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USO DE FERRAMENTAS DE AGRICULTURA DE PRECISÃO PARA A ANÁLISE DO SUPRIMENTO HÍDRICO DO ARROZ IRRIGADO POR INUNDAÇÃO

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1 RESUMO

O aumento da eficiência no uso da água, além de maximizar a produtividade das culturas agrícolas, possui grande importância no contexto atual de preservação dos recursos hídricos. O presente estudo teve como objetivo avaliar a eficiência de ferramentas de agricultura de precisão para a análise do suprimento hídrico do arroz irrigado por inundação, e foi realizado em talhão de lavoura comercial de 33 hectares em propriedade rural em Cachoeira do Sul - RS. A avaliação foi realizada com o mapeamento do tempo de entrada de água, bem como o mapeamento do índice de vegetação VARI, por meio do uso de RPAS e de softwares de geoprocessamento. Os resultados obtidos são de redução nos componentes de rendimento e na produtividade do arroz de 16.645,50 para 12.122,98 kg ha^{-1}, na medida que ocorre o atraso da entrada de água de irrigação no talhão no intervalo a partir de 24 h até 96 h do início da irrigação. O mapeamento do VARI indicou que há correlação linear positiva entre os valores do índice e a produtividade do arroz. O uso de geotecnologias demonstrou-se como ferramenta muito eficaz para a análise da irrigação em arroz.

Palavras-chave: geotecnologias, *Oryza sativa*, irrigação.

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USE OF PRECISION AGRICULTURE TOOLS FOR ANALYSIS OF WATER SUPPLY OF FLOOD IRRIGATED RICE

2 ABSTRACT

In addition to maximizing the productivity of agricultural crops, increasing water use efficiency is highly important in the current context of preserving water resources. The present study aimed to evaluate the efficiency of precision agriculture tools for analyzing the water supply of flood-irrigated rice and was carried out in a 33 hectare commercial crop plot on a rural property in Cachoeira do Sul - RS. The assessment was carried out by mapping the water input time and the vegetation index of the VARI through the use of RPAS and geoprocessing software. The

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results revealed a reduction in the yield components and rice productivity from 16,645.50 to 12,122. 98 kg ha $^{-1}$, as the input of irrigation water into the field is delayed from 24 h to 96 h from the start of irrigation: The VARI mapping indicated that there is a positive linear correlation between the index values and rice productivity. The use of geotechnology has proven to be a very effective tool for analyzing rice irrigation.

Keywords: geotechnologies, *Oryza sativa*, irrigation.

3 INTRODUCTION

The increased demand for food, driven by the constant growth of the world population, coupled with the global context of climate change (such as global warming), represents a major challenge for agricultural production (IPCC, 2013; Lemi; Hailu, 2019). While the need to increase food production intensifies, so does the demand for more sustainable technological approaches. In the state of Rio Grande do Sul (RS), irrigated rice cultivation has great economic importance. In the 2022/23 harvest, the state produced 7,238,560 tons, corresponding to 72% of the national production, which totaled 10,033,300 tons (Brazil, 2023). The average productivity in the RS stands out, reaching 8,786 kg ha^{-1} in that harvest—an increase of 77% compared with the 1990/91 harvest, which was 4,950 kg ha^{-1}. These figures place the state among the regions with the highest rice productivity in the world, and it is also a benchmark for grain quality.

However, a considerable productivity gap still exists. While the state average remains high, some plots belonging to the best producers achieve yields exceeding 13,000 kg ha^{-1} with cultivars and more than 15,000 kg ha^{-1} with hybrids. Chung *et al*. (2000) reported that in the same field, the maximum rice yield can be more than double the minimum yield. In this scenario, precision agriculture (PA) emerges as a fundamental tool, combining a set of technologies aimed at improving management and productivity and considering the spatial and temporal variability of factors that affect crop yields (Inácio; Cortez, 2023).

The main irrigation system adopted in Rio Grande do Sul for irrigated rice is the continuous flooding system (Scivitaro). *et al*., 2009), in which the land is divided into smaller areas, called plots or dikes, leveled at zero elevation or with a slight slope. Flood irrigation is characterized by the application of water in a continuous layer, covering the entire soil surface. This method is essential for the good development of rice, as it guarantees water availability, helps control pests and diseases, and directly influences the availability of nutrients (Scivittaro, 2026).

The use of technologies based on remotely piloted aircraft systems (RPASs), popularly known as drones, has revolutionized global agriculture, enabling mapping, aerial image capture, spraying, and crop monitoring. Drones have demonstrated promising results, as they allow the identification of problems previously undetectable to the naked eye (Lima; Silva; Freitas, 2019). For Valencia (2020), remote sensing is a fundamental tool for generating better yields in cultivated areas and supporting decision-making in agricultural management.

Another relevant tool is vegetation indices, which are obtained from images captured by drones. The normalized difference vegetation index (NDVI) is one such example. The difference vegetation index (vegetation index) is widely used because, according to Pereira *et al*. (2021), it allows for increased efficiency in the production process through better management of fertilization or seeding density. Kazemi and Parmehr (2023), in turn, state that indices based on the visible spectrum (RGB) can also be used in rice crop management, representing a viable alternative to the high costs of multispectral sensors. Gitelson *et al. (2002) highlight that the* VARI (visible) vegetation index Atmospherically The Resistant Index exhibits good sensitivity, low saturation in higher ranges, and a high capacity to represent the green plant fraction.

In this context, monitoring irrigation using the RPAS allows for the evaluation of the time it takes for water to enter the fields via the surface; identifying areas with delayed or inefficient irrigation; monitoring plant development; and contributing to decisions related to infrastructure improvements, team management, and time optimization. Therefore, this study aimed to use precision agriculture tools to analyze the water supply of irrigated rice using flooding in a field located in the municipality of Cachoeira do Sul – RS.

4 MATERIALS AND METHODS

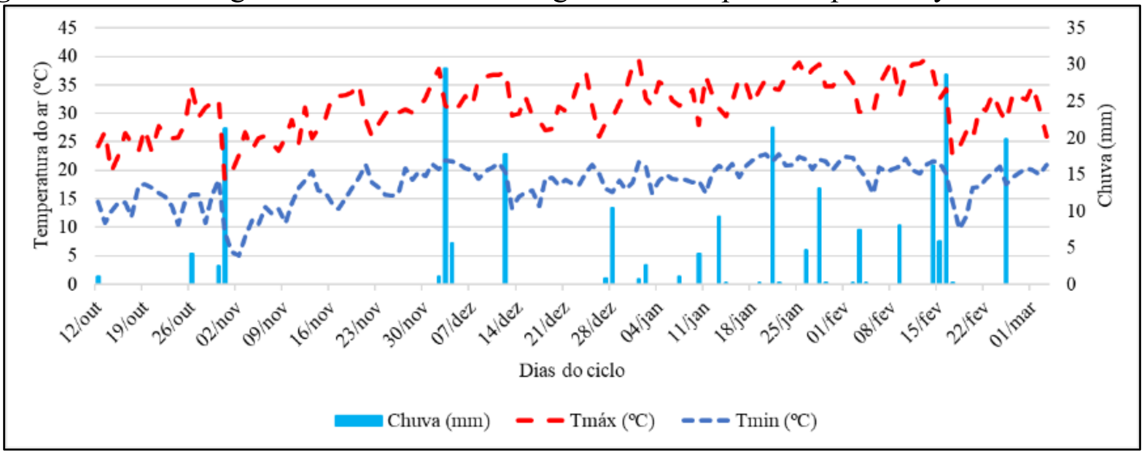
This study was conducted during the 2022/23 growing season in a 33-hectare plot belonging to a commercial rice farm managed under a minimum tillage system with early soil preparation. The rural property is located in the Irapuazinho area in the municipality of Cachoeira do Sul/RS (30°26'4.23"S, 53°10'18.59"W; altitude: 53 m). The predominant soil in the experimental area is classified as Planosol. Skilled Eutrophic Arenico belongs to the Vacacaí mapping unit (Streck *et al.*, 2008). The soil and relief characteristics of the region favor the adoption of flood irrigation. The local climate is classified as humid subtropical (Cfa) according to Köppen.

The plot was sampled on a grid totaling 38 points (Figure 1), where the surface irrigation water entry time and the visible vegetation index (VARI) were evaluated. Atmospherically (Resistant Index). The cultivar used was IRGA 431 CL, an early-cycle variety. Sowing took place on October 12, 2022, within the ideal period recommended for the crop, with a sowing density of 95 kg ha^{-1}. Plant emergence, i.e., the phase in which the seedling breaks through the soil surface, was observed on October 29, 2022. Irrigation began on November 16, 2022, between the V1 and V2 phenological stages (formation of the collar of the first and second leaves of the main stem), after a period of low rainfall (Figure 2). Base fertilization was carried out with 120 kg ha^{-1} of the commercial formula 11-52-00, corresponding to the nitrogen (N), phosphorus (P), and potassium (K) contents, respectively. Nitrogen topdressing was applied by broadcasting, totaling 200 kg ha^{-1} of N, split into two periods: 50% at the V1 stage and 50% at the R0 stage.

Figure 1. 1with a sampling grid.

Source: Authors (2025).

Figure 2. Meteorological data observed throughout the crop development cycle.



Prepared using data from UFSM Cachoeira do Sul – Metos Brasil Group
Source: Authors (2025).

To assess water ingress into the plot, flights were conducted as described in Table 1 at a height of 120 meters. The images were obtained with 65% lateral overlap and 75% frontal overlap, resulting in approximately 120 to 150 images per flight for the generation of orthomosaics. The aircraft used was a DJI Mini 2 drone equipped with a 12-megapixel red, green, and blue (RGB) sensor.

From the captured images, orthomosaics were generated using Agisoft software. Metashape Professional version 1.5.1. To create the irrigation evolution map, curves were drawn over each orthomosaic, which were subsequently interpolated to obtain images with continuous values. From these images, the values referring to the water entry time, expressed in hours from the start of irrigation, were extracted at the points of the previously defined sampling grid. The analyses in a geographic information system (GIS) environment were performed using ArcGIS Desktop 10.8 and QGIS 3.30 software.

Table 1. Flight dates and times.

Flight number	Development stage/purpose	Date	Time
1	V1-V2 - Water Inlet	November 17th	6:00 PM
2	V1-V2 - Water Inlet	November 19th	09:00
3	V1-V2 - Water Inlet	November 20th	5:00 PM
4	V3-V4 - Irrigation shutdown	05/Dec	10:00
5	R2 – Rubberizing – VARI	11/Jan	11:00

Source: Authors (2025).

On the basis of the data obtained from the fifth flight (Table 1), the visible vegetation index was calculated. Atmospherically Resistant Index (VARI), described by Gitelson *et al*. (2002), which is calculated according to Equation (1) below:

$$VARI = \frac{(G-R)}{(G+R-B)} \quad (1)$$

where VARI = visible atmospherically resistant index (visible atmosphere resistance index); R = red band; G = green band; and B = blue band.

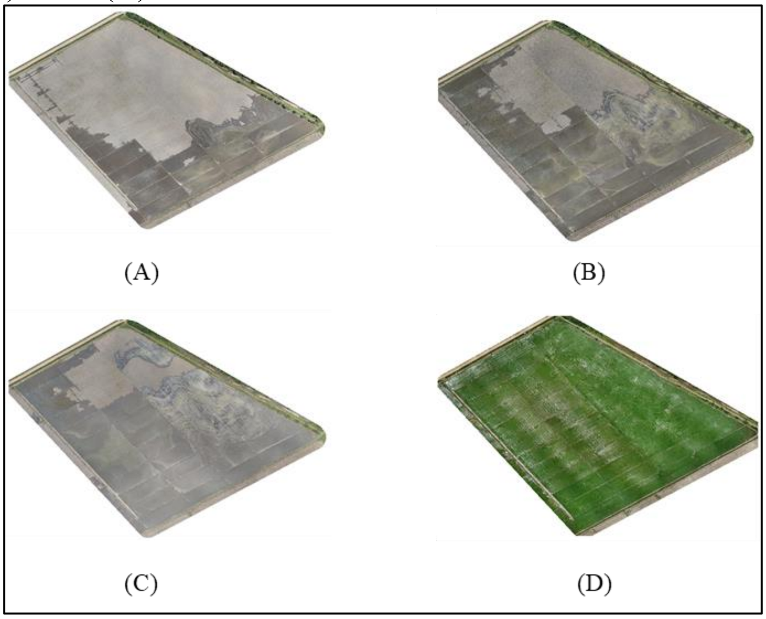
Harvesting was carried out on March 3, 2023, when the plants were at stage R9 (complete physiological maturity of the grains), with grain moisture between 20% and 24%, according to Sosbai (2018). Sampling was performed at 11 points in the plot (Figure 1), defined on the basis of the irrigation water entry time (0–24 h, 24–48 h, 48–72 h, and 72–96 h), using 0.5 m × 0.5 m sample plots, with three replicates per point. The following yield components were evaluated: number of panicles per square meter (panicles m^{-2}), number of grains per panicle, and productivity (kg ha^{-1}). For the productivity calculation, the weight obtained in the plots was corrected to 13% moisture and then extrapolated to an area of 10,000 m^2 (1 hectare). The average values observed for the number of panicles per square meter, number of spikelets per panicle, and rice productivity for the different water entry times were compared using the t test for comparison of means using Statistica® software, version 7.

5 RESULTS AND DISCUSSION

The orthomosaics obtained after each flight (Figure 3) and the results of mapping and interpolating the water entry time in the plot (Figure 4A) illustrate the evolution of the irrigation depth. The advance of the water depth in the plot occurred over a total time of 101 hours (Figure 4A). In the first 48 hours, the water reached approximately 50% of the area, indicating an adequate water supply in that region. However, the dynamics of water entry in the rest of the plot did not follow the same trend. The daily irrigation rate varied considerably: on the first day, it was 0.26 ha h^{-1}; on the second day, it was 0.37 ha h^{-1}; on the third day, it was 0.19 ha h^{-1}; and on the fourth day, it was 0.50 ha h^{-1} (Figure 4B). These data reveal heterogeneity in the advancement of irrigation, which can negatively influence productivity in areas with delays in water supply.

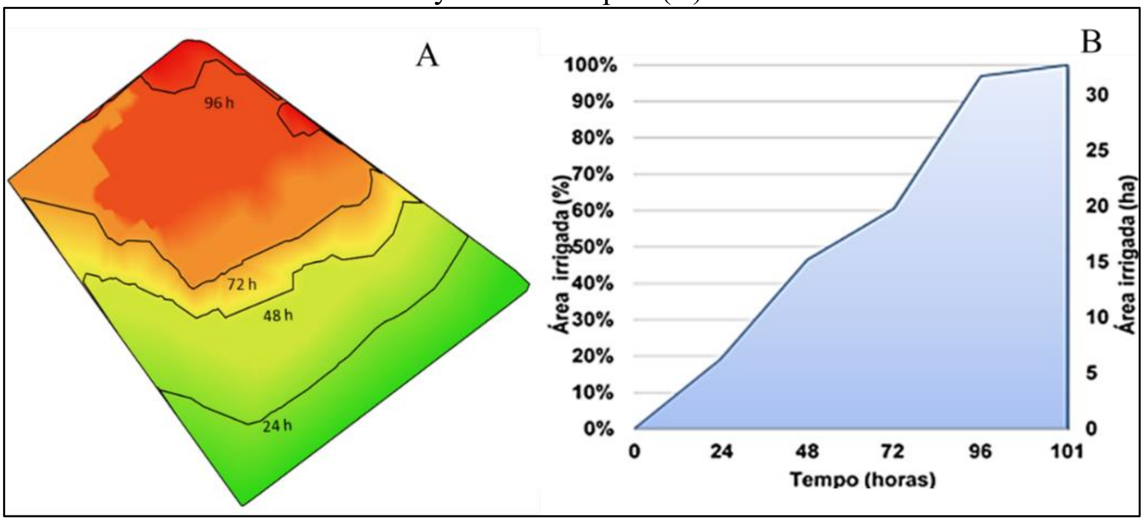
According to Ramírez *et al*. (2007), rice productivity can be reduced, on average, by approximately 1,000 kg ha^{-1} for every 10 days of delay in irrigation. Similarly, Bergamann *et al*. (2019) observed productivity losses of 86.8 kg ha^{-1} per day of delay from the V3 stage. These results demonstrate the importance of water entry at the ideal time and with adequate water depth, as this practice is positively correlated with other agronomic factors, such as nutrient availability (especially nitrogen), control of pest and disease incidence, and weed control (Grohs). *et al*., 2019).

Figure 3. Monitoring the orthomosaics of irrigation water inputs obtained from flights 1 (A), 2 (B), 3 (C) and 5 (D).



Source: Authors (2025).

Figure 4. Map of spatial variability in water entry time in the plot (A) and in the irrigated area as a function of water entry time in the plot (B).

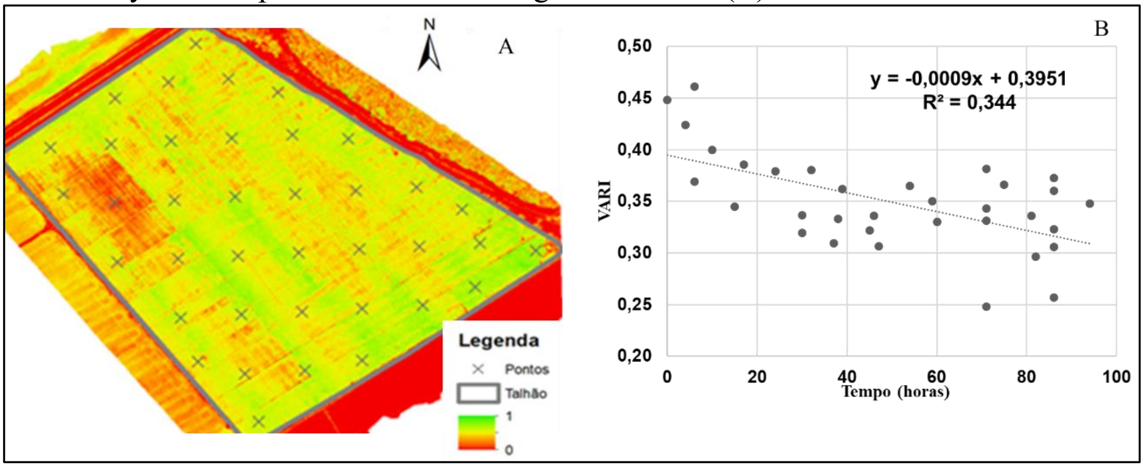


Source: Authors (2025).

A geospatial map of the VARI (Figure 5A) shows that the regions of the plot with the highest index values coincide with the locations where the irrigation water arrived most quickly (Figure 4A). The VARI, obtained at the R2 phenological stage, ranged from 0.25 to 0.47, with the maximum value recorded at a point where the irrigation water arrived at 6 hours and the minimum value at a point where the water took 71 hours to reach. The negative linear correlation between the VARI and the time of irrigation water entry into the plot is shown in Figure 5B, indicating a lower vegetation index (lower green level) in plants located in areas with the greatest delay in water arrival. This behavior may be related to lower nitrogen (N) uptake by the crop because of the delay in water supply. The R^2 value was considered low, which is attributed to the high dispersion of the sampled points, reflecting the influence of other management factors, in addition to irrigation, that also affect plant development, such as fertilizer distribution, soil compaction, or sowing failure.

Furthermore, it was possible to associate VARI values with the final crop productivity (Figure 6A), demonstrating that this index can be an effective tool for representing plant growth and development conditions and identifying areas affected by stresses that negatively impact productivity. The VARI vegetation index shows good sensitivity and low saturation even in higher ranges, with a high capacity to represent the vegetation cover fraction, as highlighted by Gitelson. *et al.* (2002).

Figure 5. Map of the VARI vegetation index (A) and relationship between the time of water entry into the plot and the VARI vegetation index (B).

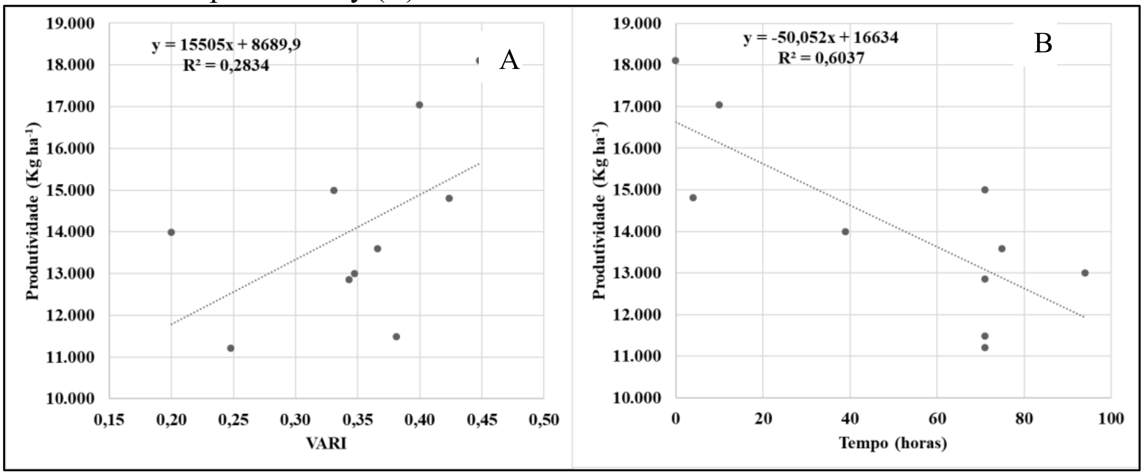


Source: Authors (2025).

The productivity data estimated by the regression equation (Figure 6B) indicate a reduction of 50 kg ha^{-1} for each hour of irrigation delay. The maximum productivity estimated by the equation, 16,645.50 kg ha^{-1}, was recorded at the location where irrigation started earliest. On the other hand, at the point where the water took longer to reach (101 h), the estimated productivity was reduced to 11,584.00 kg ha^{-1}, indicating a significant difference. This significant reduction in productivity may be related to the water deficit that occurred at the beginning of crop development, caused by the low frequency of rainfall in the period preceding the start of irrigation (Figure 2). As shown in Table 2, the productivity component most impacted by the delay in irrigation was the number of panicles per square meter, which may have been influenced by lower plant establishment in the areas that were irrigated late because of initial water stress.

Furthermore, the delay in water entry affected the utilization of nitrogen (N), which was applied as topdressing in the form of urea (CH_4N_2O), before the start of irrigation. Ammonia (NH_3) volatilization is the main pathway for the loss of N applied to the soil surface, especially in the absence of moisture for its incorporation (Tasca *et al.*, 2011). Notably, after potassium (K), nitrogen is the nutrient most exported by the rice plant. This element is essential because it is a component of chlorophyll, promoting an increase in leaf area, which increases the efficiency of intercepting solar radiation, the photosynthetic rate and, consequently, grain productivity (Fageria; Moreira; Coelho, 2011). Thus, the results presented (Figure 6 and Table 2) reinforce the importance of adjusting the irrigation infrastructure to ensure greater agility in closing the water level in the plots that use the flood irrigation system. Improving the efficiency of the water supply is fundamental to maximizing the productive potential of rice cultivation.

Figure 6. Relationships of the vegetation index (VARI) with productivity (A) and water entry time with productivity (B).



Source: Authors (2025).

Table 2. Results of descriptive statistics for the variables (panicle m $^{-2}$, grain panicle $^{-1}$ and productivity).

Entry times	Variable	Average group 1	Average group 2	t value	gl .	p value
Up to 24 hours x up to 48 hours	Panicles (m^2)	673.33	654.67	0.3057	10	0.77
	Grains/panicle (und)	126.19	117.60	1.2255	10	0.25
	Productivity (kg ha^{-1})	16,645.50	13,982.19	2.4657	10	0.03**
Up to 24 hours x up to 72 hours	Panicles (m^2)	673.33	550.92	2.6880	19	0.01**
	Grains/panicle (und)	126.19	118.24	1.4155	19	0.17
	Productivity (kg ha^{-1})	16,645.50	12,628.51	4.0792	19	0.00**
Up to 24 hours x up to 96 hours	Panicles (m^2)	673.33	543.67	2.9116	13	0.01**
	Grains/panicle (und)	126.19	117.80	1.6707	13	0.12
	Productivity (kg ha^{-1})	16,645.50	12,122.99	5.9297	13	0.00**
Up to 48 hours x up to 72 hours	Panicles (m^2)	654.67	550.92	1.5763	13	0.14
	Grains/panicle (und)	117.60	118.24	-0.0803	13	0.94
	Productivity (kg ha^{-1})	13,982.19	12,628.51	0.8935	13	0.39
Up to 48 hours x up to 96 hours	Panicles (m^2)	654.67	543.67	2.6106	7	0.03**
	Grains/panicle (und)	117.60	117.80	-0.0786	7	0.94
	Productivity (kg ha^{-1})	13,982.19	12,122.99	3.4410	7	0.01**
Up to 72 hours x up to 96 hours	Panicles (m^2)	550.92	543.67	0.153	16	0.88
	Grains/panicle (und)	118.24	117.80	0.078	16	0.94
	Productivity (kg ha^{-1})	12,628.51	12,122.99	0.475	16	0.64

In what way: The t value measures the difference between the means of two samples relative to the standard error; p value probability value; df degrees of freedom
Source: Authors (2025).

The number of grains per panicle (Table 2) was strongly related to the genetic factors of the material used, with no significant variation observed as a function of the duration of irrigation water entry. On the other hand, the number of panicles per square meter decreased by 22% when the water arrived between 24 and 72 hours and by 20% between 48 and 96 hours after the start of irrigation.

The number of panicles m^{-2} is a key indicator of the productive capacity of rice crops. According to Bergmann *et al*. (2019), the ideal range for obtaining high yields in irrigated rice is between 459 and 655 panicles m^{-2} — values that were achieved in this study and that reflect yields exceeding 12,000 kg ha^{-1}, surpassing the state average of 8,786 kg ha^{-1} recorded in the 2022/23 crop season (Brazil, 2023).

Thus, it is evident that there is real potential for increasing rice productivity in Rio Grande do Sul and that the use of precision agriculture tools, such as monitoring and controlling irrigation water inputs, can significantly contribute to this progress. The observed data (Table 2) indicate that the reduction in productivity is more pronounced between 24 and 48 hours after the start of irrigation. The maximum productivity of 16,645.50 kg ha^{-1}, obtained in areas where irrigation occurred within 24 hours, was reduced to 13,982.19 kg ha^{-1} in areas irrigated between 24 and 48 hours. This represents a loss of 111 kg ha^{-1} per hour of delay in this interval. For the period from 48 to 72 hours, the reduction was 47 kg ha^{-1} per hour and 29 kg ha^{-1} per hour between 72 and 96 hours.

These results reinforce the importance of, under conditions similar to those in this study, carrying out irrigation within the first 24 hours after the start of the operation, which corresponds to an irrigation rate of approximately 1.37 ha h^{-1}, to maximize crop productivity. Implementing this strategy, in addition to optimizing yield, contributes to significantly reducing the water footprint of rice production, promoting greater sustainability and efficiency in the use of water resources.

6 CONCLUSION

The use of precision agriculture tools, such as images obtained by RPAS (drones) and geoprocessing software, has proven effective for mapping irrigation water inputs and generating vegetation index maps (VARI). These tools provide a solid basis for analyzing water supply in flood-irrigated rice cultivation.

The VARI was higher in the areas of the plot where the irrigation depth arrived first and lower in the areas with a longer waiting time for the start of irrigation. This difference made it possible to establish a direct relationship between the VARI and rice productivity, with productivities exceeding 15,000 kg ha^{-1} being recorded in areas with a VARI above 0.40 at stage R2.

The average productivity of 16,645.50 kg ha^{-1}, obtained in irrigated areas within the first 24 hours after the start of the process, was reduced to 13,982.19 kg ha^{-1} when irrigation occurred between 24 and 48 hours and to 12,122.98 kg ha^{-1} when the water entry time exceeded 72 hours.

Therefore, for the conditions evaluated in this study, ensuring that flood irrigation is completed within the first 24 hours is essential to maximize the productivity of irrigated rice and reduce the impacts of water deficit at the beginning of the crop cycle.

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