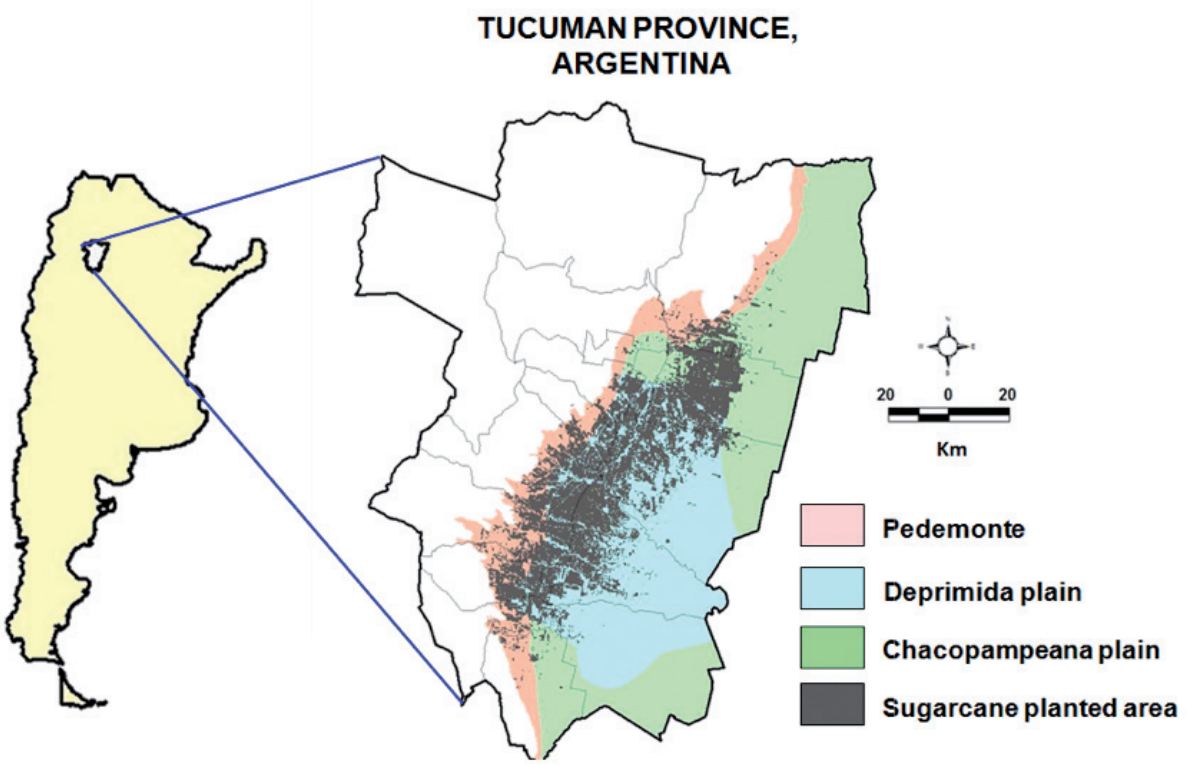

Figure 2. Location of studied area. Tucuman province, Argentina.

https://catalogos.conae.gov.ar/landsat8/ and https://scihub.copernicus.eu/dhus/#/home, respectively. These satellite images were geometrically corrected with a reference system corresponding to the map projection: Posgar 94, Datum WGS 84. The sensors used are passive, i.e. they receive energy from an object illuminated by an external source, usually the sun. Multispectral classifications were made by analyzing the spectral bands located in the Red, Near Infrared and Middle Infrared, where vegetation has its greatest spectral response. The bands analyzed were 4, 5 and 6 from the Landsat 8 OLI satellite, and 4, 8 and 11 from Sentinel 2A and 2B MSI.

The coverage with sugarcane zoning area according to production levels (Fandos et al., 2022) was also used as a baseline. To obtain this layer, sugarcane classifications according to production levels between 2011 and 2020 were used as a basis. The layers contained three categories, according to cultural yield: low, medium and high. For the analysis, pixels corresponding to the low, medium and high levels were assigned the values 1, 10 and 100, respectively. For the sugarcane area zoning, three production zones were considered: low, medium and high. The assignment of classes to each zone was made considering the highest value, depending on whether it was located in the unit, ten or hundred. Classes with no predominance of values were assigned by prioritising the lowest production level.

In the present work, the coverage corresponding to zoning by production levels was updated, incorporating information on production levels for the 2021 growing season (Fandos *et al.*, 2021).

The coverage of production zones was then superimposed with those corresponding to the area occupied with sugarcane crops in 2001 and 2021, which allowed the differentiation of production zones in the initial area of the study and in the expansion area.

Subsequently, the coverage of production zones was superimposed with that corresponding to the agrological regions of the Tucumán province (Zuccardi and Fadda, 1985).

The software used was ERDAS Imagine (version 8.4.) and ARC GIS (version 9.0).

RESULTS AND DISCUSSION

Figure 3 shows the initial sugarcane plantation area in 2001 and the sugarcane crop expansion area as surveyed in 2021, with the different production zones discriminated from one another.

The spatial distribution of the production zones in the initial sugarcane area and in the area of recent expansion, according to agrological regions, is shown in Figure 4.

Figure 4 shows that, although low production zones are present throughout the sugarcane area, they are predominant in the central sector of the Deprimida plain. This may be associated with the presence of a water table relatively close to the soil surface which suffers lacks of a defined drainage network in the eastern sector. This combination leads to the accumulation of excess water, which is detrimental to the productive quality of the soil (Sanzano, 2019).

In the Chacopampeana plains, low yields could be associated with the growing water deficit towards the east and a low structural stability of the soils due to low silt

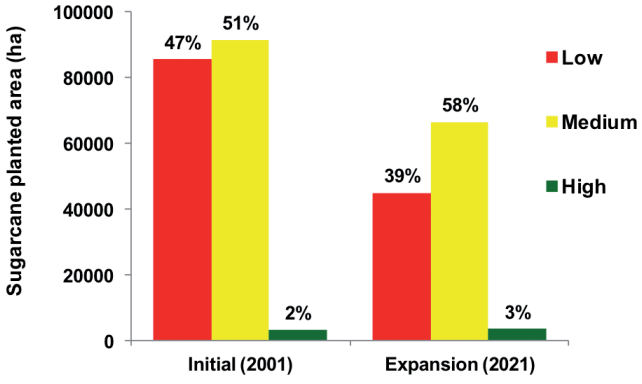

Figure 3. Sugarcane area according to production zones in the initial sugarcane area of the study (2001) and in the recent expansion area. Tucumán, Argentina.

contents. This generates conditions conducive to large-scale surface runoffs that cause moderate to severe water erosion processes. In the Pedemonte region, low yields could be related to the lack of adequate management to mitigate the negative effects of torrential rainfall, which, together with steep slopes and soils with low water retention capacity, generates soil losses due to water erosion (Sanzano, 2019).

The higher percentages of zones with intermediate and high production in the expansion area contradict the theory that meteorological conditions would not be the most appropriate for achieving high sugarcane yields (Figure 1). The explanation could be that, in addition to the physical and chemical aspects of the soil, the yield of most sugarcane fields in Tucumán is greatly influenced by aspects related to crop management, which is conditioned, in turn, by the size of the plots and land tenure regime. It is exactly crop management what allows either overcoming physiographic and edaphic limitations, or simply not taking advantage of environments suitable for sugarcane growths.

The traditional sugarcane planted area has more than 200 years of uninterrupted production in general, while the expansion area has a productive background mainly in the cultivation of soybeans. It has been shown that the impact of sugarcane/soybean rotation under the conditions analysed is very important. There are precedents that indicate that the rotation of sugarcane fields with soybean results in improved sugarcane yields during its life cycle, as well as better conservation of the soil resources (Giancola *et al.*, 2012). Garside *et al.* (2001) indicated that properly managed soybean crops can improve the yield of the ensuing sugarcane crop cycle by 20% to 30% in the first and second harvests, respectively.

Another factor to consider is new production technologies, such as green cane harvesting and management of the cane field with crop residues, which

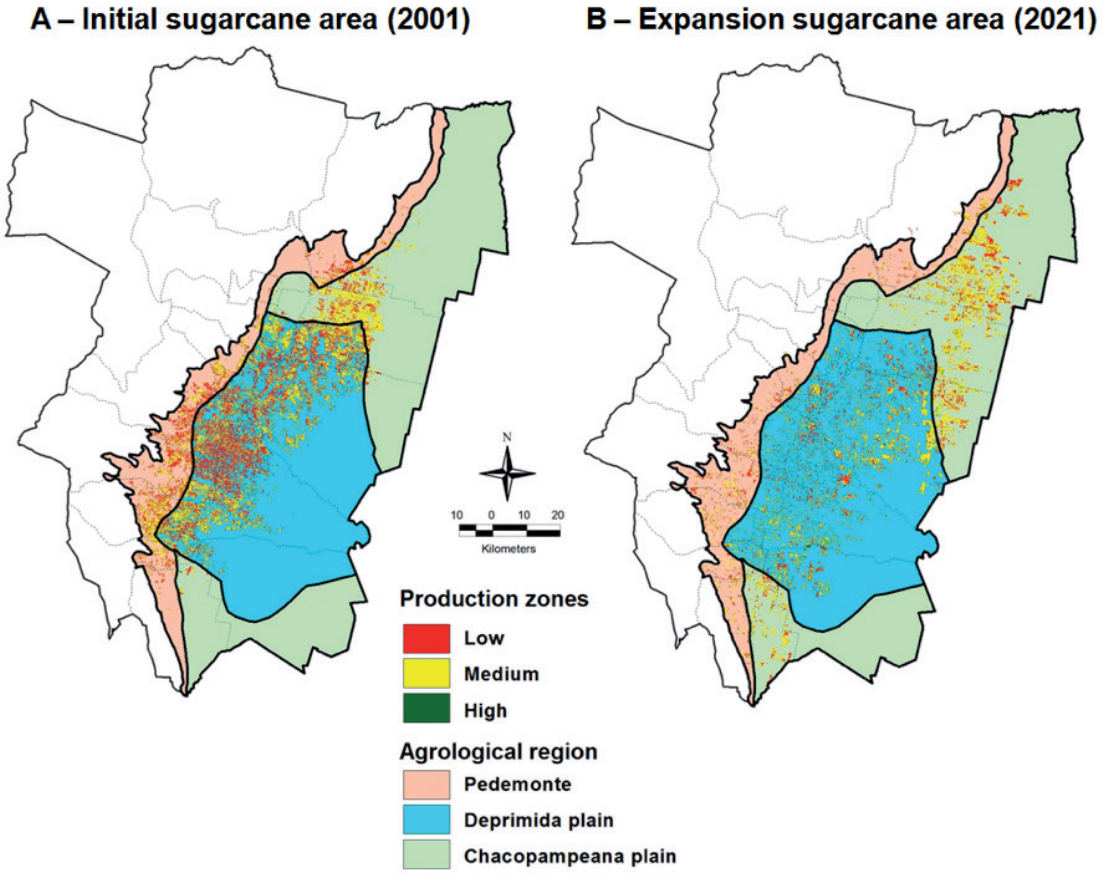

Figure 4. Spatial distribution of sugarcane production areas according to agrological regions. A: Initial study area (2001). B: Recent sugarcane expansion area. Tucumán. Argentina.

have been shown to have an important impact on production levels, especially in areas with lower water availability (Fernandez de Ullivarri *et al.*, 2021).

In addition, the incorporation of the mechanical harvesting system has made it possible to prioritise harvesting in areas with the greatest presence and incidence of cold weather on raw material quality. At this point, it is important to highlight that mechanised harvesting must be carried out at the optimum speed and in suitable soil conditions to minimise the risk of damage to stubble, which can lead to reduced cane longevity (Fernandez de Ullivarri *et al.*, 2015).

Finally, it is worth mentioning that in the sugarcane expansion area there is a predominance of medium and large producers, who apply maximum levels of technology in the management and harvesting of sugarcane. In this sense, intermediate and high production areas prevail in the region of the Chacopampeana plain, the northern and southern sector of the Deprimida plain and the southern sector of the Pedemonte, coincidentally with departments where producers or sugarcane companies have a larger economic scale and a diversified production base (Benedetti *et al.*, 2019), together with negotiating power in the market. By contrast, in the traditional zone a significant percentage is managed by small producers, mainly in the central sector of the Deprimida plain. This area is characterized by small-scale sugarcane production with low technology, family labour (Santillán *et al.*, 2012) and a high concentration of sugarcane burning (Carreras Baldrés *et al.*, 2021). It is worth mentioning that smallholding is a constraint to both the incorporation of technology and the adoption of good agricultural practices, as this type of farming is rooted in traditional monoculture and ancestral cultural practices (Giancola *et al.*, 2012).

CONCLUSIONS

Sugarcane crops expanded towards the north, east and south of the traditional sugarcane planted area, covering mostly the agrological region of the Chacopampeana plain and, to a lesser extent, the Deprimida plain and the Pedemonte.

The environmental conditions in the expansion area, characterised by a higher probability of severe frosts, lower rainfall, and rainfed crops, led to the assumption of lower yields than in the traditional sugarcane planted area. However, higher percentages of intermediate and high production zones were found than in the traditional sugarcane planted area, which showed that proper management of the sugarcane crop is a major factor influencing yields of sugarcane fields in Tucumán.

In some cases, sugarcane field management makes it possible to overcome physiographic and edaphic limitations; in other cases, good environments for sugarcane cultivation are not taken advantage, and this is greatly influenced by the size of the plots and the land tenure system, which condition access to new management technologies.

The thematic maps generated facilitate the identification of different production zones in the different agrological regions, which is a very useful tool for choosing the most appropiate and sustainable agricultural practices for sugarcane production. On the other hand, they serve as a basis for subsequent analyses that include other environmental, agronomic or economic variables.

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