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Water management irrigation t under central pivot irrigation system: an exploratory analysis of the sector in the state of Goiás

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ABSTRACT

Aim of the study: To analyze the efficiency of agricultural irrigation management in the municipalities of Goiás State with the largest area irrigated by a central pivot system.

Methodology/approach: A qualitative and quantitative approach was used with an exploratory objective by conducting a document analysis, drawing comparisons between the information of the registration of irrigators in Goiás and regulatory institutions with regard to the technical and economic efficiency of irrigation systems.

Originality/Relevance: The growing use of technologies that require water resources has led to scientific and political discussions, seeking to define institutional criteria to regulate the environmental and social impact of irrigated agriculture. Principal results: It was found that 48.52% of the irrigators who were consulted do not use any form of management of irrigation systems that promote the efficient use of water, either technically or economically.

Theoretical/methodological contributions: By identifying the decision-making model for the use of irrigation systems based on rational expectations, the work highlights the need to gain further knowledge regarding the parameters that aid the decision making of irrigator farmers, with a view to achieving the efficient use of water resources.

Conclusion: The results suggest that to achieve intertemporal efficiency in the management of irrigation systems, it is necessary to adopt managerial strategies that reduce losses in reservoirs and in the conduction and application of water in irrigated areas. It is also necessary to improve irrigation methods and the maintenance of equipment, as well as the economic selection of products that will be the result of the use of water. This is because the increased supply of these products is the social benefit resulting from the use of a public good, water.

Keyword: Irrigation. Technical efficiency. Economic efficiency.

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Gestão da água sob sistema de irrigação tipo pivot central: uma análise exploratória do setor no estado de Goiás

RESUMO

Objetivo do estudo: Analisar a eficiência do manejo da irrigação agrícola nos municípios goianos com maior área irrigada por pivô central.

Metodologia/abordagem: Foi adotada abordagem qualitativa e quantitativa com objetivo exploratório, mediante realização de análise documental comparativa entre informações do cadastramento dos irrigantes de Goiás e instituições reguladoras de eficiência técnica e econômica de sistemas de irrigação.

Originalidade/Relevância: A ampliação no uso de tecnologias que se apropriam dos recursos hídricos tem gerado discussões no meio científico e político, buscando a definição de critérios institucionais que regulem os impactos ambientais e sociais da agricultura irrigada. Principais resultados: foi possível verificar que 48,52% dos irrigantes consultados não adotam nenhuma modalidade de gestão dos sistemas de irrigação que promova o uso eficiente, técnica e economicamente, da água.

Contribuições teóricas/metodológicas: Ao identificar o modelo de tomada de decisão sobre uso dos sistemas de irrigação com base em expectativas racionais, o trabalho destaca a necessidade de aprofundar os conhecimentos a respeito dos parâmetros que subsidiam a tomada de decisão do produtor irrigante, com vistas ao alcance da eficiência do uso do recurso hídrico.

Conclusão: Os resultados permitem inferir que, para que haja eficiência intertemporal na gestão dos sistemas de irrigação, torna-se necessário adotar estratégias de manejo que reduzam as perdas nos reservatórios, na condução e na aplicação de água nas áreas irrigadas, no aprimoramento dos métodos de irrigação e manutenção em equipamentos, bem como na seleção econômica dos produtos que serão fruto da utilização desse recurso, uma vez que o aumento da oferta destes é benefício social decorrente da utilização de um bem público, a água.

Palavras-chave: Irrigação. Eficiência técnica. Eficiência econômica.

Gestión del agua bajo sistema de irrigación del tipo pivote central: un análisis exploratorio del sector en el estado de Goiás

RESUMEN

Objetivo del estudio: Analizar la eficiencia del manejo del riego agrícola en los municipios goianos con mayor área irrigada por pivote central.

Metodología/abordaje: Se adoptó un enfoque cualitativo y cuantitativo con objetivo exploratorio, mediante realización de análisis documental comparativo entre informaciones del registro de los riego de Goiás e instituciones reguladoras de eficiencia técnica y económica de sistemas de riego.
Originalidad/Relevancia: La ampliación en el uso de tecnologías que se apropia de los recursos hídricos ha generado discusiones en el medio científico y político, buscando la

definición de criterios institucionales que regulen los impactos ambientales y sociales de la agricultura irrigada.

Principales resultados: fue posible verificar que el 48,52% de los irrigantes consultados no adoptan ninguna modalidad de gestión de los sistemas de riego que promuevan el uso eficiente, técnica y económicamente, del agua.

Contribuciones teóricas/metodológicas: Al identificar el modelo de toma de decisión sobre el uso de los sistemas de riego basados en expectativas racionales, el trabajo destaca la necesidad de profundizar los conocimientos acerca de los parámetros que subsidian la toma de decisión del productor irrigante, con vistas al alcance de la eficiencia del uso del recurso hídrico.

Conclusión: Los resultados permiten inferir que, para que haya eficiencia intertemporal en la gestión de los sistemas de riego, es necesario adoptar estrategias de manejo que reduzcan las pérdidas en los depósitos, la conducción y la aplicación de agua en las áreas irrigadas, en el perfeccionamiento de los métodos de riego y el mantenimiento en equipos, así como en la selección económica de los productos que serán fruto de la utilización de ese recurso, una vez que el aumento de la oferta de éstos es beneficio social derivado de la utilización de un bien público, el agua.

Palabras clave: Riego. Eficiencia técnica. Eficiencia económica.

1 Introduction

In recent decades, Brazil has exponentially increased its use of irrigation, which rose from 2.3% of cultivated land in 1970 to 8.3%, in 2012. This growth is the result of development programs created in the 1980s, such as the National Program for the Rational Use of Irrigable Meadows (Provárzeas), in 1981, the Irrigation Equipment Funding Program (Profir), in 1982, the National Irrigation Program (Proni), in 1986, and the Northeast Irrigation Program (Proine), in 1986. Together, these programs enabled public investment in collective projects and provided a stimulus for the private sector, which is responsible today for 96.6% of irrigated areas (ANA, 2013).

These directed actions promoted the centralization of irrigation in specific regions. Today, because of the demand for water, these actions have led to conflicts between the agricultural sector and human supply because, on average, an irrigated hectare requires the same amount of water to meet the needs of 100 people (BRASIL, 2008).

The importance of discussion regarding the availability and use of water for irrigation echoes the issues of the optimum use of this resource to meet increasing competition between users and the gradual reduction in quantity and quality, given the demand of urban users, agriculture and industry, in addition to the need to maintain diverse ecosystems (ANA, 2007).

Therefore, achieving an efficient irrigation system not only ensures a financial return for the irrigator as a result of the capital invested to enable production, but especially urban supply and the minimization of environmental damage.

According to Andrade (2001), the decision to irrigate should be motivated by issues related to the need and possibility to execute the irrigation process. Among the attributes of irrigation that affect crop productivity, the author highlights the efficient use of water to meet the needs of plants during their production cycle. Therefore, to achieve the efficient use of this resource, its optimization in relation to the application of fertilizers should be taken into consideration, along with the possibility of intense soil use with a succession of crops up to three times a year and the rational use of machinery, tools and labor throughout the year.

To Tang, Folmer and Xue (2015), the yield resulting from the use of irrigation systems should take into account the inflow of water as well as the combination of this factor with other inputs, such as fertilizers, plant protection products, seeds and labor, which need to be compensated for what is produced by m^3 of water.

Thus, water as a production factor entails costs, even though its price is not explicit. Furthermore, its economic value is expressed in expenditure on energy for pumping, investments to acquire equipment to transport water from its source to the field, and especially its social cost of opportunity as a public good (Albuquerque, 2004).

The public management of common water resources needs to meet the demands of diverse current and future users. It also needs to ensure the conservation of ecosystems, as guaranteed by law. At the same time, there is the challenge of producing food through the intensification of the use of capital invested in technologies in the field, in harmony with environmental conservation and sustainable farming practices (Brito, Silva, & Porto, n.d.).

Since the enactment of Law 9.433/1997, which instituted the National Water Resources Policy, political instruments have been developed to regulate the use of water resources for diverse purposes. In this respect, the Drainage Basin Committees were created, decentralized entities that represent public and private interests and have decision-making power. To enforce the shared and sustainable management of water resources as required by law, these committees need to unify the actions of all governments, enabling the conservation and restoration of bodies of water to guarantee the sustainable use of water resources. Therefore, this set of institutions, by regulating the behavior of water resource users, defines expectations with regard to the functions of a certain segment of society, in the case of the present study, the agricultural irrigation sector.

Goiás State is the watershed of Brazil. The sources of the rivers that form the São Francisco Basin, the Paraná Basin and the Basin of Tocantins/Araguaia are located there (Nascimento, 1991). In the particular case of Goiás state, the growing use of technologies that require water resources has led to discussions in the scientific and political communities in an attempt to define institutional criteria to regulate the environmental and social impacts of irrigated agriculture (Chagas, Leal, Campos, Peixoto, & Giustina, 2017).

Considering that irrigation has been expanding in Brazil since the nineteen eighties, that water is free in a number of regions and that the complexity of the management of this technology requires farmers to achieve higher levels of learning, this study questions whether the water used in irrigation systems has been efficiently managed.

In this sense, the present study aims to conduct an exploratory analysis of documents that allows inferences on the adequacy of the management profile of irrigation farmers regarding certain technical and institutional parameters of efficiency in the irrigation process.

By describing the managerial profile of the irrigation farmer in Goiás State, this work provides directions for the public authorities concerning the forms of management and regulations of water resources that effectively promote the adoption of efficient and sustainable practices. This will aid future research to provide better guidance for these policies.

2 Methodological Procedures

Goiás State is a watershed in Brazil, as rivers that feed several drainage basins are located on its territory (Martins, Laranja, Santos, Ferreira, & Lima, 2014). As part of the region of the Tocantins/Araguaia, São Francisco and Paraná Basins, the state of Goiás covers an area of 340,111,783 km2, which corresponds to 3.99% of Brazilian territory. The state has 246 municipalities, with a total population, in 2010, of 6,003,788, of whom 90.29% inhabit the urban regions, and 9.71% live in rural areas (IBGE, 2017). It has an average annual precipitation of 1564 mm, 197 mm below the national average, with water balance, in qualitative-quantitative terms, classified as in a satisfactory condition (ANA, 2013).

To conduct this research, an exploratory approach or preliminary study was used, with a bibliographic review of the literature of the field, seeking to achieve greater familiarity with the problem to gather evidence on it. A descriptive approach was used to identify and analyze the aspects related to the phenomenon in question. For this purpose, the functionalist method with an inductive nature was used (Lakatos & Marconi, 2001). The method works as determined by society with its institutional functions. The inductive nature allows for generalization based on the evidence of similar behavior in certain groups (Lakatos & Marconi, 2001).

The data submitted to document analysis were obtained from the project for registering irrigators in Goiás State. This project, the Irrigator Profile in Goiás State, was conducted by the Goiás State Development Secretariat (SED), formerly known as the State Secretariat for Agriculture, Livestock and Irrigation (SEAGRO). In 2013 and 2014, in partnership with EMATER, FAEG, FIEG, FUNDEPEC, OCB-GO and SEMARH, the SED registered the irrigators in Goiás State in order to understand the reality of the irrigated areas in qualitative and quantitative terms.

The sample studied by the state government was made up of 2544 registrations, corresponding to 52% of the estimated population of irrigators in Goiás. The study shows the historical evolution of irrigation in the state, identifying the systems installed from 1978 to 2014. The data on the sample (MAPA, n.d) were compared with the documents that institute the behavior expected from farmers that use irrigation systems, which provide the theoretical grounding for the present study.

It is important to highlight that the sample and institutional documentation in question are not exhaustive. They were selected at random, with a degree of coherence and cohesion that suited the purpose of a preliminary study as a basis for further research. The selection criteria for the sample were as follows. The system had to be operational and using central pivot irrigation equipment, as this system represents most (62%) of the registered systems, which corresponds to 90 % of the area irrigated by the sample population. Furthermore, as pointed out by Schmidt (2007), the predominant adoption of the pivot system has been consolidated in new irrigation areas and areas of expansion due to the high degree of automation of the system and better use of productive resources.

3 Theoretical framework

3.1 Regulatory institutions of the use of water resources in Goiás State

The promulgation of Law 9.433/1997 established as a territorial unit for the application of the National Water Resources Policy, as determined by the National Water Resources Council in Resolution 32 of 15 October 2003, the drainage basin (DB) and its divisions. In other words, it defined the environment that encompasses a basin, groups of basins or sub-basins with similar characteristics to aid the process of management and decision-making inherent to water resources.

The State Water Resource Council, through Resolution 003, of 10 April 2001, established the directives for the formation and functioning of the Drainage Basin Committees (DBCs) of Goiás State, whose watercourse is a state domain. It is defined in Article 1 that the DBCs are collegiate bodies with normative, deliberative and consultative prerogatives that can be adopted in the DB under their jurisdiction, functioning in accordance with Federal Law 9.433 of 8 January 1997 and State Law 13.123 of 16 July 1997. The DBCs were created by State Government Decree, based on a report that proposed their creation following an assessment approved by the State Water Resource Council, acting in accordance with Article 37 and representative composition according to Article 39 of the Waters Law:

> Article 37 – The Drainage Basin Committees will operate in:
> I – an entire drainage basin;
> II – a drainage sub-basin of a tributary of the main watercourse or a tributary of this tributary; or
> III – a group of contiguous drainage basins or sub-basins. Single paragraph: The institution of Drainage Basin Committees in rivers under the jurisdiction of the Federal Government will be established by an act of the President of the Republic.
> [...]
> Article 39. The Drainage Basin committees are made up of the following representatives:
> I – of the Federal Government;
> II – of the States and Distríto Federal, whose territories are located, albeit partially, in their respective operational areas;
> III – of Municipalities wholly or partly located in their operational areas;
> IV – of water users in their operational area;
> V – of civilian water resource entities who can prove that they operate in the basin (ANA, 2013).

The aspects commonly approved by the State DBCs are that the representatives are not paid, their mandate lasts for two years, the President and Vice-President are elected by their peers and the representativeness of the votes on the committee are 40% for the state and municipalities, 40% users and 20% civilian and professional entities in the field.

The DBCs are collegiate structures that make up the National Water Resources Management System, whose members are water users, representatives of civilian society and the public authorities. To enforce the shared and sustainable management of water resources, as required by law, the committees need to unify the actions of all governments in the municipal, state or federal spheres to ensure the sustainable use of water resources. These committees are divided into state and interstate basins. It falls to them to draft the water resources plans and define the policies that meet the demands of each location. Their actions encompass the management of the availability of water resources in quality and quantity, considering their multiple uses in the face of growing demand for water in different sectors. They also encourage the rational use of water through the economic valuing of this resource as an input for production (ANA, 2014). In this respect, Table 1 shows the general characteristics of the Drainage Regions (DR) on the territory of Goiás State.

Table 1 – Characterization of the drainage regions of Goiás State

Drainage Region	Main rivers of the Basin	Brazilian States	General Characteristics
Paraná	Tietê, Ivaí, Paranaíba, Iguaçu, Grande, Pardo, Amabaí, Aporé, Rio Verde, Dourados, Sucuruí, Piquiri, Paranapanema.	São Paulo (25%) Paraná (21%) Mato Grosso do Sul (20%) Minas Gerais (18%) Goiás (14%) Santa Catarina (1.5%) Distrito Federal (0.5%)	• Serves 32.1% of the national population, with 93% of the people residing in urban areas; • Has the greatest demand for water in the country, accounting for 31%, which compromises the capacity for water supply; • Regarding consumption, 42% of total demand is for irrigation and 27% for industry; • Is the most economically developed region in the country; • Has 40 state basin committees and 2 interstate basin committees.
Tocantins / Araguaia	das Almas, Santa Clara, Cana Brava, dos Patos, Uru, Tocantizinho, Sono, Cacau, Mupi, Barra Grande, Araguaia and its tributaries, Claro, Cristalino, Caiapó and Crixá-Açu.	Tocantins (30%) Pará (30%) Goiás (21%) Maranhão (4%) Mato Grosso (15%) Distrito Federal (0.1%)	• Serves 11% of the national population, with 76% in urban areas; • Has the greatest potential for irrigated agriculture, especially flood irrigation; • Regarding consumption, 62% of total demand is for irrigation and 16% for watering animals; • Has 6 state basin committees; • The region of this basin has environmental problems due to mineral exploration and increasing agricultural activities.
São Francisco	São Francisco and its tributaries, Grande, Corrente, Paracatú, Paraopeba, Abaeté, das Velhas and Jequitaí.	Bahia Minas Gerais Pernambuco Alagoas Sergipe Goiás Distrito Federal	• Serves 75% of the country's population, with 77% in urban regions; • The greatest quantity and diversity of freshwater fish are concentrated in the Northeast region; • Region ripe for the development of tourism due to archeological sites and historical locations, etc.; • Regarding consumption, 77% of total demand is for irrigation and 11% for urban supply; • Has 16 state basin committees and 2 interstate basin committees.

Source: Adapted from the Conjuncture of Water Resources in Brazil (ANA, 2013).

The National Water Agency (ANA) is an autarchy, created under special conditions and linked to the Ministry of the Environment. It seeks to develop a dialogue with agencies from many spheres of public and private power regarding the use of water resources under the jurisdiction of the federal government by stimulating the creation of the DBCs and providing support to the states in the creation of management entities, in other words, creating a value chain for water resources.

Water resources in Goiás, in terms of availability, are associated with the respective drainage basins on the state's territory: the River Araguaia Drainage Basin, the River Paranaíba Drainage Basin, the River Tocantins and part of the River São Francisco basin. The state is part of two Interstate Water Resource Plans, drafted for the São Francisco and Tocantins-Araguaia Basins, which have already been concluded, and the Paranaíba Basin, which is in the implementation phase.

Among the DBCs in the state is the Meia Ponte, which covers the Meia Ponte River and its tributaries, encompassing the state capital and almost all the surrounding municipalities. In this DBC, the main factors of environmental degradation and water pollution are urban and rural waste, high levels of contamination due to plant protection products and the great demand for water for irrigation purposes.

The DBC of the Vermelho River, formed by the Vermelho Rover and its tributaries (Uvá River, Água Limpa and Ferreira River), serves 11 of the 246 municipalities of Goiás. In the basin, the predominance of extensive livestock is responsible for environmental degradation because of the inadequate management and occupation of the soil. Equally worrying is the expansion of irrigated agriculture in the municipalities of Santa Fé, Jussara, Britânia and Aruanã, which are included in the jurisdiction of this DBC.

The DBC of the Corumbá and Veríssimo rivers and the tributaries in Goiás of the São Marcos River, or the drainage basins of the southeast of the state, operates in the drainage region of Paraná, in the drainage basin of the Paranaíba River, the southeast region of Goiás. It represents 44 of the state's municipalities (including Cristalina, Morrinhos, Ipameri, Luziânia and Rio Quente), which are totally or partly included in it. The centralized region is the home of a considerable part of the state's agriculture and important agroindustrial complexes that affect the environmental resources of diverse sectors.

The Baixo Paranaíba or Southeast Goiás DBC encompasses the Paranaíba River drainage basin in the southeast of the state and the tributaries of the Paranaíba River in the east-west direction, with eighteen of the state's municipalities totally or partly included in this region. Due to the economic configuration of the region, focusing on farming and large industries, along with the disordered occupation by the population, the water capacity is compromised, leading to conflicts over the use of water.

The limits of the DBC of the Turvo and dos Bois Rivers are to the north of the das Almas River, the west of the Caiapó River, the east of the Meia Ponte River, the southwest of the Claro River and to the south flowing into the waters of the Paranaíba River. The region of this basin in composed of 46 municipalities, with conflict between the public supply sector and the sector of irrigation and small users along the various sources of the basin, such as the Turvo, Verde or Verdão, Ribeirão Santa Bárbara and Ribeirão Bonsucesso Rivers.

In turn, the DBC of the Paranaíba operates in the Paranaíba River drainage basin, formed by part of the states of Goiás and Minas Gerais, the entre urban section of the Distrito Federal and a small part of the state of Mato Grosso do Sul. Its tributaries in the Distrito Federal are the basins of the São Marcos, São Bartolomeu, Corumbá and Descoberto rivers. The tributaries in Goiás are the São Marcos, Veríssimo, Corumbá, Meia Ponte, Turvo, dos Bois, Alegre, Claro, Verde, Corrente and Aporé rivers. In Mato Grosso do Sul, the tributaries are the Santana and Aporé rivers, and in Minas Gerais, the Paranaíba River, made up of the source of the Dourados River. The waters of the São Marcos River, which flows through the municipality of Cristalina, and others, are largely used for irrigating farmland, generating energy and mining, and there have been conflicts between these sectors over the use of water.

Thus, the Water Resources Plan for the Rio Paranaíba Drainage Basin (2012, p. 150) states:

The growth of modern agriculture in the basin has accentuated the pre-existing process of the degradation of the *cerrado* (ecoregion) and introduced new variables: the intense use of water for irrigation and the risk of contaminating the soil, the waters and the water table due to the use of pesticides. This growth is linked to larger industrial areas and urban regions, causing greater demand for water consumption and, at the same time, greater degradation of water resources by industrial waste and sewage. The constant increase of the use of water for irrigation, to meet the needs of expanding industrialization and to supply cities with a continuously growing population inevitably places greater demand on the Paranaíba Basin for water to generate electricity now and in the future.

A common fact identified in the implementation of DBCs is the need to regulate the use of water, given its limited availability in terms of quantity and quality, to be managed by the different spheres of government to promote sustainability. This can be done by imposing restrictions on the multiple uses of the resource and economically valuing the demanded flow rate, aiding the participation and articulation of the diverse social and economic sectors involved. However, although permitted since 1997 by Law 9.433, no committee in the state has effectively moved to charge for the use of water.

The law also constitutes the National Water Resources Policy. Its hierarchy of managerial agencies at the national and state levels and their main jurisdictions are as follows. Councils promote the articulation of national, regional and state planning and that of the sectors/users, and they resolve conflicts. The MMA/SRHU (Ministry of the Environment/Secretariat of Water Resources and Urban Environment) legislates on the National Water Resources Policy and helps to set the Federal Government Budget. The ANA (National Water Agency) is a federal agency that implements the National Water Resources Policy, and authorizes and inspects the use of water resources under the jurisdiction of the Federal Government. The State Agency authorizes and inspects the use of water resources under the jurisdiction of the state. The Basin Committee makes decisions on the Water Resources Plan (when, how much and why to charge for the use of water resources). The Water Agency is the technical wing of the Basin Committee.

From what has been shown in this section, it may be inferred that DBCs are public management agencies for common resources, with representatives from the different sectors of society (public, civil and users). The predominant representation of users (40%) and the public authorities (40%) over the civil and professional agencies (20%) is evidence of the goal of decision making on the management of the water resources in the basin in accordance with the legal and utility limits. It also legitimizes the public management of common resources and the characterization of the basins based on their environmental and social fragility, indicating the limits of strategic decision making based on the sustainability parameters of the basins. The fact that the representatives are not paid shows that they have a real interest in the management of the basin with a view to regional development. Finally, the hierarchy of the management entities is demonstrative of the bureaucratic characteristics established by the legal directives, allowing the institution of regulations based on priorities and technical parameters. Therefore, it is hoped that the social function of irrigators, in addition to the production criteria for agricultural products, should result in environmental conservation and the fair distribution of products generated using water resources.

3.2 Technical and administrative criteria: directives for the efficient use of water for irrigation in Goiás

In irrigated agriculture, greater productivity is necessarily a consequence of the optimum combination of the inputs used in production and the use of water. The efficient use of water results from the highest production level achieved from this resource at every level, with a fixed quantity of other production factors. Thus, the relationship between soil, water, plants and atmosphere is a fundamental aspect for consideration in the planning and execution of an irrigation project. To establish the interrelationship between these elements and identify their limitations, it is necessary to draft an irrigation plan. Its stages should consider the features of the location, the crop to be planted, the irrigation system to be used and the technical competence required to manage irrigation systems (Bernardo, Soares, & Mantovani, 2006).

As highlighted by Schmidt (2007), selecting the method and adequate system for the region, the adequate management of the system and the maintenance of the equipment are necessary parameters for achieving socio-economic and environmental efficiency in the use of water. This is because intense use of the soil in irrigated areas (on average three harvests a year) can result in environmental damage, such as soil degradation, contamination or depletion of water resources and more widespread use of pesticides.

It is estimated that the average irrigation efficiency worldwide is 37%, This is because, in addition to the waste of water resources, an aggravating factor is the contamination of the soil by the volume of water lost and mixed with pesticides and toxic elements that can compromise the availability of water and its quality (Paz, Teodoro, & Mendonça, 2000).

According to Paz, Teodoro and Mendonça (2000, p. 11): “Irrigation methods and equipment can and should be improved to reduce losses and lead to the adequate management of the soil, plants and climate, resulting in the more efficient use of water. Inefficient methods are incompatible with current policies on the use of water [...]”. An equally important aspect in the drive for efficient irrigation is the choice of an adequate method for the crop in question. According to Andrade (2001, p. 15), the efficiency of an irrigation system can be gauged from certain standards of minimum efficiency: “Surface irrigation systems, in general, require greater flows with less frequency. Sprinkler and localized systems can be adapted to sources of water with lower flows. Surface irrigation systems are potentially less efficient (30-80%) compared with sprinkler (75-90%) and localized (80-95%) systems.”

Thus, an irrigation project should be prepared considering this technology in a systemic context, complemented by technical, environmental and managerial features, aligned with the parameters set by the public agencies that regulate water resources. The Technical Authorization Manual (2012) is a reference document for authorization to use water resources in Goiás State. It is based on Resolution 09, of 2005, of the National Water Resources Council. It addresses in detail the main technical procedures involved in processes and analyses of requests for authorization organized by the main types of use of water resources. This document presents a sequence of stages to be followed in the authorization process, beginning with the request for a rate of concession or authorization until the issuing of the authorization declaration or bulletin. It includes the whole period while the request is pending for consolidation up to 60 days following the provision of proof that the project complies with the regulations.

According to Seckler, Molden and Sakthivadivel (2003), a major advance in the efficiency of irrigation was achieved by aligning the goal of implementing an irrigation system with compliance with the real evapotranspiration requirements of the crop. Based on the relationship between the reference evapotranspiration (ETo) and crop evapotranspiration (ETc), it is possible to identify, at different phases of development of the crop, the kc or crop coefficient. These values are presented in the format of a table, including different crops and their respective vegetative cycle. Goiás State suggested the Penman-Monteith method (FAO, Bulletin 56) as the standard for estimating the kc, to be used as a reference for preparing irrigation projects, as stated in the state's Technical Authorization Manual (2012).

According to the Technical Authorization Manual (2012, p. 27), irrigation efficiency (Ei), calculated from the monthly net volume of irrigation, discounting the losses of capture, conduction and application, is the legally established parameter. Irrigation efficiency, through the irrigation system, should be compatible with ANA Resolution 707/2004 (ANA, 2004). The resolution sets minimum efficiency indicators (Table 2) for the rational use of water. Applications with lower efficiency levels are only accepted if they are duly justified. In Technical Note 364/2007/GEOUT/SOF-ANA, in addition to the values established in Resolution 707/2004, values are presented for minimum efficiency for a larger number of irrigation methods.

Table 2 – Water efficiency indicators for irrigation systems

Irrigation Method	Minimum Efficiency (%)
Drip irrigation	95*
Micro sprinkler	90*
Perforated tube	85*
Subirrigation	60
Underground drip irrigation – porous pipe	95
Self-propelled sprinkler system	80
Conventional sprinkler system	80
Central pivot sprinkler system	85
LEPA central pivot sprinkler system	95
Open furrow	65
Closed furrow	75
Flood	60

Source: ANA (2004) – Prepared by the authors.

As shown throughout this section, to achieve technical efficiency in irrigation it is necessary to establish a systemic view regarding all the elements involved in the implementation of an irrigation project, with this being the initial framework for attaining allocative efficiency and, consequently, economic efficiency. In other words, to cite Catermol (2004, p. 125), "[the] criterion of allocative efficiency states that the existing resources in an economy should be allocated in such a way that allows the maximum possible net benefit to be extracted from their use". This factor is a model for appreciating the capacity to generate benefits through the efficient allocation of scarce resources considering alternative uses.

4 Results and discussions

The adoption of irrigation management techniques emerges as a strategy to improve the use of technology that enables lower water consumption and reduces production costs. However, the adoption of water management depends on the profile of the rural entrepreneur and his perception of the use of this input.

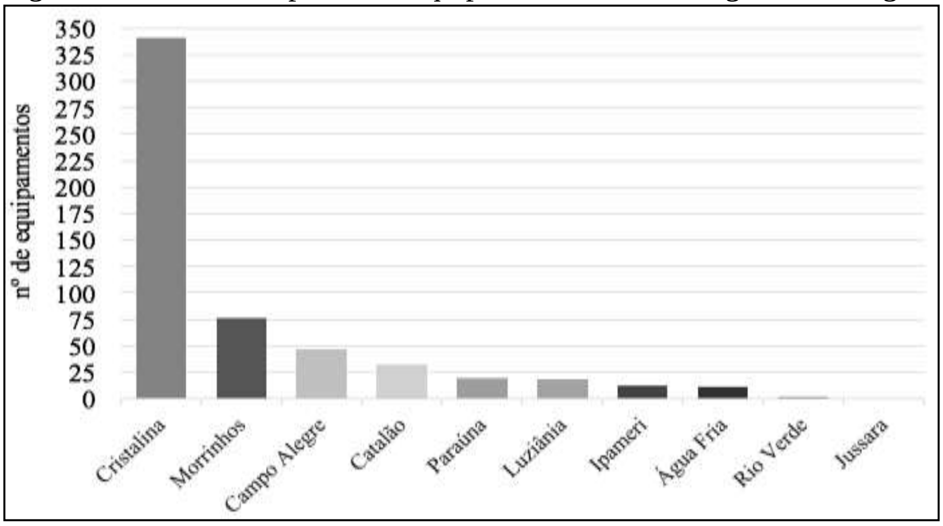
The registration of irrigators in Goiás State (SEAGRO, 2014) shows the historical evolution of irrigation in the state, identifying the systems installed between 1978 and 2014. From 1978 to 1987, 57 pieces of irrigation equipment were installed. From 1988 to 1997, the number of pieces of equipment installed soared to 526 and, from 1998, the state saw a wide expansion of this production model. In 2007, 980 pieces of equipment were implemented and over 981 from 2008 to 2014. Of this total, the vast majority of irrigation systems sold used the central pivot model, which is a type of sprinkler, corresponding to 1587 pieces of equipment.

Considering that in Goiás approximately 250,000 hectares of agricultural land are irrigated, representing less than 5% of the irrigated area in Brazil, the research data revealed that 45.6% of the irrigated area is concentrated in only ten municipalities. This high concentration (Figure 1) is perceived even within this group, as is the case of the municipality of Cristalina, which has five times more systems in operation than the next in the line, Morrinhos, although both have equal municipal areas (IBGE, 2017).

In this respect, it can be inferred that the expansion of irrigation and, consequently, the formation of irrigation complexes, could be explained by the rational expectations model first implemented by John Muth in 1960. The model is based on the hypothesis that agents form expectations through conditional probability with regard to the set of information available in the economic system. This means that information on the prediction model, government policies and previous values of other important variables for defining expectations enable experiences and constitute a database for agents to anticipate or react rationally to future policies and actions in the present, thus minimizing the adverse effects of these policies.

Therefore, a) this configuration would be subject to access to scarce information; b) the structure of the economic system guides the formation of expectations; and c) a public projection will only affect the operations of the economic system if they are based on privileged information. Thus, considering supply, demand and market balance of a specific product and its short-term price variations, it is possible for agents in the market and who have privileged information to profit from this knowledge by creating, more than expectations, market opportunities. In other words, the model could explain what motivates this concentration and the destination of irrigation systems, assuming the hypothesis that the more consolidated regions and crops are responsible for attracting similar investments in a complex decision-making environment.

Figure 1 – Number of pieces of equipment used with irrigation management



Source: Prepared by the authors.

This high regional concentration has direct implications for the conflict over the use of water resources, with reflections on ecosystems and the urban industrial context (Furquim & Abdala, 2016). Of the management methods and technologies that are used by irrigators, the following may be highlighted:

- Watering frequency – consists of the intervals of time between one irrigation and another, i.e., it considers the water holding capacity of the soil to estimate the interval between irrigations. Therefore, watering frequency will be greater when the soil is more capable of storing water and can be done with fixed watering and variable blade, or variable watering and fixed blade (Frizzone, 2007).
- Soil profile structuring – involves techniques that optimize the infiltration of the water applied to the surface of the land, reducing surface runoff and helping to raise the soil's storage capacity (Schmidt, 2007).
- Tensiometer – equipment that monitors alterations in water content, measuring the soil's water retention capacity (Azevedo & Silva, 2003).
- Computational system – software or applications that help farmers to access technical and managerial support for their activities from a database, with on-site visits to their property. It integrates the characteristics of the soil, climate, crop to be grown and irrigation system used, in keeping with information from weather stations, satellite images and other tools that provide support in decision making (Bernardo, Soares, & Mantovani, 2006).

- Water stress management – consists of optimizing the use of water, associating the volume applied with the quantity to be produced in order to enable irrigation proportional to demand, according to the development cycle of the crop (Silva, 2003).

Considering these management models, it can be seen that the computational system and water stress management are the methods that, despite their greater managerial complexity, present a more systemic approach in terms of the efficient use of water resources.

According to the registers of irrigators in Goiás State (SEAGRO, 2014) considering the main management techniques used by managers of irrigation systems in the state (Table 3), it was found that in Paraúna, Morrinhos and Catalão, approximately 30% of those registered do not manage their water, with watering frequency being the most used method. In Ipameri, Campo Alegre de Goiás and Cristalina, in around 50% of the equipment is not managed, and the most common system is the use of computational systems. In Rio Verde, Luziânia, Jussara and Água Fria de Goiás, there is no water management for over 70% of the equipment. On average, 48.52% of the irrigators do not manage the water in their irrigation systems.

Table 3 – Management methods of irrigation systems used by managers in Goiás State

Municipality	Number of pieces of equipment	Management method	No management
Cristalina	661	Watering frequency – 89 Soil profile – 1 Rural trade union – 1 Embrapa – 1 University of Piracicaba – 4 Computational system – 245	320
Jussara	34	-	34
Paraúna	27	Tensiometer – 10 Watering frequency – 1 Computational system – 9	7
Morrinhos	111	Watering frequency – 76	35
Luziânia	61	Water stress – 7 Computational system – 9 Watering frequency – 2	43
Campo Alegre de Goiás	92	Computational system - 30 Watering frequency – 17	45
Água Fria de Goiás	53	Watering frequency – 11	42
Rio Verde	64	Computational system - 2	62
Ipamerí	29	Tensiometer – 4 Watering frequency – 4 Computational system – 7	14
Catalão	49	Rain gauge – 4 Watering frequency – 21 Computational system – 8	16

Source: SEAGRO, 2014.

The data also reveal that Goiás State has a significant percentage of irrigation equipment that has been in use for over twenty years. Of the total pieces of equipment in 2014, 470 were over twenty years old, and of these, 408 are of the central pivot type, which helps to reduce the efficiency of the irrigation method by up to 50%, in other words, going against the grain of what is advocated in terms of the efficient economy of resources. Another cause for concern is that approximately 30% of the sample population are not authorized to capture water resources, which constitutes a sign of the inadequacy of the irrigation system in terms of the technical and ecological parameters required for authorizing the use of this resource.

However, there are cases of the construction of dams to collect rainwater as a technique for the efficient water use in irrigation, as dams increase the supply of the resource. Nevertheless, according to Furquim (2017), this technique is tentative in order to avoid conflicts over the use of water, as these dams do not ensure the supply required for three harvests a year. Moreover, the major challenge with regard to the use of dams lies in the cost of building them, which varies between a thousand and four thousand reais per irrigated hectare added to the project. Even so, the research data on the registration of irrigators in Goiás (SEAGRO, 2014) show that approximately 20% of the irrigation systems did not use dams, with the water captured directly from its source.

Finally, it is important to highlight that the concept of irrigation efficiency should also incorporate the economic aspect of the use of water. According to Albuquerque (2004, p. 14), “[the] classic concept of *irrigation efficiency* used by engineers omits the economic parameters. To determine irrigation efficiency at its optimal level, economists seek to discover the value of irrigation water and the cost of adding it to the production system when controlling or managing it”.

Therefore, water, like other resources, should be allocated efficiently as it is a factor of a production system with the capacity to reduce economic costs.

In this sense, Kijne, Barker and Molden (2003) described the economic efficiency of the use of irrigation as the capacity of the agricultural system to transform water into food and do so efficiently. This represents an economic performance indicator that considers the basic elements of an irrigation system, expressed as the proportion of product output for each unit of water that the system consumes. In other words, the water component in irrigation is presented in a certain economic context, constituting one of the parameters (factors) of a function of production, which ought to be managed to achieve optimum use of the resource.

Cook, Gichuki and Turral (2006) presented, based on the concept of the productivity of water proposed by Kijne, Barker and Molden (2003), different parameters for an economic analysis (Table 4). These authors proposed an economic analysis based on an allocative efficiency indicator. Therefore, what should be analyzed by the water productivity (WP) performance (WP) indicator is the cost-benefit relationship based on the water production factor.

Table 4 – Parameters to estimate water productivity

Parameter	Indicator
Physical water productivity in the field, on the farm or in the context of the system.	Yield (kg) of total biomass, or above-ground biomass, or grains or fodder.
Economic water productivity in the context of agriculture.	Gross value of the product or net value of the product, or net benefit of irrigated production compared with rainfed production.
Economic water productivity on the basin scale.	Any of the previous evaluations, including support for subsistence, such as for cattle, fish or agroforestry
Macroeconomic water productivity on a regional or national scale.	Monetary value of all direct and indirect economic benefits, minus the associated costs, for all the uses of water in the domain of interest.

Source: Cook, Gichuki and Turral, 2006.

Therefore, with WP as an indicator, it is possible to identify the results of water management in terms of allocative efficiency of the resource, in other words, based on the social benefits resulting from the allocation of the productive resource. An example occurs in relation to the use of water to produce crops with a low market value, reducing the global productivity of the basin in economic terms (Mdemu & Francis, 2013).

According to Abdala (2012) and Furquim (2017), central pivot irrigation systems in Goiás have been increasingly allocated to produce products with a low production value per unit of area. These authors concluded that the logic of allocation of the water factor to irrigation systems in the state has not been an example of allocative efficiency.

It is important to highlight that the analysis presented here is based exclusively on the sample of the population of the registration project, researching the profile of irrigators in Goiás (SEAGRO, 2014). However, when compared with the information in the reference documents, the results allow a survey of a set of proposals for continuing the research that will contribute more robustly to the development of the irrigation sector in Goiás State.

Thus, it is important to gain deeper knowledge of the parameters that support the decision making of irrigation farmers in relation to the management profile of their system. The purpose of this is to achieve efficiency in the use of water resources. In this sense, the following research questions may be suggested:

- What is the average profitability of irrigated crops in Goiás State? When deciding what to plant, are farmers maximizing their profits and optimizing the use of water resources?
- Is rational expectations theory an adequate model for understanding the decision making of irrigation farmers?
- How would charging for water affect production decisions, farming configurations and the sustainability of irrigated agriculture in the state, with different pricing levels?
- What are the most effective political tools for achieving the sustainability of irrigated agriculture, those of command and control or market tools?
- What factors are responsible for the inadequate adaptation of irrigation farmers to the institutional functions expected of them established by law?
- The answers to these questions would provide the issues raised here with more robustness, as this work is in the form of an exploratory analysis, remaining in the stage of gathering evidence.

Final considerations

The result of this work consists of presenting the dilemma regarding the private use of water, which is actually a common good regulated by the State. From this premise, the study seeks to find evidence of gaps in the sector in the municipalities in question, as they do not have standard irrigation management that promotes the efficient use of water as an input for production to achieve socially and environmentally responsible competitive agriculture.

Therefore, this work contributes to the public sector regarding the establishment of policies with a view to improving the managerial processes of irrigation systems in Goiás State.

Especially when the volume of water consumed by the sector is estimated, agricultural production stands out due to the highly intense use of water, corresponding to 70.1% of all the water captured in the world, while the industrial sector and public supply account for 20% and 9.9%, respectively. When the distribution effectively consumed per sector is confirmed, the water earmarked for human supply returns at a rate of up to 70%. After use in industrial production, a great deal of the water extracted is also returned. However, in irrigated agriculture, between 70% and 95% of the water is consumed (Martins et al., 2014).

Considering that water is a resource of increasingly limited availability in terms of quantity and quality, and has multiple uses, its sustainable use is a conditioning factor in the promotion of economic development and social well-being.

The sustainable use of water in irrigation is intrinsically related to greater technical and economic efficiency of the use of water and can be achieved through actions that limit the amount of water used per unit of any activity, aiding the conservation of bodies of water.

Therefore, to achieve inter-temporal efficiency it is necessary to adopt management strategies that reduce losses in reservoirs, in the conduction and application of water in irrigated areas, in the improvement of irrigation methods and equipment maintenance. It is also necessary to improve the economic selection of products that will be the fruit of the use of water, as the increased supply of these products means a social benefit resulting from the use of a public good, water.

The need for and concern over efficiency levels in the use of irrigation systems have already been voiced in the market. This is especially the case in partnerships between irrigation farmers and agro-industries, as these have demanded proof of efficiency and the even application of pivot water to supply irrigators with inputs, with a view to achieving the optimized use of these inputs (Furquim, 2017).

As irrigation technologies are imperative for the modernization of Brazilian agriculture, raising the water element to the level of a productive resource and considering it as a differential for the development of competitive agribusiness is a major challenge for the irrigation sector of Goiás State.

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