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DINÂMICA TERRITORIAL DA IRRIGAÇÃO POR PIVÔS CENTRAIS NO ESTADO DO TOCANTINS, BRASIL

DEIVISON SANTOS[1]; TAÍS SOUZA DOS SANTOS DIAS[2]; LAURA RESPLANDES SOUSA PAZ[3]; BALBINO ANTÔNIO EVANGELISTA[4] E MARCO ANTÔNIO GARCIA MARTINS CHAVES[5]

[1] Núcleo Temático de Sistemas Agrícolas, Embrapa Pesca e Aquicultura, Cx. Postal nº 90, 77008-900, Palmas - TO, Brasil. E-mail: deivison.santos@embrapa.br.
[2] Faculdade de Engenharia Ambiental, Universidade Federal do Tocantins, 77001-090, Palmas - TO, Brasil. E-mail: tais.dias@mail.uft.edu.br.
[3] Programa de pós-graduação em Desenvolvimento Regional Sustentável, Universidade Federal do Tocantins, 77001-090, Palmas - TO, Brasil. E-mail: laurapaz.engamb@gmail.com
[4] Núcleo Temático de Sistemas Agrícolas, Embrapa Pesca e Aquicultura, Cx. Postal nº 90, 77008-900, Palmas - TO, Brasil, balbino.evangelista@embrapa.br.
[5] Gerência de Formação e Controle de Estoque, Companhia Nacional de Abastecimento,70390-010, Brasília - DF, Brasil, marco.chaves@conab.gov.br

1 RESUMO

O objetivo deste trabalho foi mapear os sistemas de irrigação do tipo pivô central no estado do Tocantins e por meio de análise espacial e checagens de campo, identificar a área e os tipos de cultivos, tais informações podem contribuir para o desenvolvimento de políticas públicas voltadas à expansão da irrigação no estado. Foram identificados 143 pivôs centrais, ocupando uma área de 14.555 ha. Por meio das checagens de campo, verificou-se a existência de seis tipos de culturas agrícolas irrigadas distribuídas em 24 municípios do estado do Tocantins, sendo elas: grãos (6.053 ha, 42%); cana-de-açúcar (5.829 ha, 40%); pastagens (2.056 ha, 14%); outros (milho-verde, pesquisa e/ou melhoramento vegetal) (227 ha, 2%); grama (216 ha, 1%) e abacaxi (172 ha, 1%). A área de pivôs centrais identificada no presente trabalho, representa 9,37% da atual área irrigada do estado, o que condiz entre 0,8% e 1,54% da área passível de desenvolvimento de agricultura irrigável sustentável identificada em estudos recentes realizados pela Agência Nacional de Águas e Saneamento Básico.

Palavras-chave: agricultura irrigada, recursos hídricos, mapeamento.

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2 ABSTRACT

This work aimed to map the central pivot irrigation systems in the state of Tocantins and through spatial analysis and field checking, identifying the area and types of crops under irrigation, such information can contribute to the development of public policies focused on the expansion of irrigation in the state. A total of 143 central pivots were identified, occupying an

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area of 14,555 ha. Through the field checking, we verified the existence of six types of irrigated agricultural crops distributed in 24 municipalities in the state of Tocantins, as follows: grains (6,053 ha, 42%); sugar cane (5,829 ha, 40%); pastures (2,056 ha, 14%); others (green corn, research and/or crop breeding) (227 ha, 2%); grass (216 ha, 1%), and pineapple (172 ha, 1%). The area of central pivots identified in this work represents 9.37% of the current irrigated area of the state, which matches between 0.8% and 1.54% of the area amenable to the development of sustainable irrigated agriculture identified in recent studies conducted by the National Water and Sanitation Agency.

Keywords: irrigated agriculture, water resources, mapping.

3 INTRODUCTION

Mapping agricultural areas in a given region is crucial for both planning and monitoring crop conditions, their location, and management options, as well as inferring production and productivity. In a scenario of predicted climate change with potential impacts on water resource availability, having this information available and systematized becomes strategic for various decision-makers in irrigated agriculture.

In this sense, government agencies have sought geotechnology and especially used remote sensing and geoprocessing techniques in studies and estimates of cultivated areas and their behavior throughout their development cycle, with the aim of constantly qualifying their agricultural statistics, as in the case of the Agricultural Monitoring Bulletin (CONAB, 2022a) or the Brazilian Harvest Monitoring Bulletin (CONAB, 2022b) , prepared by the Brazilian Supply Company (Conab).

Geotechnologies are also important tools for research and development actions and for public policies, providing greater knowledge about the dynamics of territorial occupation and land use (EMBRAPA, 2015) and feeding models, outlining scenarios that allow the development of decision support systems (DSSs) with diverse applications, such as the Agrometeorological Monitoring System (EMBRAPA; CEPAGRI/UNICAMP, 2022) and the Agricultural Climate Risk Zoning (ZARC) (STEINMETZ; SILVA, 2017).

In the current harvest (2021--2022), 1.70 million ha of grains, fibers and oilseeds (GFO) were cultivated in the state of Tocantins (CONAB, 2022c), which represents an accumulated growth of more than 90% in relation to the 2011/2012 harvest, highlighting the growth of more than 30% that occurred between the 2012/13 and 2013/14 harvests (CONAB, 2022b) .

In the 2015/16 harvest, there was an abrupt drop in productivity due to climate changes related to the El Niño phenomenon, which caused irregular and scarce rainfall, in addition to air temperatures above average for the period, which may be an indicator of the low resilience of grain production systems to the occurrence of extreme climate events (CONAB, 2022b) .

According to Sentelhas *et al* . (2016) , 77% of the losses in potential, attainable and real soybean productivity in the Peixe-TO region are related to water deficit, and 23% are related to deficient management.

The adoption of irrigation, crop rotation and precision agriculture are considered mitigating measures for losses in potential, achievable and real productivity, contributing to sustainable intensification (SENTELHAS *et al* ., 2015) .

The correlation between the current irrigated area and the potential irrigated area and with the seasonal water availability in a given river basin can be an indication of

whether irrigated agriculture is being developed sustainably, also guiding the capacity for expansion of the activity in the region, in addition to contributing to the planning of the agricultural sector and decision-making in resource management (AGÊNCIA NACIONAL DE ÁGUAS E SANEAMENTO BÁSICO, 2021; GRAFTON *et al*., 2018; USP; ESALQ, 2020).

Therefore, the objective of this work was to map the central pivot irrigation systems in the state of Tocantins and, through spatial analysis and field checks, identify the area and types of crops under irrigation. This information can contribute to the development of public policies aimed at expanding irrigation in the state.

4 MATERIALS AND METHODS

4.1 Characterization of the study area

The study was carried out in the state of Tocantins, which has 139 municipalities within its boundaries (SECRETARIAT OF PLANNING AND BUDGET, 2012) and is located in the northern region of Brazil. The climate in Palmas, TO, is characterized as tropical with a dry winter (Aw) (ALVARES *et al*., 2013), with an average rainfall of 1,641 mm per year, a maximum air temperature of 34°C and a minimum of 19°C, and a relative humidity of 71%, which can vary from 84% in March to 48% in September (NASA, 2022). The state's territory has 30 hydrographic basins, totaling 27.762 million h an in the second largest hydrographic region in the country, which is the Tocantins and Araguaia rivers (SECRETARIAT OF PLANNING AND BUDGET, 2012).

4.2 Tools used

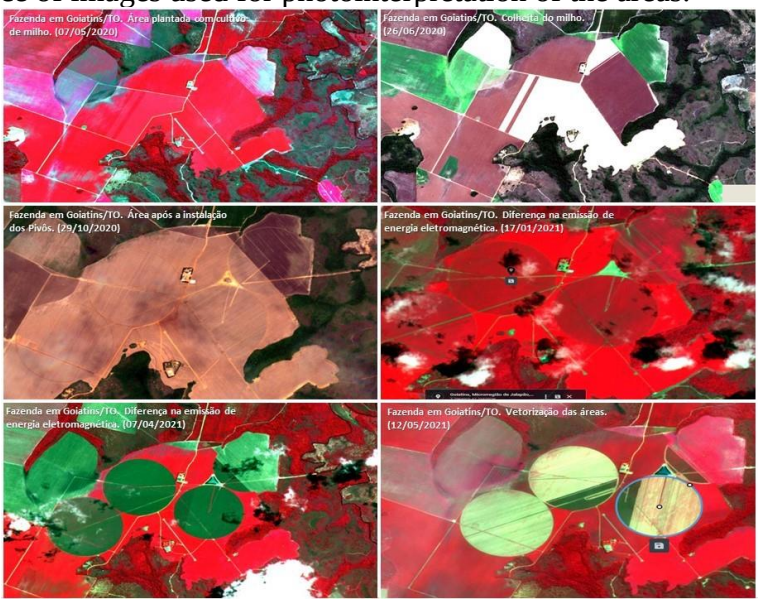
The study consisted of the application of remote sensing techniques and field visits to characterize areas with central pivot irrigation systems and identify agricultural crops cultivated in the state of Tocantins.

The images used for mapping the areas irrigated by central pivots were obtained on the *Land Viewer platform* (EARTH OBSERVING SYSTEM, 2021) and were composed of spectral bands 2, 3, 4 and 8 provided by the *"Multispectral" sensor*. *Instrument* " (MSI) aboard the SENTINEL-2 Mission satellites, with a spatial resolution of 10 m and a temporal resolution of five days. The following RGB compositions were used: 4, 3, and 2 (true color) and 8, 4, and 3 (false color). The images refer to the months of May 2019 to May 2021.

The identification key used to recognize the spectral targets of this study (areas irrigated by central pivots) considered the following aspects, which were the parameters used to separate the pivot areas from the rainfed areas: distinction of the spectral response of the irrigated agricultural crops in relation to the neighboring areas, ordering pattern (the circular shape of the pivots) and the spectral signature of the targets in dry periods.

The recognition of crop areas was carried out through photointerpretation, considering the reflectance patterns of the objects under analysis, analyzing the spectral behavior of these areas according to the development stages of the crops, following the planting calendar of the region (Figure 1).

Figure 1. Sequence of images used for photointerpretation of the areas.



Source: Adapted from Land Viewer (EARTH OBSERVING SYSTEM, 2021).

During the soil preparation and planting period, the spectral response of crop areas in the image typically reflects exposed soil. During the development period, the spectrum of annual crops with high vegetative vigor differentiates them from other classes, such as pastures and native forests. After confirming the area as cropland, the pivot areas were manually vectorized and classified according to the crop planted.

The mapping was validated in the field during visits carried out by the Conab team during their crop survey work, which was carried out throughout the region's agricultural calendar.

The data generated in the work of Borghetti *et al.* (2017) and USP/ESALQ (2020), which used municipal boundaries as a spatial scale in their results, were subsequently spatialized and georeferenced, resulting in a vector layer with a classification of areas with potential for the implementation of central pivot irrigation systems and priority areas for sustainable use.

After the database necessary to obtain the results proposed in this study was constructed, the vector files were overlaid by geoprocessing techniques via the ArcMap software from the ArcGisTM package (ESRI), version 10.3.1, enabling the analysis of the locations of crops irrigated by central pivots.

5 RESULTS AND DISCUSSION

A total of 143 central pivots occupying an area of 14,555 ha were identified. Through field checks, the existence of six types of irrigated agricultural crops distributed across 24 municipalities in the state of Tocantins was verified (Tables 1 and 2).

Table 1. Location, irrigated crops (others refer to green corn, research and/or plant breeding), in the municipalities of the state of Tocantins, identified via remote sensing and validated in the field, from May 2019 to May 2021.

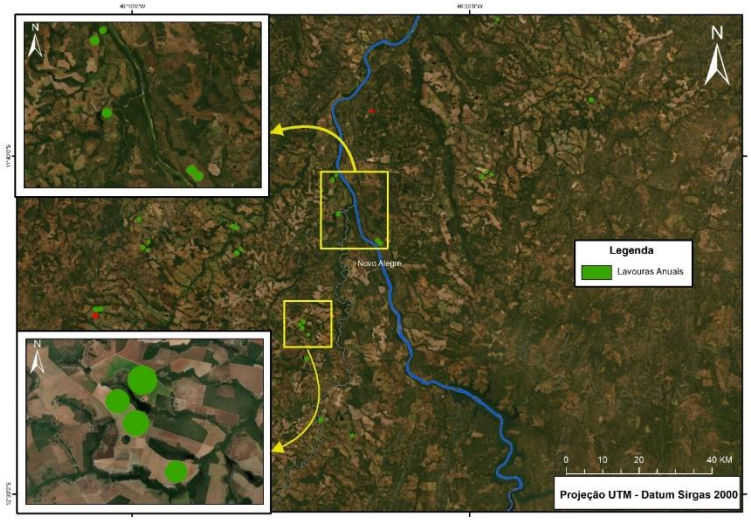
Municipality	Irrigated agricultural crops					
	Grains	**Cane**	**Pastures**	**Others**	**Gram**	**Pineapple**
Rio Negro Apartment	99.91					
Araguaçu	84.2		172.51			
Brej . of Nazareth	813.97					
C. Lindos	256.00		114.92			
Cariri do TO	615.96		139.01			
Caseara			72.90			
Figueirópolis	76.58			22.62	146.29	
Goiatins	207.79	494.18				
Gurupi	219.32					
Ipueiras			99.44			
Miracema do TO	74.95					
Mount Carmel	199.42					
Palmas	445.28					
TO Paradise	90.80					
Father Alfonso	258.32	5,335.03				
Fish	952.66		50.03			
Pium			1,320.77			
National Palace	526.77		86.89	204.73	69.59	
Sandolandia	114.34					
Santa Rosa do TO	188.47					
St. Val of the Nativity	208.32					
Silvanopolis	398.59					
Sucupira	305.76					
Tocantinia						172.45
Grand total	6,053.21	5,829.21	2,056.47	227.35	215.88	172.00

Table 2. Location, irrigated area and number of central pivot irrigation systems in the municipalities of the state of Tocantins identified via remote sensing and validated in the field from May 2019 to May 2021.

Municipality	Irrigated area (ha)	Number of pivots
Rio Negro Apartment	99.91	1
Araguaçu	172.51	3
Brej . of Nazareth	813.97	8
C. Lindos	370.92	5
Cariri do TO	754.97	7
Caseara	72.9	1
Figueirópolis	245.49	4
Goiatins	701.97	5
Gurupi	219.32	3
Ipueiras	99.44	1
Miracema do TO	74.95	1
Mount Carmel	199.42	2
Palmas	445.28	5
TO Paradise	90.8	4
Father Alfonso	5,593.35	37
Fish	1,002.69	12
Pium	1,320.77	10
National Palace	887.98	12
Sandolandia	114.34	1
Santa Rosa do TO	188.47	2
St. Val of the Nativity	208.32	3
Silvanopolis	398.59	7
Sucupira	305.76	3
Tocantinia	172.45	6
Grand total	14,554.57	143

The center pivots on annual grain crops totaled 71 units, irrigating 6,053 ha across 20 municipalities, corresponding to 42% of the total. The municipality of Peixe, in the southern region of the state and on the banks of the Tocantins River, has the largest area, with 953 ha under center pivot irrigation (Figure 2).

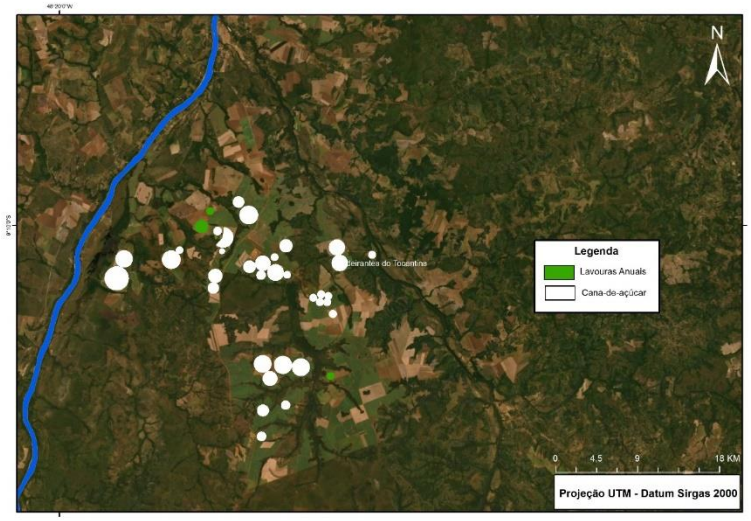
Figure 2. Central pivots on annual crops in the municipality of Peixe - TO.



Source: Adapted from ArcGIS Basemap (ESRI, 2021).

Irrigated sugarcane production occurs at 5,829 h, corresponding to 40% of the entire area occupied by pivots in the state of Tocantins. In this survey, a single pivot was identified covering an area of 530 h a. Sugarcane production is concentrated in the municipality of Pedro Afonso (92%), which is located on the banks of the Tocantins River (Figure 3).

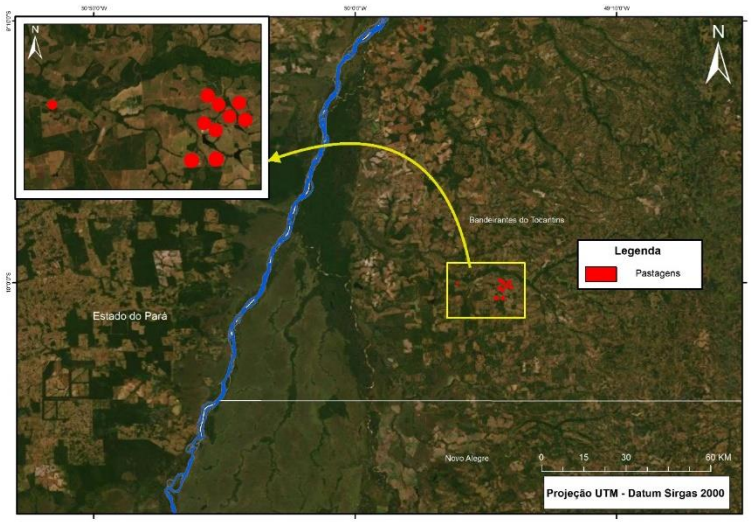
Figure 3. Central pivots over sugarcane in the municipality of Pedro Afonso - TO, with the Tocantins River highlighted in blue.



Source: Adapted from ArcGIS Basemap (ESRI, 2021).

Pastures occupied third place in terms of area, with 2,056 ha, corresponding to 14% of the total area, with an emphasis on the municipality of Pium, in the central-western region of the state, which contains 1,320 ha of irrigated pastures (Figure 4).

Figure 4. Central pivots over pastures in the municipality of Pium - TO, with the Araguaia River highlighted in blue.



Source: Adapted from ArcGIS Basemap (ESRI, 2021).

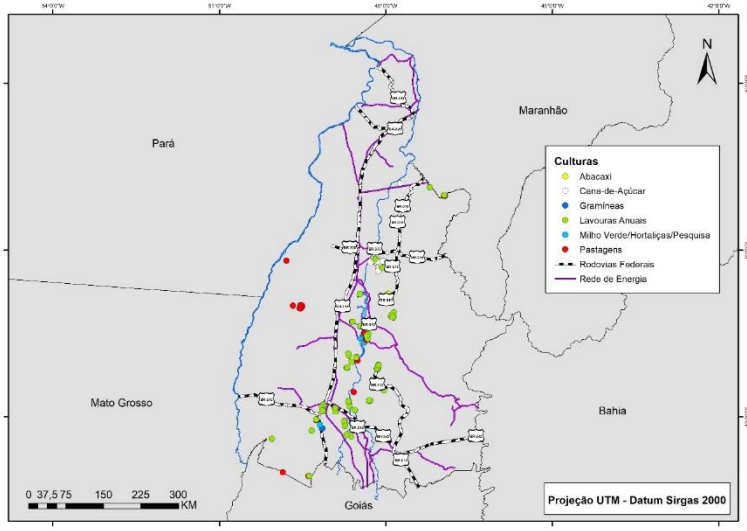
The study identified five central pivots on areas for horticulture production and research and/or plant breeding, covering a total of 227 ha and representing 2% of the state's pivot area, four in the municipality of Porto Nacional, in the central region bordering the municipality of Palmas, and one central pivot in the municipality of Figueirópolis, in the southern region, between the Tocantins and Araguaia River basins.

Three central pivots used for grass cultivation were found, one in the municipality of Porto Nacional, with 70 ha, and two central pivots in the municipality of Figueirópolis, with 65 and 81 ha, respectively, totaling 216 ha, corresponding to 1% of the irrigated area.

Finally, six central pivots were counted on pineapple crops, both in the municipality of Tocantínia, 87 km north of the state capital, Palmas, totaling 172 ha of irrigated area, equivalent to 1% of the state's irrigated area. Pineapple production is of great socioeconomic importance to the state of Tocantins, as pineapple is the second most cultivated fruit crop (4,727 ha) and has the highest production value (over R$ 155 million) (IBGE, 2022).

The central pivot irrigation equipment identified in this study follows a distribution trend along the axis of BR-153 and presents a clear spatial dependence in relation to the distribution of the 500 kV high-voltage electrical grid (NATIONAL WATER AND BASIC SANITATION AGENCY, 2019; SECRETARY OF PLANNING AND BUDGET, 2019), as shown in Figure 5.

Figure 5. Spatial distribution of central pivots identified in the state of Tocantins in relation to highways and power lines from May 2019--May 2021.



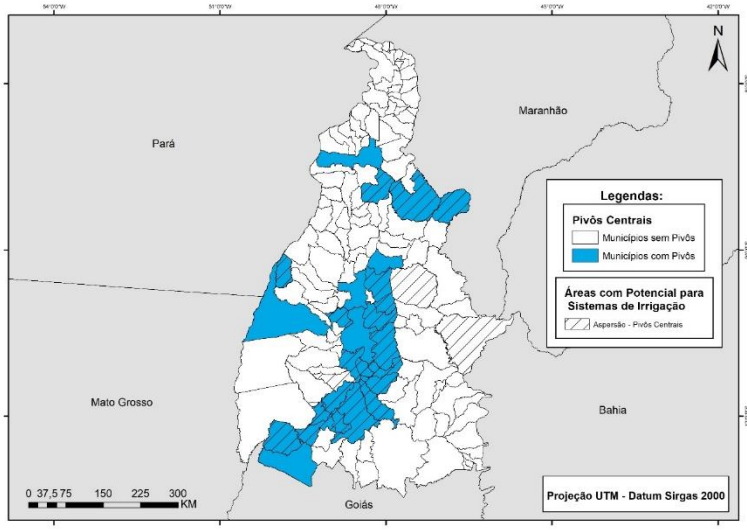
Source: Adapted from the National Water and Sanitation Agency (2019); Tocantins (2019).

In a study carried out by Guimarães and Landau (2020), 16,890 ha were found to be occupied by 185 central pivot machines in Tocantins, an increase of 2,335 ha and 42 central pivot machines in relation to the present study. However, the authors of the aforementioned study performed visual identification of the central pivots through satellite images inserted into the *Google Earth Pro platform*, with no field verification.

After spatializing and georeferencing data obtained by USP/ESALQ (2020), it was found that 22 municipalities in the state of Tocantins have the potential for the use of irrigation systems, covering an area of over 1.8 million ha, more than tenfold the current irrigated area of 155,404 ha (NATIONAL WATER AND BASIC SANITATION AGENCY, 2021). According to this study, part of the increase in the irrigated area would have occurred due to the intensification of 361,482 ha, representing 233% growth in relation to the current irrigated area, and part of the increase in the irrigated area, covering 1,247,675 ha, representing an 803% increase in relation to the current irrigated area. In addition, the area with subirrigation or elevation of the water table represents 54,197 ha or 35% of the current irrigated area.

However, 27% of the pivots identified in this study are not located in these areas but rather in the municipalities of Araguaçu, Araguaína, Miracema do Tocantins, Pedro Afonso, Pium, and Porto Nacional, occupying an area of 8,173 ha of central pivots, or 4.67% of the current irrigated area (Figure 6). Notably, of the potential areas, only the municipalities of Aliança do Tocantins, Mateiros, and Rio Sono do not yet have central pivot irrigation systems.

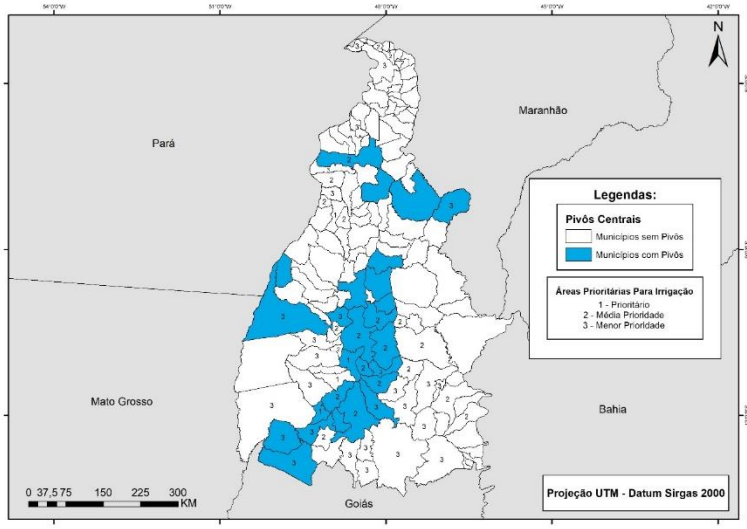
Figure 6. Municipalities in the state of Tocantins with potential for irrigated agriculture and municipalities identified with central pivots.



Source: Adapted from Public Policy Group (2020) .

The vectorization of data from the Irrigation Atlas (NATIONAL WATER AND BASIC SANITATION AGENCY, 2021) revealed that 37% of the municipalities in the state of Tocantins have priority areas for the implementation of sustainable irrigated agriculture, totaling 946,036 ha, or 609% more than the current area, divided into lower priority (25 municipalities), medium priority (23 municipalities) and priority (4 municipalities) (Figure 7).

Figure 7. Municipalities in Tocantins with priority areas for the implementation of irrigation systems.



Source: Adapted from Borghetti *et al.* (2017).

With respect to the priority classification of municipalities with central pivots, nine municipalities are located in areas with medium priority, with 46 pivots occupying an area of 3,487 ha, which represents 24% of the area irrigated by central pivots; seven municipalities have lower priority, with 30 pivots on 2,607 ha, equivalent to 18% of the area irrigated by central pivots; and only two municipalities

have higher priority, with 16 pivots on 1,669 ha, or 11% of the area irrigated by central pivots.

However, eight municipalities where central pivot irrigation systems were identified are not located in priority areas, with 51 pivots on 6,792 ha of irrigated area, representing 47% of the area irrigated by central pivots. We therefore understand that 53% or 92 pivots, on 7,763 ha, are located in priority areas (Figure 7).

Despite the potential for the development of irrigated agriculture revealed by several studies (NATIONAL WATER AND SANITATION AGENCY, 2021; BORGHETTI *et al*., 2017; GOVERNMENT OF THE STATE OF TOCANTINS, 2011), the adoption of irrigation systems in the state of Tocantins is very timid and still restricted to irrigated perimeters (localized irrigation or conventional sprinklers), which have received public investment for water and electrical infrastructure, in addition to the systematization of the areas. However, there are few projects with central pivots, which indicates the preponderance of a typical agricultural frontier logic, which is horizontal expansion, in contrast to the sustainable intensification represented by the use of irrigation.

For the potential for irrigated agriculture in the state of Tocantins to become a reality, public policies must be developed to encourage the adoption of irrigation systems by the private sector, as there are already territorial management projects indicating where irrigation can be developed, as well as water management mechanisms for this purpose.

6 CONCLUSIONS

1. There are 143 types of central pivot irrigation equipment in the state of Tocantins, covering 14,554.57 ha across six types of irrigated agricultural crops.
2. Grain irrigation occupies the largest area, 6,053.21 ha (42%), followed by sugarcane, with 5,829.21 ha (40%), pastures, with 2,056.47 ha (14%), others (green corn, research and plant breeding), with 227.35 ha (2%), grass, with 215.88 ha (1%) and pineapple, with 172.00 ha (1%).
3. The area of central pivots identified in this work represents 9.37% of the current irrigated area of the state, which corresponds to between 0.8% and 1.54% of the area capable of developing sustainable irrigated agriculture identified in recent studies.

7 REFERENCES

NATIONAL WATER AND SANITATION AGENCY (Brazil). Ministry of Regional Development. **ANA metadata catalog** . Brasília, DF: ANA, 2019. Available at: https://metadados.snirh.gov.br/geonetwork/srv/por/catalog.search#/home . Accessed on: February 18, 2022.

NATIONAL WATER AND SANITATION AGENCY (Brazil). **The tlas of irrigation** : water use in irrigated agriculture. 2nd ed. Brasília, DF: ANA, 2021. Available at: https://biblioteca.ana.gov.br/asp/download.asp?codigo=148256&tipo_midia=2&iIndexSrv=1&iUsuario=0&obra=88090&tipo=1&iBanner=0&iIdioma=0. Accessed on: February 18, 2022.

ALVARES, CA ; STAPE, JL; SENTELHAS, PC; GONÇALVES, JLM; SPAROVEK, G. Köppen's climate classification map for Brazil.

Meteorologische Zeitschrift , Berlin, v. 22, n. 6, p. 711-728, 2013. DOI: https://doi.org/10.1127/0941-2948/2013/0507. Available at: https://www.schweizerbart.de/papers/metz/detail/22/82078/Koppen_s_climate_classification_map_for_Brazil. Accessed on: November 24, 2021.

BORGHETTI, JR; SILVA, WLC; NOCKO, HR; LOYOLA, LN; CHIANCA, GK (ed.). **Sustainable irrigated agriculture in Brazil** : identification of priority areas. Brasília, DF: FAO, 2017. Available at: https://www.fao.org/3/a-i725°pdf. Accessed on: February 18, 2022.

CONAB. Summer cultivation - 2021/2022 harvest. **Agricultural monitoring bulletin** , Brasília, DF, v. 11, n. 1, p. 1-20, Jan. 2022a. Available at: https://www.conab.gov.br/component/k2/item/download/41003_455b01c2b7ae1b94dfc0d608ec834be7. Accessed on: Feb. 18, 2022.

CONAB. **Grains by federation unit** : Historical series of harvests. Brasília, DF: CONAB, 2022b. Available at: https://portaldeinformacoes.conab.gov.br/safra-serie-historica-graos.html . Accessed on: October 3, 2022.

CONAB. **Monitoring of the Brazilian Harvest** : grains, Brasília, DF, v. 9, n. 5, Feb. 2022. 2021/22 Harvest, Fifth survey. 2022c. Available at: https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos/item/download/41108_0d2fd92e8d257bd422 cc07a50f7f1a3c. Accessed on: October 3, 2022.

EMBRAPA. **MATOPIBA** . Geoweb . Brasília, DF: Embrapa Territorial, 2015. Available at: http://mapas.cnpm.embrapa.br/matopiba2015/. Accessed on: February 18, 2022.

EMBRAPA; CEPAGRI. **Agritempo** . Agrometeorological Monitoring System . Brasília, DF: Embrapa Agricultura Digital; Campinas: CEPAGRI, 2022. Available at: http://www.agritempo.gov.br/agritempo/index.jsp . Access on : Feb 18 , 2022.

EARTH OBSERVING SYSTEM. **Land Viewer** . Mountain View: EOS Data Analytics, 2022. Available at: https://eos.com/landviewer. Accessed on: February 18, 2022.

ESRI. **ArcGIS Online Basemaps** . São José dos Campos: ESRI, 2022. Available at: https://www.arcgis.com/home/group.html?id=702026e41f6641fb85da88efe79dc166# !. Accessed on: February 18, 2022.

GOVERNMENT OF THE STATE OF TOCANTINS. Secretariat of Sustainable Development and Water Resources. Secretariat of Agriculture and Livestock. **Tocantins State Irrigation Plan** : Summary Report. Palmas: MAGMA Engineering , 2011.

GRAFTON, RQ; WILLIAMS, J.; PERRY, CJ; MOLLE, F.; RINGLER, C.; STEDUTO, P.; UDALL, B.; WHEELER, SA; WANG, Y.; GARRICK, D.; ALLEN, RG. The paradox of irrigation efficiency. **Science** , Washington DC, v. 361, n. 6404, p. 748-750, Aug. 2018. DOI: http://dx.doi.org/10.1126/science.aat9314. Available at: https://www.science.org/doi/10.1126/science.aat9314. Accessed on: Feb. 18, 2022.

USP; ESALQ. **Territorial analysis for the development of irrigated agriculture in Brazil.** Piracicaba: Public Policy Group, 2020. Available at: https://www.gppesalq.agr.br/_files/ugd/995

7b7_08c174c8c60e4d9cb8213f9e040f563a.pdf. Accessed on: October 3, 2022.

GUIMARÃES, DP; LANDAU, EC **Georeferencing of central pivot irrigation systems in Brazil** : Base Year 2020. Sete Lagoas: Embrapa Milho e Sorgo, 2020. (Research and Development Bulletin, 222). Available at: http://ainfo.cnptia.embrapa.br/digital/bitstream/item/219375/1/Bol-222.pdf. Accessed on: November 24, 2021.

IBGE. **Agricultural production** . Temporary crops. Brasília, DF: IBGE, 2022. Available at: https://cidades.ibge.gov.br/brasil/to/pesquisa/14/10193 . Accessed on: February 18, 2022.

NASA. **Power** . Data access viewer. Washington: NASA, 2022. Available at: https://power.larc.nasa.gov/data-access-viewer/. Accessed on: February 16, 2022.

SENTELHAS, PC; BATTISTI, R.; CHAMBER, GMS; FARIAS, JRB; HAMPF, AC; NENDEL, C. The soybean yield gap in Brazil: magnitude, causes and possible solutions for sustainable production. **The Journal Of Agricultural Science** , Cambridge, vol. 153, no. 8, p. 1394-1411, apr. 2015. DOI: http://dx.doi.org/10.1017/s0021859615000313. Available at: https://www.cambridge.org/core/journals/journal-of-agricultural-science/article/soybean-yield-gap-in-brazil-magnitude-causes-and-possible-solutions-for-sustainable-production/DB059CC032A27B7C5A07FF896F56E8D5. Accessed on: February 18, 2022.

SENTELHAS, PC; BATTISTI, R.; MONTEIRO, LA; DUARTE, YCN; VISSES, FA Yield Gap: concepts, definitions and examples. **Agricultural Information** , Piracicaba, n. 155, p. 9-12, Sep. 2016. Available at: http://www.ipni.net/publication/IA-BRASIL.NSF/0/9C05063FB033C24A83258042004C8594/$FILE/Page9-12-155.pdf. Accessed on: Feb. 18, 2022.

SECRETARIAT OF PLANNING AND BUDGET. **Atlas of Tocantins.** Support for territorial management planning. Palmas: SEPLAN, 2012. Available at: https://www.to.gov.br/seplan/atlas-do-tocantins/1asvwxbj530d. Accessed on: February 18, 2022.

SECRETARIAT OF PLANNING AND BUDGET. **IDE Tocantins metadata catalog .** Palmas: GEoNetwork 3.10.2.0, 2019. Available at: https://geoportal.to.gov.br/geonetwork/srv/eng/catalog.search#/home . Accessed on: February 18, 2022.

STEINMETZ, S.; SILVA, SC **Beginning of studies on Agricultural Climate Risk Zoning (ZARC) in Brazil** . Santo Antônio de Goiás: Embrapa Rice and Beans, 2017. (Documents, 312). Available at: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/168747/1/Silvio-Steinmetz-Doc-312.pdf. Accessed on: February 18, 2022.