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ANÁLISE DA PRODUTIVIDADE DA SOJA EM CINCO ANOS AGRÍCOLAS COM A UTILIZAÇÃO DA IRRIGAÇÃO SUPLEMENTAR NA REGIÃO CENTRAL DO RS

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1 RESUMO

O objetivo deste trabalho é avaliar a influência da irrigação suplementar na produtividade da soja em cinco anos agrícolas com diferentes padrões metrológicos, na região central do estado do Rio Grande do Sul. Foram instalados experimentos a campo nos anos agrícolas 2018/19, 2019/20, 2020/21, 2021/22 e 2022/23, na área experimental da Estação Agronômica da Universidade Estadual do Rio Grande do Sul (UERGS), localizada no distrito de Três Vendas, no município de Cachoeira do Sul-RS, Brasil. A cultivar analisada foi a BMX Garra com semeadura no mês de novembro em todos os anos agrícolas. A irrigação foi por aspersão convencional a partir da recomendação realizada pelo cálculo do balanço hídrico e monitoramento da umidade volumétrica do solo. As lâminas de irrigação acumuladas a longo do ciclo da soja variaram entre 70 e 244 mm, respectivamente, para os anos agrícolas 2018/19 (El Niño) e 2022/23 (La Niña), aumentando entre 334,8 e 2.238,3 kg ha^{-1} a produtividade da soja. Na média dos cinco anos, a irrigação proporcionou aumento no número de vagens por planta, massa de mil grãos e produtividade de 29,8, 7,52 e 51,8%, respectivamente, demonstrando-se uma tecnologia de fundamental importância para a manutenção e elevação de tetos produtivos na região.

Palavras-chave: *Glycine max*, manejo agrícola, suprimento hídrico.

OLIVEIRA, Z.B.; BARANZELLI, L.F.; KNIES, A.E. ANALYSIS OF SOYBEAN PRODUCTIVITY IN FIVE AGRICULTURAL YEARS WITH THE USE OF SUPPLEMENTAL IRRIGATION IN THE CENTRAL REGION OF RS

2 ABSTRACT

The objective of this work was to evaluate the influence of supplementary irrigation on soybean productivity over five agricultural years with different metrological standards in the central region of the state of Rio Grande do Sul. Field experiments were carried out in the agricultural years 2018/19, 2019/20, 2020/21, 2021/22 and 2022/23 in the experimental area of the Agricultural Station of the State University of Rio Grande do Sul (UERGS), located in the district of Três Vendas, in the municipality of Cachoeira do Sul-RS, Brazil. The cultivar analyzed was BMX Garra, which was sown in November of all the agricultural years. The

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irrigation was performed via a conventional sprinkler on the basis of the recommendation made by calculating the water balance and monitoring the volumetric soil moisture. The irrigation depths accumulated throughout the soybean cycle varied between 70 and 244 mm for the agricultural years 2018/19 (El Niño) and 2022/23 (La Niña), increasing between 334.8 and 2238.3 kg ha^{-1} soybean productivity. On average, over the five years, irrigation increased the number of pods per plant, the mass of one thousand grains and the productivity to be 29.8%, 7.52% and 51.8%, respectively, demonstrating that irrigation is a fundamentally important technology for maintaining and increasing production ceilings in the region.

Keywords: *Glycine max*, agricultural management, water supply.

3 INTRODUCTION

Soybean (*Glycine max* L.) is a crop of great global importance because of its composition and range of industrial applications. In addition, agricultural technological advances combined with modern production systems have increased the productivity and profitability of this crop, making it one of the main commodities in the world. According to the USDA (2023), in the 2022/2023 harvest, the global production of this oilseed was 369 billion tons in an area of approximately 136 billion hectares cultivated. Brazil is currently the world's largest producer, with approximately 154.6 billion tons produced in 44.1 billion hectares cultivated in the 2022/2023 harvest (CONAB, 2023).

Although Brazilian soybean crops have a high degree of technical development, low water availability during the crop cycle still represents the greatest limitation to achieving the maximum productive potential of the crops. The impact of water deficit on soybean productivity depends on the intensity, duration and time of occurrence, in addition to the sensitivity of the cultivar (Neumaier *et al*., 2020; Matzenauer; Barni; Maluf, 2003). The lack of rain in the reproductive phase is a frequent problem in soybeans and causes a reduction in productivity in nine out of every twenty harvests in RS (Matzenauer; Barni; Maluf, 2003).

In Rio Grande do Sul, the water regime is influenced by the El Niño Southern Oscillation (ENSO) phenomenon (Matzenauer; Radin; Maluf, 2018). According to Berlato and Fontana (2003) and Montecinos, Díaz and Aceituno (2000), ENSO is the main cause of interannual variability in rainfall in the state. ENSO has two phases: the warm phase, called El Niño, which presents rainfall above the climatological average for the southern region of Brazil, and the cold phase, called La Niña, which is characterized by rainfall below the climatological average, especially in the spring–summer of the year in which the phenomenon begins (Fontana; Berlato, 1996; Puchalski, 2000). According to Fontana and Berlato (1996), it is then possible to relate the variability in soybean productivity with the presence of the ENSO phenomenon in the RS.

According to Oliveira, Knies and Gomes (2020), in the central region of the RS, the need for supplementary irrigation of soybeans varies according to the sowing season, rainfall distribution and expected irrigation management, with greater or less depletion of soil water. In this context, they reported that the total irrigation depth varied between 60 and 135 mm. Assman and Oliveira (2023), simulating the need for irrigation for soybean crops over twenty agricultural years (2001--02 and 2021--22) in Cachoeira do Sul - RS, reported that the demand varied between 75 mm and 345 mm and was influenced by the regular distribution, intensity and quantity of rainfall throughout the crop development cycle. Machado *et al.* (2023) reported average increases in soybean productivity of 198% (cultivar Raio), 72% (cultivar Garra) and 51% (cultivar Zeus) via supplementary irrigation in the central region of the RS.

Nevertheless, most of the areas cultivated with soybeans in RS are in the rainfed regime (Sentelhas *et al*., 2015), with few crops that use irrigation in hillside areas. In this context, the present study aims to evaluate the influence of supplementary irrigation on soybean productivity in five agricultural years with different weather patterns in the central region of the state of Rio Grande do Sul.

4 MATERIALS AND METHODS

Field experiments with soybean crops were carried out in the 2018/19, 2019/20, 2020/21, 2021/22, and 2022/23 agricultural years in the experimental area of the Agronomic Station of the State University of Rio Grande do Sul (UERGS), which is located in the district of Três Vendas in the municipality of Cachoeira do Sul (29°53' S and 53° 00' W, altitude of 125 m), in the central depression of the state. The climate, according to Köppen, is defined as humid subtropical (Cfa). The soil of the experimental area was classified as a typical dystrophic red argisol (Embrapa, 2013).

The experiments were carried out in a factorial scheme (4 × 2) with four soybean cultivars under two water regimes, i.e., irrigated and rainfed, in a randomized block design with four replications. However, in this study, the cultivar analyzed was BMX Garra IPRO (Garra), as it was the only cultivar that was used for these five years. The cultivar has a GMR of 6.3, that is, an average cycle for the study region of 134 days. Sowing was carried out each year, using a tractor (Massey Ferguson MF4275) - seeder (Massey Ferguson MF 407, 7 rows) set in a no-tillage system, with the sowing dates shown in Table 1, within the period recommended by the agricultural zoning of climatic risk (ZARC). Crop management and appropriate cultural treatments followed the agronomic recommendations appropriate for soybean crops. Fertilization followed the soil analysis and recommendations of the Fertilization and Liming Manual for RS and Santa Catarina (CQFS, 2016).

Table 1. Sowing, harvesting and soybean cycle length dates for each agricultural year

Agricultural Year	Sowing Date	Harvest Date	Cycle Days
2018-19	11/21/2018	03/29/2019	128
2019-20	11/19/2019	03/15/2020	126
2020-21	05/11/2020	03/13/2021	128
2021-22	11/29/2021	11/04/2022	133
2022-23	11/26/2022	02/04/2023	127

Source: Authors.

For all the agricultural years, part of the experiment was irrigated (irrigated water regime), and part of the experiment was without irrigation (rainfed water regime). The irrigation system used was the conventional sprinkler system, which consists of Agropolo NY 25 model sprinklers spaced 12 × 12 m apart and operates at a rate of 12 mm h $^{-1}$. The irrigation structure also included a 7 HP motor pump, the main pipe with a diameter of 75 mm and the lateral pipe with a diameter of 50 mm.

Irrigation management was carried out on the basis of the soil water balance, where the irrigation depth varied according to the crop phenological stage. The aim was to maintain soil water storage with a depletion fraction close to 40% of the available water capacity (AWC) at a depth of 0--60 cm, where the soybean root system exploration layer is located. The variable layer from 10 to 60 cm was considered according to the evolution of the crop cycle. The AWC (0–60 cm) is 101.04 mm since the volumetric moisture of the field capacity (FC) is 0.3184 cm^{3} cm^{-3} and the permanent wilting point (PMP) is 0.15 cm^{3} cm^{-3}.

Crop evapotranspiration (ETc) was estimated according to Allen *et al.* (1998), with reference evapotranspiration (ETo) obtained from the meteorological station installed at the UFSM Cachoeira do Sul Campus. The temperature data presented in this study were also obtained from the same station. The adjustment of the Kc value (simple) used to calculate ETc was performed via the canopy cover fraction (Fc) as an indicator of the inflection of the Kc curve. The Canopeo application was used to obtain the Fc value.

The water balance was measured by monitoring the CAD, which was based on the determination of the volumetric soil moisture, measured by an FDR set (frequency domain reflectometry, Campbell Scientific). Monitoring was carried out punctually a few days before irrigation, as the system did not automatically send data.

The plants were harvested manually, according to the dates shown in Table 1, in the central region of each plot, with three to four replicates (depending on the agricultural year), totaling a harvested area of 3 m2 ^{per} plot. After being harvested, the grains were threshed, cleaned, the moisture content was determined, and the grains were weighed. The grain mass was corrected to 13% moisture and then estimated per hectare (kg ha^{-1}). From these same samples, the thousand grain mass (MMG) (g) was determined from the count of 1000 grains, which were weighed and corrected to 13% moisture. To analyze the yield components, four plants were randomly harvested from each plot and processed by hand to determine the number of pods per plant and the number of grains per pod.

5 RESULTS AND DISCUSSION

Among the agricultural years evaluated, the 2018/19 agricultural year was marked by the El Niño phenomenon and the other years by the occurrence of the La Niña phenomenon, classifying it as moderate between 2019/20 and 2021/22 and weak in 2022/23 (GGWEATHER, 2022). Thus, the 2018/19 agricultural year had greater water availability and the lowest need for irrigation, and the 2022/23 agricultural year, even with La Niña classified as weak, was the year with the greatest water restriction, demanding a greater need for supplementary irrigation (Table 1). In all the agricultural years, greater irrigation depths (Table 2) were applied during the period with the greatest evapotranspiration demand of the crop (rapid growth phase and reproductive phase).

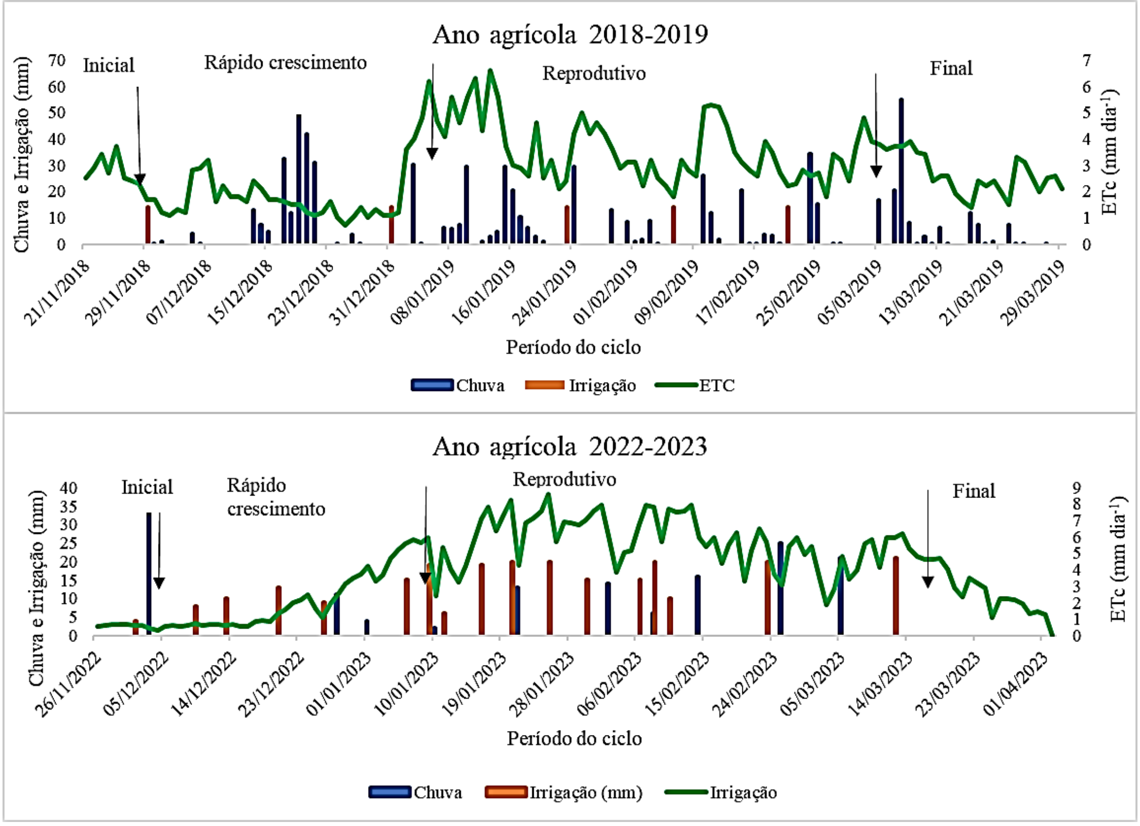
Table 2. Cultivation coefficient (Kc) and irrigation depth by subperiod of the soybean development cycle and accumulated rainfall in the cycle for the five agricultural years evaluated

Period	**Kc**	**Irrigation blade (mm)**				
		2018/2019	**2019/2020**	**2020/2021**	**2021/2022**	**2022/2023**
Home	0.1	14	12	27	27	12
Fast growing/vegetative	interpolated 0.1 to 1.15	14	60	56	73	72
Average/reproductive	1.15	42	45	60	90	139
End	interpolated from 1.15 to 0.3	0	12	25	0	21
Total irrigation (mm)		**70**	**129**	**168**	**190**	**244**
Total rainfall (mm)		**686**	**313**	**426**	**394**	**152**
Total accumulated blade (mm)		**756**	**442**	**594**	**584**	**396**

Source: Authors.

Figure 1 shows the distribution of rainfall throughout the soybean development cycle for the agricultural years 2018/19 (El Niño) and 2022/23 (La Niña).

Figure 1. Water balance parameters for the agricultural years 2018/19 (El Niño) and 2022/23 (La Niña).



Source: Authors.

In the 2018/19 agricultural year, frequent rainfall events exceeded the soil's water storage capacity, necessitating irrigation at longer intervals between rainfall events, which was associated with high crop evapotranspiration (between 6 and 7 mm day $^{-1}$). On the other hand, in the 2022/23 agricultural year, rainfall is insufficient to meet the crop's water demand throughout practically the entire cycle, with irrigation being the main form of water supply for the crop.

Supplemental irrigation was necessary in all agricultural years, with accumulated irrigation depths in the cycle ranging from 70 (El Niño year) to 244 mm (La Niña year), with the average accumulated irrigation depth for the four La Niña years being 183 mm (Table 2). In a study analyzing metrological data from 1976--2008 for RS, Farias, Neumaier and Nepomuceno (2024) reported that although the total amount of rainfall during the entire soybean development cycle reached values close to 700 mm, the yields achieved were not high due to the poor distribution of rainfall, especially during the reproductive period of the crop, limiting the achievement of high productivity.

In addition to rainfall, it is important to analyze air temperature (Table 3), which influences the thermal sum, to which soybeans are responsive (cycle duration), and heat stress, which can harm soybean productivity. According to Farias, Nepomuceno and Neumaier (2007), soybeans adapt better to regions where temperatures range between 20°C and 30°C, with the ideal temperature for their development being approximately 30°C. On the other hand, temperatures below 13°C have an inhibitory effect on flowering (Rodrigues *et al*., 2001). In all the agricultural years, the thermal amplitude was high, with minimum temperatures lower and maximum temperatures higher than ideal for good crop development. The 2018/19 agricultural year had milder temperatures due to the greater number of rainy days, which was also reflected in lower crop evapotranspiration (Figure 1). On the other hand, the agricultural years 2021/22 and 2022/23 presented very high values of maximum air temperature, which coincided with the reproductive phase of the crop, and in the agricultural year 2021/22, this temperature peak occurred during the flowering period (R1).

Table 3. Results of air temperature (maximum, minimum and average) observed during the soybean development cycle in the five agricultural years evaluated.

Agricultural years	Air temperature (°C)		
	Tmin	Tmax	Tmed
2018-19	7.8	33.5	20.7
2019-20	10.3	38.8	25.2
2020-21	8.6	38.6	23.8
2021-22	7.0	41.8	24.2
2022-23	9.7	39.6	25.3

Source: Authors.

The soybean productivity components evaluated for each agricultural year (Table 4) reflect the reported environmental conditions. Notably, supplemental irrigation resulted in positive increases in the number of pods per plant, with the exception of the 2021/22 agricultural year, in which this productivity component was reduced in both water regimes (irrigated and rainfed), which can be attributed to the abortion of flowers and legumes due to heat stress (Table 3).

The number of grains per pod component was very similar between the water regimes (irrigated and rainfed) but varied between the agricultural years. According to Mundstock and Thomas (2005), the number of grains per pod is a yield component directly linked to the genetics of the cultivar. Navarro Junior and Costa (2002) reported that the reduction in the number of pods per plant, without reducing the leaf area, caused a small increase in the number of grains per pod and in the MMG, which may explain the greater MMG in the 2021/22 agricultural year, with the exception of MMG, which was greater in rainfed plants.

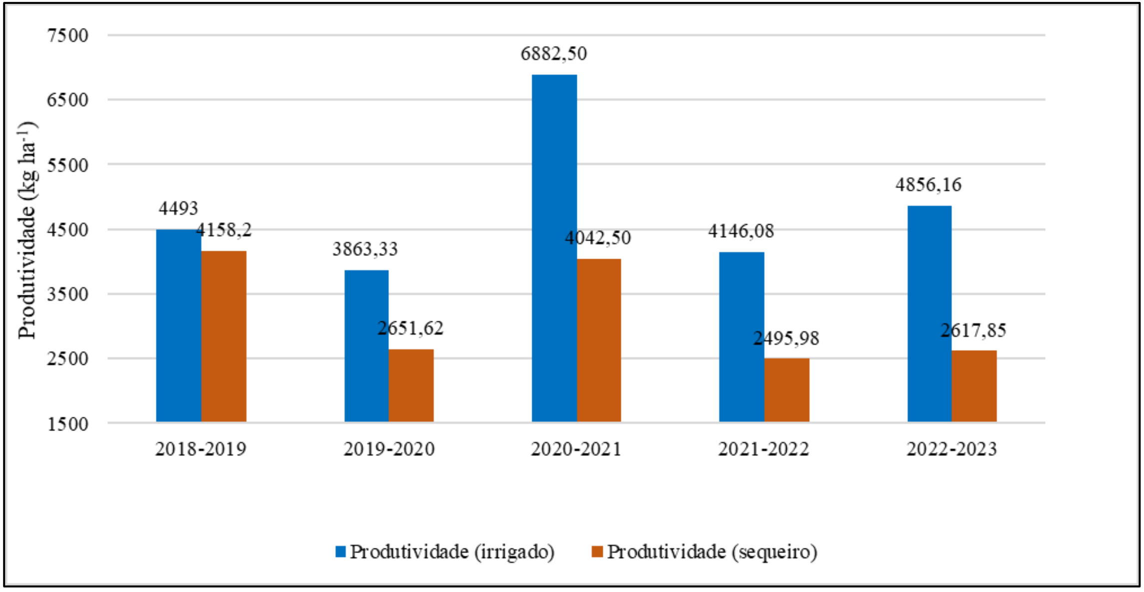
Table 4. Results of soybean productivity components for the five agricultural years evaluated.

Components	**irrigated**	**Dryland**
	2018/19	
Pods plant $^{-1}$	62.84	51.91
Bean pods $^{-1}$	2.28	2.04
MMG	166.64	156.28
	2019/20	
Pods plant $^{-1}$	65.06	52.56
Bean pods $^{-1}$	2.30	2.43
MMG	180.02	162.06
	2020/21	
Pods plant $^{-1}$	86.38	61.13
Bean pods $^{-1}$	2.19	2.22
MMG	207.15	196.01
	2021/22	
Pods plant $^{-1}$	30.88	27.75
Bean pods $^{-1}$	2.10	2.10
MMG	221.99	247.74
	2022/23	
Pods plant $^{-1}$	68.33	37.67
Bean pods $^{-1}$	2.20	2.24
MMG	231.82	175.08

Source: Authors.

A comparison of the productivity of each year (Figure 3) revealed that the 2018/19 agricultural year had the highest productivity in the dryland regime because of the greater water supply (Table 2). However, in the irrigated water regime, the productivity in this year was lower than that in the other years. According to Farias, Nepomuceno and Neumaier (2007), excessive rainfall and cloudy days impair photosynthesis, soil aeration, root development and biological nitrogen fixation, in addition to interfering with other processes that reduce soybean productivity. The highest soybean productivity occurred in the 2020/21 agricultural year with supplemental irrigation, which may be related to a better distribution of rainfall throughout the development cycle and less extreme temperatures (Tables 2 and 3).

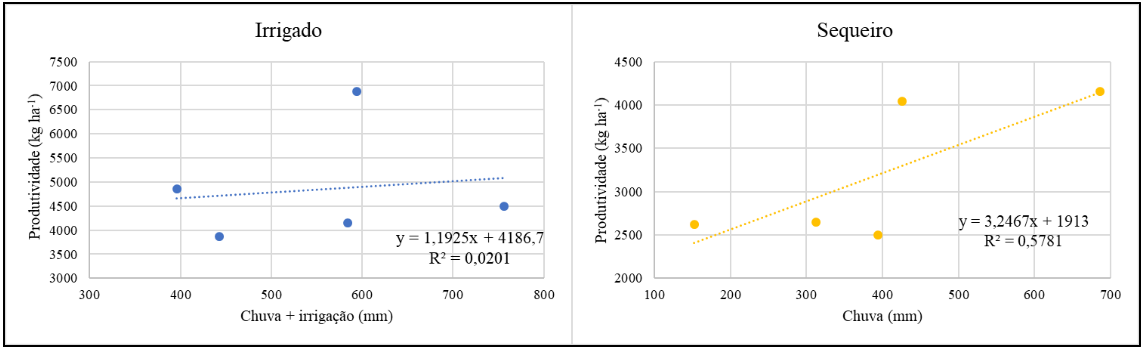
Figure 3. Soybean productivity as a function of water regime (rainfed and irrigated) for five agricultural years.



Source: Authors.

It is possible to establish a relationship between a greater amount of rainfall and an increase in the productivity of dryland soybeans (Figures 3 and 4). However, this same relationship cannot be established for irrigated soybeans. Water deficit is the environmental factor that most limits high soybean productivity in Brazil, causing, on average, a loss of ± 543 kg ha $^{-1}$ (Sentelhas *et al.*, 2015). However, other meteorological elements can both enhance and mitigate the effects of water deficit on the productivity of this crop, including solar radiation, which affects the gross photosynthesis of the crop, and air temperature, which, together with the photoperiod, is a moderating factor for the growth and development of soybeans, in addition to affecting maintenance respiration and floral abscission under extreme weather conditions (Bonato, 2000; Farias; Nepomuceno; Neumaier, 2007). Since these factors cannot be controlled, supplemental irrigation has proven to be a fundamentally important technology for maintaining and increasing the productive ceilings of crops, minimizing or canceling out the impacts of water deficit.

Figure 4. Relationship between average soybean productivity in each year and the amount of water (rain and rain + irrigation) used throughout the cultivation cycle.



Source: Authors.

On average, over the five years, irrigation increased the number of pods per plant, MMG and productivity by 29.8%, 7.52% and 51.8%, respectively (Table 5). Pigatto, Oliveira and Knies (2023), working in the same location (agricultural year 2022--23) with twenty-two soybean cultivars, reported an increase of 114% in the number of pods per plant, 30% in the MMG and 111% in productivity. For the same study site (agricultural 2021-22), Machado *et al.* (2023) reported that productivity increases with irrigation ranging from 0.5 to 1.9 depending on the cultivar adopted.

Table 5. Results of the increase in productivity and soybean productivity components through supplemental irrigation.

	Average for 5 agricultural years		
Variable	**irrigated**	**Dryland**	**Increment (%)**
Productivity (kg ha $^{-1}$)	4848.21	3193.23	51.83
Pods per plant	63.09	48.69	29.58
Beans per pod	2.21	2.21	0.26
MMG (g)	201.53	187.43	7.52

Source: Authors.

6 CONCLUSIONS

On average, over the five agricultural years evaluated, supplementary irrigation provided an increase in the number of pods per plant, the mass of a thousand grains and the productivity of 29.8, 7.52 and 51.8%, respectively, demonstrating that supplementary irrigation is a technology of fundamental importance for maintaining and increasing productive ceilings in the central region of the RS.

The accumulated irrigation depth throughout the soybean cycle ranged from 70 mm (2018/19 - El Niño) to 244 mm (2023/23 - La Niña), increasing soybean productivity at the study site from 334.8 to 2238.3 kg ha $^{-1.}$

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