Revista Brasileira de Agricultura Irrigada
Brazilian Journal of Irrigated Agriculture
ISSN: 1982-7679 (on-line)
v.18, p. 10 – 20, 2024
Fortaleza, CE - www.inovagri.org.br

DOI: 10.7127/rbai.v1801300

PROSPECTS OF SURFACE IRRIGATION IN BRAZIL

PERSPECTIVAS DA IRRIGAÇÃO POR SUPERFÍCIE NO BRASIL

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ABSTRACT: In Brazil,surface irrigation systems are used extensively despite their reduced irrigation efficiency, with surface-irrigated areascovering1.547 Mha, of which 1.129 Mhaare for flooded rice production. This review providesan overview of surface irrigation systems in Brazil, in addition to the perspectives and public policies implicit in granting water supply. Adopting technologies in surface irrigation systems can favor increased efficiency in water use, maximing crop productivity, and consequently, impacting the sustainability of irrigated agriculture positively

Keywords: E*ficiency of water use, Technological advancement, Sustainability.*

RESUMO: A área irrigada por superfície no Brasil é de 1,547 milhões de hectares, sendo 1,129 milhões de hectares com produção de arroz inundado. Apesar da reduzida eficiência de irrigação, o sistema de irrigação por superfície apresenta uma área expressiva de uso. Dessa forma, o objetivo da presente revisão foi abordar um panorama da situação da irrigação por superfície no Brasil, além das perspectivas e políticas públicas implícitas no processo de concessão de uso da água para esses fins. Notou-se que a adoção de tecnologias nos sistemas de irrigação por superfície, pode favorecer o incremento da eficiência no uso da água, maximizando a produtividade das lavouras e consequentemente, impactando positivamente a sustentabilidade da agricultura irrigada.

Palavras-chave: *Eficiência do uso da água, Avanços tecnológicos, Sustentabilidade.*

Protocolo 1300.24 - 04-03-2022- Aprovado em -05-03-2024
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Editor de área: João Pereira Filho

INTRODUCTION

The food and agriculture organization (FAO) survey (2017) reported that Brazil, which has an irrigated agricultural area of ~5.1 Mha, is among the top ten countries with the largest irrigated areas. The irrigated areashave the potential to increase to ~35 Mha(ABIMAQ, 2019). Irrigation systems in Brazil consume 3.01 billion L/h of water (836 m^3/s),corresponding to more than 70% of the total water supply reserved for agriculture (ANA, 2014). The irrigated areas in Brazil can be divided into four groups:flooded rice, sugar cane, central pivots,and others, with areas spanning 1.54, 2.07, 1.40, and 2.00 Mha, respectively. The northern region of Brazil, i.e., the state of Tocantins, has a lower irrigated area (2.8%)compared to that in the Southeast region (39%), which can be attributed to a greater diversification of irrigation methods and types (ANA, 2017).In addition to Brazil, surface irrigation occupies a large portion of the irrigated areas in Asia and the European Union. Farmers employ this method because of its advantages such as low investment cost, applicability to small farm sizes, and low profitability and irrigation costs (MASSERONI et al., 2017).

Most surface irrigation systems are inadequately designed and managed, thereby resulting inpoor system efficiency. Such systems perform satisfactorily when managed appropriately (BERNARDO et al., 2019), and therefore, improving water resource management in nonpressurized systems is necessary to address the high water supply requirements for irrigation. Managing water resources requires applying public policies, which grant access to water supply for different purposes, to ensure sustainable consumption and resource conservation. Therefore, several countries have established different policies for regulating water resources. This review highlights the use of surface irrigation in Brazil, policies involved in the concessionsin water supply, and the use in irrigated production.

BRIEF HISTORY OF SURFACE IRRIGATION

In 1999, 174 of the 225 countriesused irrigation to meet the water demands for crops (DÖLL; SIEBERT, 2000). The first global survey on irrigated agricultural areas was published by the FAO (United Nations) in 1999, in their report titled, “A digital global map of irrigated areas.” This survey reported that, among the total irrigated areas in the 1990s, 67.8%wereon the Asian continent.The United States of America, Europe, Africa, and Australia accounted for 16.4, 10.1, 4.7, and 1.0% of the remaining areas, respectively. The AQUASTAT database has the most current data on irrigated areas by country, which can be obtained from the FAO. Table 1 provides details onthe top ten countries in terms of irrigated agricultural areas. India, China, and the United States are the top three countries with the largest irrigated areas. Among all countries, Brazil has a considerably large area, highlighting its potential for agricultural expansion.

The data provided in Table 1 also presents the distribution of different irrigation systems in each country.

Table 1. Evolution of irrigated areas by country. The areas are divided based on the types of irrigation systems in each country.

Countries	Surface-irrigated area (Mha)		Sprinkler-irrigated area (Mha)		Locally irrigated area (Mha)		Total irrigated area (Mha)		% Effectively irrigated area	
	1997	2017	1997	2017	1997	2017	1997	2017	1997	2017
India	54.6	68.2	0.85	1.6	0.33	0,64	55,8	70,4	96,5	93,9
China	52.3	65.8	1.0	3.2	-	0.8	53.3	69.8	87.5	83.6
USA	-	12.1	-	12.8	-	1.8	-	26.7	-	83.8
Pakistan	-	19.3	-	-	-	-	17.7	19.9	-	-
Iran	7.3	8	0.14	0.30	0.2	0.4	7.6	8.7	92.0	73.8
Indonesia	4.7	6.7	-	-	-	-	4.7	6.7	-	-
Thailand	4.9	6.4	-	-	-	-	4.9	6.4	85.2	78.9
Turkey	4.0	4.7	0.26	0.50	0.01	0.15	4.3	5.3	77.9	98.6
Brazil	-	1.5	-	1.0	0.16	2.5	-	5.0	-	87.9
Bangladesh	3.9	5.0	-	-	-	-	3.9	5.0	69.3	54.2

*Mha - Million hectares
Source: FAO (2021)

The data collected by the Secretariat of Water Resources in 1995 indicated that Brazil had an irrigated area of ~2.63 Mha, with the surface irrigation method covering almost 60% of the irrigated area. The distribution of surface irrigated areas by the state is summarized in Table 2 (EMBRAPA, 1996).

Table 2. Distribution of surface irrigation methods in Brazil, 1990s.

Regions	Irrigated area (1000 hectares)	
	Flood	Furrow
North	5	-
Northeast	70	153

Regions	Irrigated area (1000 hectares)	
	Flood	Furrow
Midwest	55	5
Southeast	250	12
South	990	-

Source: Adapted from Telles (1993).

SURFACE IRRIGATION

Main systems

Forsurface irrigation, the water supply system can be designed to use an open channel or a pipe with different cross-sections in the channel (rectangular, triangular, trapezoidal, and/or parabolic).Pipes can be used for providing water to the area to be irrigated (ADAMALA et al., 2014).

Water is distributed into the soil by gravity and used for flood irrigation, furrows, basins, or strips. Surface irrigation systems demonstrate poor efficiency when they are not designed and managed properly.Feitosa et al. (2017) investigated the replacement of a surface irrigation system in the Mandacaru Public Irrigation Project in 2010.

The conversion of the old systemimplemented in the 1960s in Juazeiro (BA) to localized irrigationincreased the efficiency of water use compared to that of irrigation projects that maintained the gravity irrigation system (FEITOSA, MACHADO, and FRANCO, 2017). These authors also reported that furrow irrigation showed low application efficiency because of water loss caused by evaporation, run-off, and percolation.

Techniques such as furrows, strips, and floods can be used for improving the performance of irrigation systems. Gonçalves and Lima (2018) reported that practices such as proper leveling of the area ensure a greater uniformity of infiltration and higher yields with surface irrigation. This technique adopts an irrigation deficit and controls the leached fractionin addition to improving drainage.Smaller irrigation depths in rice flooding can reduce infiltration and percolation loss, thereby favoring rainwater storage. Lorensi et al.(2010) stated that flood irrigation can temporarily or permanently depend on the type of crop to be irrigated, and it can be adapted to various crops resistant to excess water.

Among the other systems, furrow irrigation can be used in the application of wastewater in the soil through fertigation. Optimizing this process can help improve the distribution of nutrients in the soil (Marques et al., 2018). Further, irrigation using alternative furrows or a drainage system can favor the drainage of the water surplus, allowing the reuse of water (GONÇALVES; LIMA, 2018).

Surface irrigation can be applied to different crops, such as soybean. Sartori et al. (2015) stated that supplementary irrigation by strips, performed under conditions of soil moisture below 60% of field capacity, resulted in an increased productivity of this crop.

Regional distribution of some surface irrigation systems in Brazil

In Brazil, a large part of surface irrigation with flooded rice crops was adopted by the states of Rio Grande do Sul and Tocantins. Other regions adopted this method to meet rice production requirements, even if on a smaller scale, including SC, MS, GO, MG, MA, PI, PE, AL, SE, and CE (ANA, 2021) (Figure 1)

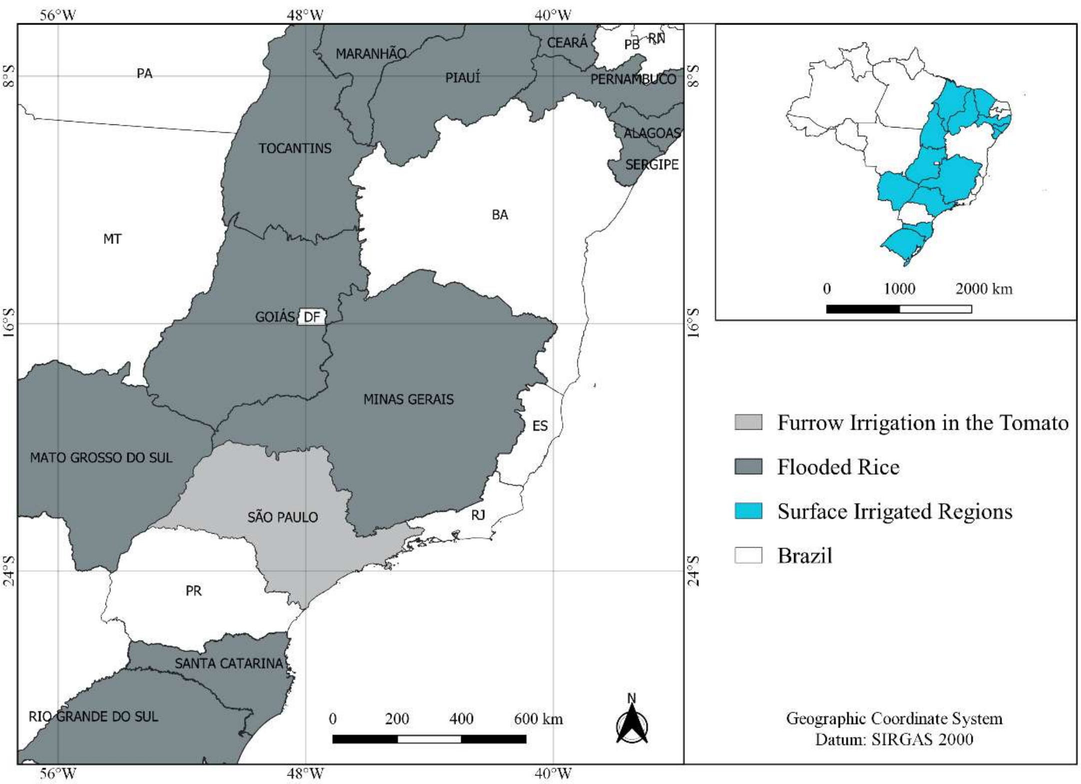

Figure 1. Categories of surface irrigation for different regions in Brazil (ANA, 2021).
Source: Elaborated by author.

In the regions of Campinas and Mogi Guaçu, municipalities in the State of São Paulo, tomatoes are cultivated using furrows irrigation techniques because of its low investment cost, ease of operation,and suitability in different locations (GOMES; TESTEZLAF, 2009).Furrow irrigation has been commonly used since the 1970s and 1980s in small agricultural properties in the northeast region, which can be attributed to its ease of operation and low cost compared to that of other irrigation systems. In these regions, the system exhibits low performance. Management practices can be adopted to significantly improve performance (ARAUJO et al., 2019).

Factors that can affect the efficiency of the irrigation systems

Irrigated agriculture necessititates high water consumption, and therefore, approaches to improve the efficiency of systems associated with the net productivity of crops have gained attention in the agricultural sphere. Technological innovations in systems engineering, scientific advances in crops, and environmental and socioeconomic factors can contribute to increasing irrigation efficiency (KOECH; LANGAT, 2018).

Soil water content is a fundamental parameter for sustainable water management. Irrigated activity was programmed by considering this factor in addition to climatic variables.Among the various techniques used for monitoring the water content in the soil, indirect measurements using thermal and electrical sensors, such as optical fiber heated with temperature sensors, are gaining interest (RODRÍGUEZ-SINOBAS et al., 2021). Computational tools such as simulation models and remote sensing are widely adopted for monitoring irrigated areas.

In the United States, irrigation efficiency has increased in areas where agricultural producerstake decisions based on information provided by the government, thereby referring to water management (MPANGA; IDOWU, 2021). In Brazil, the National Water Agency established under Law 9984/00 is responsible for water management. In Brazil, Rio Grande do Sul has gained popularity in terms of rice production, especially flooded rice. Andres et al. (2009) stated that intermittent irrigation with multiple aerations is implemented in the southern region of this state, with the results showing water savings of 30–40%, without compromising crop productivity.

Santos et al. (2021) conducted a study in Goiás and Tocantins for anlayzing the effect of irrigation management on the agronomic performance of irrigated rice cultivars. In this study, the authors obtained better performance results with smaller volumes of blades, increasing the efficiency of use.

PUBLIC POLICIES FOR MANAGING WATER RESOURCES IN IRRIGATED AREAS

Law no. 9,433/1997, instituted in Brazil in 1997, envisions the management of multiple uses of water in a decentralized and participatory manner, leading to the establishment of the National Water Resources Policy (PNRH) and National Water Resources Management System (SINGREH) (BRASIL, 2019).

According to the National Water Agency (ANA) (2020), the main normative instrument of SINGREH's is the National Water Resources Council (CNRH), which includes the Water Resources and Environmental Quality Secretariat. Further, the State Water Resources Councils includes managers responsible for water resources in the state (State Entities), as decided by the Hydrographic Basin Committees and Water Agencies.

SINGREH is operated through inputs from each agency, which are divided into three levels: federal, state, and hydrographic basin (Figure 2).

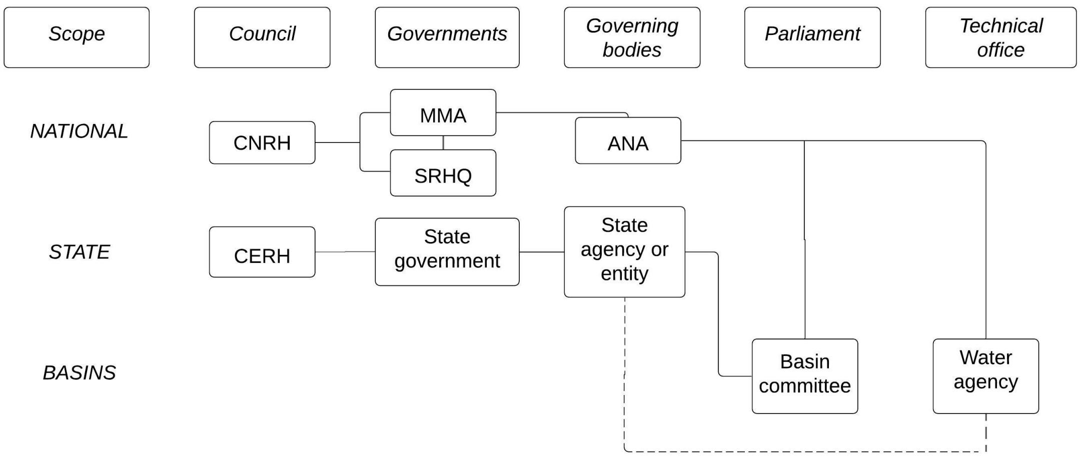

Figure 2. Structure of SINGREH, which presents entities and their level of activity (ANA, 2020).
Source: Elaborated by author.

The Hydrographic Basin Committees act as a consultative and deliberative member in managing water resource management unitscharacterized by delimiting the hydrographic basin as a regional planning unit.

These committees assess interests in the uses of water in hydrographic basins and approve the PNRH, arbitrate conflicts on the use of water (at the first administrative level), establish mechanisms, and suggest charges for water use, among others (ANA, 2011; WOLKMER; PIMMEL, 2013).

ANA cites the development of a new PNRHto establish water security in Brazil, seeking to address the new challenges related to climate change and the risk of scarcity in hydrographic basins. A new PNRH is planned for promoting greater integration with sectoral policies for sanitation, water, and irrigation infrastructures, among others (BRASIL, 2018).

The Atlas Irrigation: The Use of Water in Irrigated Agriculture initiative by ANA for obtaining information about irrigated agriculture in Brazil included the percentage of irrigated areas and other relevant information. Further, water resources management can be monitored by publishing reports on the conjuncture of water resources, which considers the implementation of management instruments, institutional advances in the system, and the current situation, every four years (ANA, 2021).

Law no. 12,787, which helped establish the National Irrigation Policy, was enacted on January 11, 2013, by the Brazilian government. The principle of this policy governed the sustainable use and management of soil and water resources, includingresources reserved for irrigation; integration with sectoral policies for water resources, environment, energy, environmental sanitation, credit, and rural insurance and their respective plans, with priority given to projects that allow for the multiple uses of water resources; and the democratic and participatory management of Public Irrigation Projects with irrigation infrastructure for common use, among others (BRASIL, 2013).

Another initiative of the federal government was the creation of the poles of irrigated agriculture, established by Ordinance MDR number 1082 on April 25, 2019, as an integral part of the actions to implement the National Irrigation Policy and encourage regional development, listing the actions for pole recognition. These poles are characterized as agricultural clusters that have irrigated agriculture with possible expansion potentialconsidering the availability of water and soil (BRASIL, 2019).

Irrigated agriculture accounts for 50% of all water consumption in Braziland the demand for crops is not consistent in regions with low availability of water resources because it is the case in the semi-arid northeast (ANA, 2021). According to Ferreira et al. (2016), the growing agribusiness in the State of Ceará reflects the need for high water consumption.

According to data collected by the Water Resources Management Company (COGERH) a reduction in water availability is observed commonly during periods of greater fruit tree irrigation. This scenario in the state of Ceará identified an unequal relationship between access to water fostered by the close relationship between large irrigated fruit companies and the government (FERREIRA et al., 2016).

Other Brazilian regions such as the Submédio São Francisco face challenges in the managing their water resources for ensuring equal access to multiple users. In this region, the water demand is at least 20% of the minimum natural flow, and it is characterized by a critical scenario (MILHORANCE et al., 2019). According to the authors, in regions of Cabrobó (PE) and Rodelas (BA), poor drainage of irrigation projects increased soil salinization, which is responsible for conflicts that are intensified by the occurrence of droughts.

These cases show the importance of policies regulating water use. Concessions for the use of water were established through a grant that ensured the right to use water resources. In the State of Minas Gerais, this procedure is governed by the Minas Gerais Institute for Water Management (IGAM) and regulated by Decree 47,343 established on January 23, 2018 (IGAM 2019).

Among the measures related to sustainable development in agriculture, unifying the environmental licensing procedures and granting access to water for use in agriculture and livestock by irrigation users is recommended to speed up the procedures (CHRISTOFIDIS, 2013).Thus, legal requirements and management instruments, such as granting and charging for the use of water, ensure the continuity of irrigation activity, improve efficiency, and reduce waste, enabling the rational use of this resource (ANA, 2021). Based on this premise, Law no. 12,183 was enacted in 2005 by the government of the State of São Paulo, providing charges for using the water resources. Therefore, the beginning of payment for the capture and use of water by producers was determined as January 1, 2010 (CAMPOS &, TESTEZLAF 2009). The authors stated that the obligation to pay the charge generated greater concern among tomato growers using furrows in São Paulorelated to approaches for reducing the impact on production.

TECHNOLOGICAL ADVANCES FOR SURFACE IRRIGATION

Surface irrigation is a promising practice in some countries, and it achieves satisfactory results from economic and environmental perspectives, with the adoption of technologies in irrigated systems. Silva Júnior and Silva (2016) reinforced this idea by stating that research contributes to the modernization of irrigated projects based on the adoption of new techniques, thereby providing agricultural producers with the rational use of water resources.

Christofidis (2013) states that Brazil has a potential of ~14% of the world's capacity to incorporate new areas into irrigated agriculture. Therefore, investment in technology for surface irrigation systems is advantageous for agribusinesses. Profitability attributed to the low initial project cost compared to that of other irrigation systems can be maxmized with an increasein the efficiency of the systems. In some countries such as Indonesia, techniques are being adopted for increasing rice productivity and maximizing water use efficiency. Farmers in the central province of Java, who opted a rice intensification system using intermittent irrigation, obtained higher yields than that when conventional flood irrigation is used, thereby highlighting the water savings from this practice (NUGROHO et al., 2018).

In Brazil, the management of saturated soil and the intermittent irrigation of rice, cultivated in tropical floodplains, are effective strategies for rationalizing water resources (SANTOS et al., 2021). Thus, the adoption of irrigation management practices is being encouraged to rationalize the use of water resources.

Manke et al. (2021) studied the water footprint of irrigated rice cultivated in Rio Grande do Sul under different irrigation management practices. As a management practice, they adopted an indirect method of soil moisture determination using tensiometry. Therefore, the maintenance of the water depth in the irrigation system by intermittent flooding was established based on the water tension values in the soil. Moreover, the adoption of other practices, such as planning through computer models, is already used in some countries for determining the design criteria crucial for improving irrigation efficiency.

According to Adamala et al. (2014), mathematical models of surface irrigation can help improve the management of these systems. The dimensions of the area, slope of the terrain, inlet flow, soil infiltration rate, and flow resistance need to be determined for using these models. The simulation of surface irrigation is a common practice. According to Valipour, Sefidkouhi, and Eslamian (2015), modeling furrow systems is the common simulation approach (53.4%) compared to modeling strip (35.9%) and basin (10.7%) systems, respectively. The authors confirmed the possibility of simulating surface irrigation events using four different models: hydrodynamics, zero inertia, kinematic waves, and volume balance. Ostad-Ali-Askari and Shayannejad (2015) developed a furrow irrigation model based on an equation derived from a zero-inertia model. Their results indicate the possibility of obtaining ideal curves for furrow irrigation projects, considering the variability of soils. Therefore, the efficiency of irrigation systems can be increased by using these technological tools.

Thus, according to Grafton et al. (2018), an increased irrigation efficiency is associated with a reduction in recoverable return flows (surface and/or groundwater) with the maximization of crop yields, thereby highlighting the importance of public policies in ensuring the sustainable use of water resources.

FINAL CONSIDERATIONS

Despite the advantages of low investment costs, ease of operation, and adaptation to several locations, surface irrigation is rarely used in Brazilbecause of the negative history of this practice, and its use in the past beinginadequate, without planning and agricultural management.

However, in the Brazilian regions, more satisfactory results were obtained for rationing water resources where new agricultural technologies were adopted for managing surface irrigation. Further, several measures were adopted by the government to promote irrigation practices, considering sustainable development and the accessibility of water resources for the most diverse poles.

The combination of best management practices with technological innovation is key to achieving sustainability in the agricultural sector. Thus, the prudent management by government agencies, in association with the integrated approach of agricultural producers, can help establish a more efficient scenario for all irrigated systems.

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