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Spatial distribution of irrigation systems using geographic information technologies in sugarcane areas

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Abstract: The projection of irrigation and drainage systems in sugarcane agriculture requires precise information on the natural conditions, the physical geography of the territory, the soil, the climate and the response of the crop to water. This work allows us to analyze the results of the implementation of geographic information systems (GIS) for spatial distribution of irrigation technologies in sugarcane areas of the Matanzas province. The physical and topographic characteristics of the soils, water availability, energy sources, location and available workforce were considered. Global positioning systems (GPS) were used for georeferencing and field measurements. The study allowed the projection of irrigation systems in the most favorable areas (5,567.39 hectares), with precision and efficiency. Of these, 1,805.2 hectares were favored with reels' machines and 3,762.19 hectares with central pivot machines, represented by geographic reference maps and relevant databases. This is crucial for decision-making and precision agriculture.
Key words: geographic information systems (GIS); sugarcane; soils

1 Introduction

Under the soil and climate conditions in Cuba, the total annual water demand for sugarcane is between 1,683 and 1,880 millimeters, of which 300 to 600 millimeters must be irrigated according to different soils, climate zones, varieties, and planting ages. Although the average annual rainfall in the country is about 1,450.5 millimeters, the distribution throughout the year is extremely uneven; The annual average rainfall reported by Matanzas Province is 1,386.1 millimeters (Onei Cuba, 2021).

Therefore, irrigation is an essential benefit for pipeline plantations, and when crops are properly cared for, irrigation can promote yield increases of over 40 ton ha^{-1} (Lamelas, 2008). Research on crops in typical red iron soil has shown a significant difference between irrigated area and rainwater irrigated area, with sugarcane plants increasing their yield per hectare by over 25% (Cajigal, 2020).

Land water is a renewable and limited natural resource that requires effective planning to ensure its conservation is coordinated with sustainable economic and social development (ANPP-CUBA, 2017).

In this regard, Cuba has made significant economic investments to revitalize irrigation and drainage activities in pipeline agriculture, with a focus on scientific and rational planning. This is based on the *Economic and Social Policy No.*

164 of the Party and Revolution, which involves the continued restructuring and development of irrigation and drainage activities, combined with advanced technology (PCC Cuba, 2017)

Geographic information systems (GIS) are supportive tools for conducting territorial analysis, and their development facilitates the processing, organization, and handling of a wide range of geographic reference information from different sources (Palacio, 2017). The natural geography of the territory, existing natural conditions, soil and its characteristics, climate, and crop response to water are variables that can be mapped and incorporated into GIS (A. Chinea&Rodr í guez, 2019). At present, the planning, organization, management, evaluation, and operation processes of the agricultural sector require the establishment of effective information management and analysis systems in terms of processing speed, storage capacity, multifunctionality, and reliability (Chambilla, 2019; Galicia and Ventura, 2018). In Cuba, there is little work related to the use and regionalization of GIS for sugarcane water demand (Chinea et al., 2021). Nevertheless, important steps have been taken in several disciplines, including irrigation and drainage activities, which have broad prospects for agricultural development in the country (Chinea & Rodríguez, 2021).

Based on geological processing, a uniform area related to soil characteristics, climate, terrain, variety, and planting age can be determined at an appropriate scale, and joint analysis of spatial expression of territorial variables can be conducted as a starting point for establishing types aimed at improving water resource availability. In this regard, the purpose is to analyze the implementation results of geographic information systems based on the spatial distribution of irrigation technology in the pipeline area of Matanzas Province.

2 Materials and methods

This study was conducted on 50,835.8 hectares of land in the province of Matanzas, which is used for sugarcane cultivation and is located in the sugar companies of the Republic of Spain, Renefraga Moreno, Mario Munios Montroy, and Jesus Rabi. The Canelo plot is located at coordinates 22 ° 20'20 "and -81 ° 40'41" north latitude, concentrated in the northern and central parts of the provincial territory. Soils formed from ferralitization and sialitization (Hernández et al. 2015) processes predominate with a greater preponderance for the former as they cover 64.22% of the sugarcane area (García et al., 2018).

According to data from GEARH-CUBA (2014), the climate observed over 30 years exhibits different behaviors. The rainfall indicates that there is an average drought period of 301.5 millimeters from November to April (December is the driest month, at 29.2 millimeters), while the average rainfall period from May to October is 1,168.2 millimeters (June is the wettest month of the year, at 260 millimeters). The annual average temperature is 28.4 to 21.5 degrees Celsius, with an average temperature of 24.5 degrees Celsius. The lowest temperature occurs in January (21.1 degrees Celsius), and the highest temperature occurs in August (average 28.4 degrees Celsius).

For the preparation of the digital databases, the geographic and thematic components of the available spatial and thematic databases were readapted. The specialized sugarcane cadastre was used, taking the sugarcane block as the minimum management unit of each sugarcane company, at a scale of 1:10,000. The National Soil Map expanded to a scale of 1:25,000 (Minag-Cuba (1999), the database of the Evaluation of the Physical Aptitude of Land for Sugarcane (Cortegaza et al. 2001), the Agricultural Database (BDA) of each sugarcane company and the climatic database were used (GEARH-Cuba 2014).

The methodologies referred to in the manual for the organization and operation of the *Land Management Service of MINAZ* [SEROT] (INICA-Cuba (2009), the methodology for the creation and updating of the specialized cadastre in sugarcane agriculture (GEOCUBA (2006) and the manual of the *Integral Service for the Exploitation of Irrigation and Drainage [SIERIED] of MINAZ* were used (INICA-Cuba 2008).

The transformation and standardization of digital formats, the digital processing of the available databases and the digital export of geographic information were carried out using the free software ILWIS Ver. 3.4. The rectangular plane coordinates of the National Geodetic System (Geodetic Datum NAD27, Cuba North) were used. The compatibility of working scales was determined from the analysis of the different spatial databases, opting for the 1:25,000 scale for the outputs. ILWIS editing tools were used to vectorize the center pivot irrigation machines with the buffer technique or area of influence, which describes a circumference calculated according to the characteristics of each system and its dimensions. The contours of the polygons corresponding to the areas to be benefited by the sprinklers or reels were vectorized from the existing digital cartography and the direct editing method was used on the PC screen. The calculation of the physical area and the determination of the coordinates of the central points or nodes of each irrigation system were complemented in the field with the use of global positioning systems (Mitsikostas, 2017). The information was verified by visual inspections in the field with the support of producers and irrigation and drainage specialists of the sugar companies.

3 Results and discussion

Geographic information systems provide a high degree of flexibility and operability for spatial analysis and feature description of planned irrigation systems, which is consistent with the results obtained (Ríos 2021). In Figure 1, the proximity of a portion of the synthetic map can be seen, where a drainage area with suitable soil and physical structure conditions for irrigation system location can be identified through digital earth processing and the technique of superimposing thematic layers. In addition, with the execution of SQL queries, the most important attributes are defined to make way for the created tables.

The simple movement of the cursor (mouse) over the resulting digital map allows detailed information bars of the projected systems to be deployed. In Figure 1, it is observed as an example, that the central pivot irrigation system (red color), has the following edaphic characteristics: typical Red Ferralitic soil, flat slope, moderately well drained drainage, compacted soil and category A2 (moderately suitable), according to the Assessment of the Physical Aptitude of the Lands for the Cultivation of Sugar Cane of the Province of Matanzas (Cortegaza et al., 2001).

The digital database provides factors that may limit the assembly of each system in each research area, mainly considering its projection: the size of the management unit (block and drainage field), providing high-quality water sources within an economically acceptable distance, suitable soil for production, and no adverse drainage problems, relatively easy to obtain power supply, system features, and terrain leveling elements.

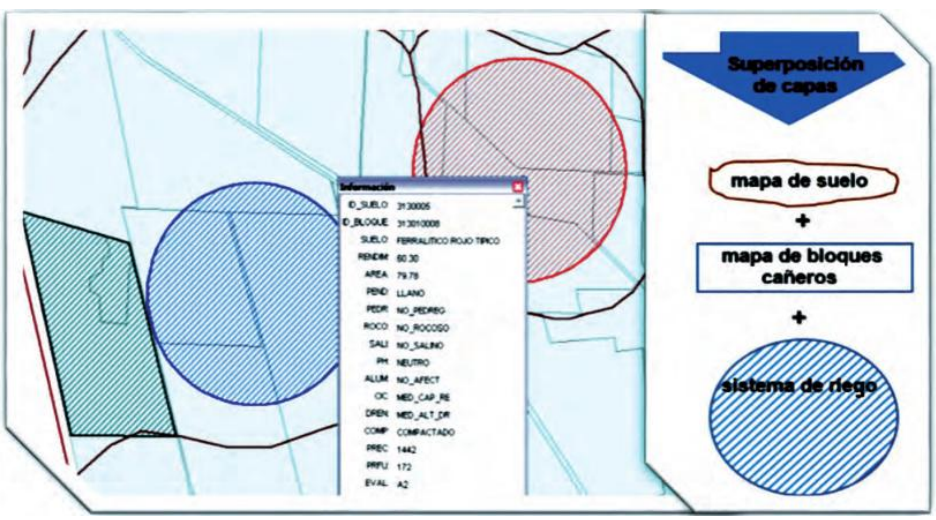

Figure 1. Section of the spatial distribution map of irrigation systems of the Mario Muñoz Monroy sugar company
On the right are shown the main thematic layers that overlap and the associated thematic information display.

Table 1 describes in three columns the main thematic vector layers named: sugarcane blocks, soil map and irrigation system; the rows show the main fields that compose them.

Table 1. Main vector layers and fields that make up the output databases

Thematic layers			
Fields	Sugarcane	Land map	Irrigation system
	province	province	province
	company	company	company
	unit	unit	unit
	block	block	block
	area	area	system number
		type of soil	area
		performance	system type
		pending	Annual assembly
		stoniness	coordinate
		pH	
		CIC	
		drainage	
		compaction	
		depth	
		current_use	

The first five fields of each thematic layer allowed the territorial identification of the position of each system, according to the province, the company, the production unit, the block and the sugarcane fields that compose it. The sugarcane blocks layer provides information on the administrative structure of the sugar companies and their contours, the production units, the sugarcane blocks that comprise them and the identification of the sugarcane areas where the irrigation systems are located. The soil map layer provides relevant information on soils and their edaphic properties, as well as the main factors that may limit irrigation activity. The irrigation system layer identifies the system number, the area covered, the type of system to be projected and the coordinates of the central point.

In similar studies (Perez et al. 2019), parameters related to working time, amount of water applied and angle of rolling were recorded. The authors propose that these databases constitute the complement of precision agriculture in irrigation and drainage activity.

Table 2 shows an example of a report or alphanumeric table obtained in the GIS, with the distribution of the reeling technique in the Jesús Rabí sugar company. Each projected system is identified with the name of the sugar company to which it belongs, a consecutive number or identifier that differentiates it from the rest of the systems, name or code of the production unit to which it belongs, code of the block where it is located, area it occupies and the X and Y coordinates of its central point or node.

Table 2. Distribution of the reeling technique in the Jesús Rabí sugar company

Company	No. Sist.	Unit	Block	Area (hectares)	Coord. X	Coord. Y
Jesús Rabí	1	BSR*	BSR	140,02	512,517	300,300
Jesús Rabí	2	FINCA	FINCA	106,67	511,994	299,349
Jesús Rabí	3	07	711	51,42	510,386	294,713
Jesús Rabí	4	03	314	28,20	517,261	299,330
Jesús Rabí	5	08	815	47,80	507,775	290,875
Jesús Rabí	6	19	1912	48,81	509,262	302,531
TOTAL	**6**			422,92		

In the example presented, the Jesús Rabí sugar company benefits from 422.92 ha using the rolling technique, which is favorable for the development of quality seeds. Similar results were obtained in tables, reports and maps for all the center pivot machines and reelers in the four sugar companies.

Table 3 shows the total balance of the distribution of irrigation systems by technique and the area they occupy in each sugar company.

Table 3. Distribution of center pivot machines and reelers in the sugarcane areas of Matanzas province

Sugar company	Central pivot machines		Enrollers	
	total	area (hectares)	total	area (hectares)
Jesús Rabí	19	1,440.53	6	422.92
René Fraga Moreno	8	626.01	7	345.95
España Republicana	11	834.24	6	354.94
Mario Muñoz Monroy	11	861.41	8	681.39
Total/Province	49	3,762.19	27	1,805.2

This result facilitated the identification of irrigation potential, the elaboration of technical executive projects according to soil type and the balance of sites with groundwater availability that did not have wells, in order to coordinate their possible sustainable exploitation and rational use of water (GOC-2017-716-EX51, 2017).

Forty-nine central pivot machines covering 3,762.19 hectares and 27 reelers covering 1,805.2 hectares were projected for a total of 5,567.39 hectares to be benefited, which represents 11% of the total area occupied with grass in the province. Figures 2, 3, 4 and 5 show, by means of thematic maps, the spatial distribution of both central pivot machines and sprinkler polygons in the España Republicana, Mario Muñoz Monroy, Jesús Rabí and René Fraga Moreno sugar companies, respectively. These are superimposed on the layer of sugarcane blocks (green polygons). This distribution responds to the variables, characteristics of the territory, main sources of supply and the technical particularities of the irrigation machines.

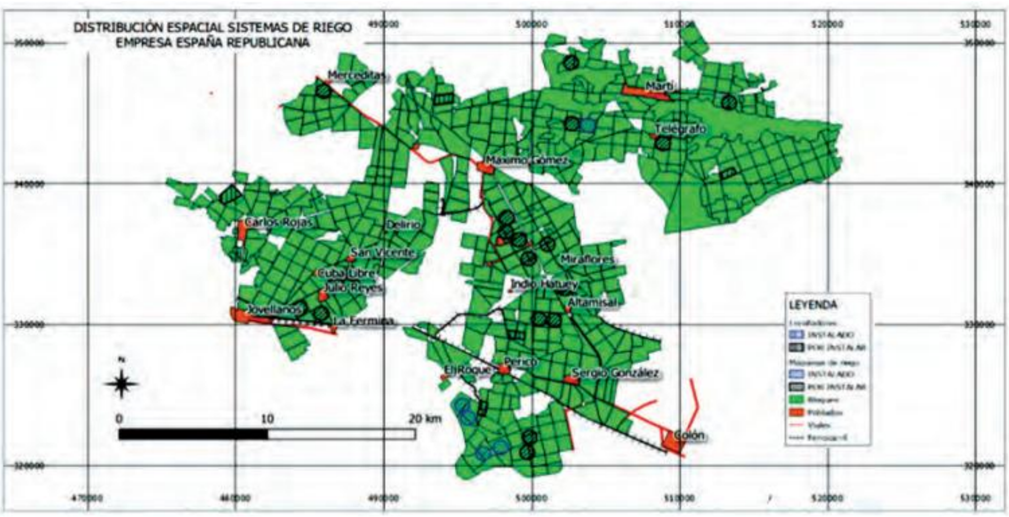

Figure 2. Map showing the spatial distribution of central pivot machines and sprinkler polygons at the Spanish Republic Sugar Factory

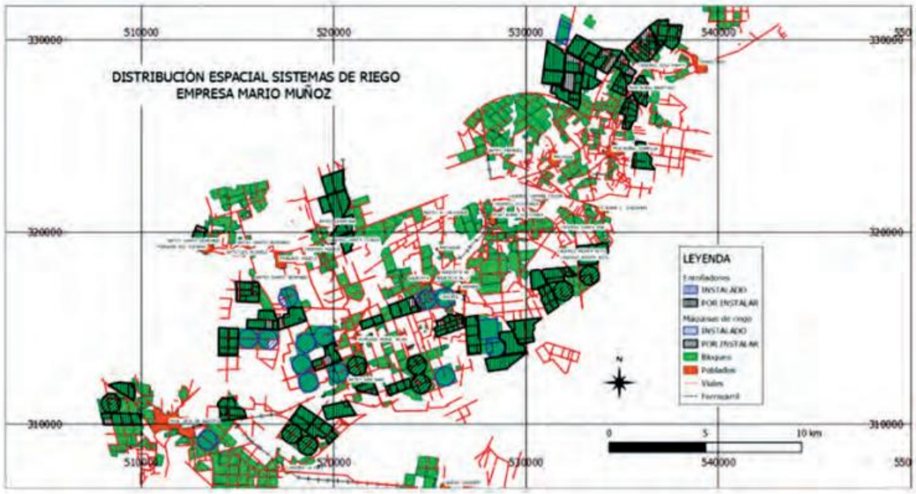

Figure 3. Map showing the spatial distribution of central pivot machines and sprinkler polygons at the Mario Muñoz Monroy sugar company

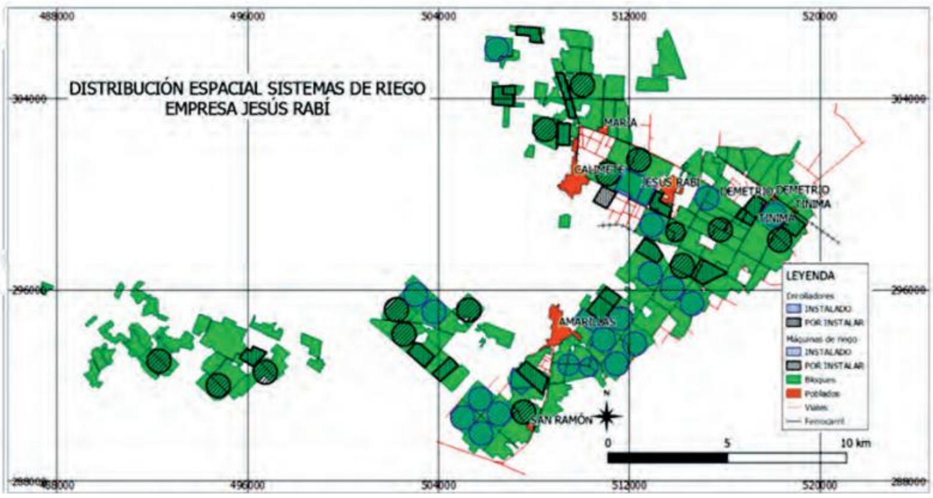

Figure 4. Map showing the spatial distribution of central pivot machines and polygons of the sprinklers or reels in the Jesús Rabí sugar company

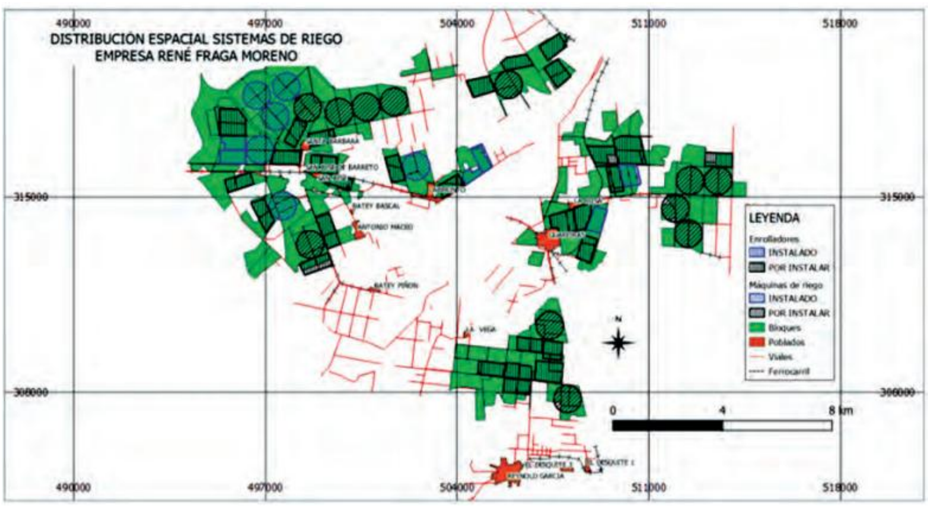

Figure 5. Map showing the spatial distribution of central pivot machines and sprinkler polygons at the René Fraga Moreno sugar company

As a result, efficient and interactive databases were generated when processing SQL queries, example of this: the query made to the vector layer "Soil map" using the expression "PEND"= "undulating" and "DREN" = "insufficient". In this case, soils with the categories of undulating slope and insufficient drainage were selected. Similar queries are useful for current and future monitoring of irrigation systems, which is consistent with Barrabia (2017). They also represent the basic support for the development of precision agriculture, as described by Avello et al. (2018) in their study, from the point of view of the use of programmable logic controllers (PLC), from web services designed to monitor the operation of the systems.

The obtained database is regularly enriched due to the "open-ended" nature of geographic information systems, which are suitable for incorporating supplementary data such as applied water volume, actual yield obtained, irrigation water management costs, etc., to generate a field with water productivity on an alphanumeric basis.

Based on the spatial distribution of the irrigation system, a multi factor analysis was conducted to lay the foundation for formulating strategic predictions and annual new investment plans for irrigation activities before 2030.

The yield in irrigated areas increased by 37.6 tons ha^{-1} compared to rainwater irrigated areas, with an estimated yield of 70.5 tons ha^{-1} for central hub machines and 50.5 tons ha^{-1} for winches. This leads to an improvement in the production and economic performance of beneficiary enterprises and production units.

4 Conclusion

Geographic information system analyzed the spatial distribution of polygons of central pivot machines, sprinklers, and winches for irrigation activities in Matanzas Province.

The results provided a precise digital graphic output, with spatial and thematic databases addressing the edaphoclimatic and technical-organizational conditions of sugar production companies and units for monitoring over time and tracing future irrigation investments.

Irrigation activities cover 5,567.39 hectares, accounting for 11% of the total sugarcane planting area in the province. Among them, 3,762.19 hectares benefited from central pivot mechanical technology, and 1,805.2 hectares benefited from winding technology. With the gradual integration of irrigation systems and their correct spatial distribution, yields have increased, with irrigated areas yielding 37.6 tons per hectare more than arid areas.

The benefits are obvious, as consultation and analysis of the provided information will improve control over irrigation activities in a sustainable manner, and enable the rational use and utilization of water and soil in agricultural management.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] ANPP-Cuba. (2017). *Ley No.124 delasaguasterrestres* [Ley 124]. Asamblea Nacional del Poder Popular.

[2] Avello, F. L., Izaguirre, C. E., Vidal, D. M. L., Martínez, L. A., & Hernández, J. A. (2018). Remote supervision and control based on wireless technology to operation of central pivot irrigation machine. *Sistemas & Telemática*, 16(44), 63-74.

[3] Barrabia, I. O. (2017). *Desarrollo de un sistema de información geográfica para el manejo del riego por pivote central en la empreza de cultivos varios" Valle del Yabú"* [Trabajo de Diploma (en opción altítulo de ingeniero Agrónomo)]. Universidad Central"Marta Abreu" de las Villas.

[4] Cajigal, G. E. (2020). *Estudio dela influenciadel riego en los rendimientos de lacañade azúcar (Saccharum officinarum L.) ensuelo Fe- rralítico Rojo típico* [Trabajo de Diploma (en opción al título de Ingeniero Hidráulico)]. Universidad Tecnológica de La Habana, CUJAE.

[5] Chambilla, C. D. C. (2019). *Implementación de Sistemas de Información Geográfica para el manejo integrado de la mosca de lafruta en SENASA* [Trabajo de Diploma (en opción al título de Ingeniero Empresarial y de Sistemas)]. Universidad San Ignacio de Loyola.

[6] Chinea, A., Muñoz, I., & Rodríguez, L. (2021). *Empleo de tecnologías de la información geográfica en el ordenamiento territorial de inversiones de riego para áreas cañeras*. X Convención Científica Internacional CIUM 2021, Matanzas, Cuba.

[7] Chinea, A., & Rodríguez, L. (2019). *Sistemas de Información Geográfica: Impacto socioeconómico, ambientaly resultadosen la agricultura cañera de Cuba*. IAgric.

[8] Chinea, H. A., & Rodríguez, I. L. (2021). Comportamiento geoespacial de algunas propiedades del suelo en el cultivo de la caña de azúcar. *Revista Ingeniería Agrícola*, 11(1), 3-8.

[9] Cortegaza, A. L., Chinea, H. A., Madan, D. L., Ojito, F. V., & Ruiz G, T. J. (2001). *Evaluaciónde la Aptitud Física de las Tierras de la Provincia Matanzas* (p. 41). Instituto Nacional de Investigaciones de la Caña de Azúcar.

[10] Gallego, S., & Ventura, E. (2018). *Propuesta para el desarrollo de una aplicación SIG móvil orientada a la comercialización de productos agrícolas* (p. 44). Uversidad Francisco José de Caldas, Facultad de Medio Ambiente y Recursos Naturales.

[11] García, D., Cárdenas, J., & Silva, A. (2018). Evaluación de sistemas de labranza sobre propiedades físico-químicas y microbiológicas en un Inceptisol. *Revista de Ciencias Agrícolas*, 34(1), 120-135.

[12] GEARH-Cuba. (2014). *Grupo Empresarial Aprovechamiento de los Recursos Hidráulicos. Base de datos. Serie de 30 años*. Grupo Empresarial Aprovechamiento de los Recursos Hidráulicos.

[13] GEOCUBA. (2006). *Metodología para la creación y actualización del catastro especializado en la agricultura cañera* (p. 14). GEOCUBA, MET 30-001:2006.

[14] GOC-2017-716-EX51. (2017). *Decreto No. 337. Reglamentode la Ley No. 124 de las aguas terrestres*. Gaceta Oficial de la República de Cuba, Consejo de Ministros.

[15] Hernández, J. A., Pérez, J. J. M., Bosch, I. D., & Castro, S. N. (2015). *Clasificación de los suelos de Cuba.* Instituto Nacional de Ciencias Agrícolas (INCA).

[16] INICA-Cuba. (2008). *Manual del Servicio Integral para la Explotación del Riego y Drenaje (SIERIED)*. INICA.

[17] INICA-Cuba. (2009). *Manual para la organización y funcionamiento del servicio de Ordenamiento Territorial en elMINAZ*. INICA.

[18] Lamelas, C. (2008). *Planificación y operación de los sistemas de riego y drenajey los recursos hídricos encañade azúcar* (p. 31) [Informe Proyecto de investigación]. Instituto de Investigaciones de la Caña de Azúcar (INICA).

[19] Minag-Cuba. (1999). *Mapa Nacional de los Suelos* [Mapa escala 1:25 000]. Ninisterio de la Agricultura (Minag).

[20] Mitsikostas, E. (2017). *Monitorización y optimización de tierras con drones y fotogrametría aérea para aplicaciones de precisión en agricultura* [Trabajo de Diploma (en opción al título de Ingeniero en la Geodesia, Cartografía y Topografía)]. Universidad de Valencia.

[21] ONEI-Cuba. (2021). *Anuario estadístico de Cuba 2020. Medio Ambiente* (p. 60) [Anuario]. Oficina Nacional de Estadística e Información, Cuba.

[22] Palacio, A. V. (2017). *Análisis de percepción en la gestión de espacios naturales y el uso de Sistemas de Información Geográfica de participación pública, 3* [Tesis (en opción al grado científico de Doctor en Ciencias

Geográficas)]. Universitat Rovira i Virgili.

[23] PCC-Cuba. (2017). *Lineamientos de la política económica y social del Partido y la Revolución para el período 2016-2021* (p. 32) [Lineamientos]. PARTIDO COMUNISTA DE CUBA.

[24] Perez, G. C. A., Pérez, A. J. J., Hernández, S. L., Gustabello, C. R., & Becerra, de A. E. (2019). Sistema de Información Geográfica para la agricultura cañera en la provincia de Villa Clara. *Revista Cubana de Ciencias Informáticas*, 13(2), 30-46.

[25] Ríos, R. (2021). La Agricultura de Precisión. Una necesidad actual. *Revista Ingeniería Agrícola*, 11(1), 67-74.