Análise de tendência e mudança nos riscos no Zoneamento Agrícola de Risco Climático (Zarc)

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Resumo - O objetivo deste estudo foi avaliar os impactos da atualização da base climática utilizada no Zoneamento Agrícola de Risco Climático (Zarc), comparando os períodos de 1984-2013 e 1993-2022. O teste de Mann-Kendall foi aplicado no período contínuo de 1984-2022 para avaliar a tendência das variáveis climáticas. Além disso, foram avaliados os impactos no risco climático agrícola, considerando eventos de déficit hídrico e temperaturas mínimas (<5°C) nos dois intervalos analisados. Os resultados evidenciaram aumento nas temperaturas médias, maior evapotranspiração e redução na precipitação, com destaque para o Sudeste e o Centro-Oeste, onde foi observado um aumento no risco de ocorrência de déficit hídrico e uma maior duração da estação seca no Brasil Central. No Sul, por outro lado, houve redução no risco associado a temperaturas extremamente baixas. Essas alterações influenciam diretamente as janelas de plantio e intensificam os riscos climáticos agrícolas, especialmente nas regiões mais suscetíveis ao déficit hídrico. O estudo reforça a relevância da atualização contínua das bases climatológicas utilizadas no Zarc, permitindo uma avaliação de riscos mais precisa e contribuindo para decisões estratégicas no planejamento agrícola.

Palavras-chave: tendência climática, janela de plantio, avaliação de riscos.

Trend analysis and risk changes in the Agricultural Climate Risk Zoning (Zarc)

Abstract - The aim of this study was to evaluate the impacts of updating the climate database used in the Agricultural Climate Risk Zoning (Zarc), comparing the periods 1984-2013 and 1993-2022. The Mann-Kendall test was applied to the continuous period of 1984-2022 to assess trends in climate variables. Additionally, the impacts on agricultural climate risk were analyzed, considering events of water deficit and minimum temperatures (<5°C) in both time intervals. The results revealed increases in average temperatures, higher evapotranspiration rates, and reductions in precipitation, particularly in the Southeast and Central-West regions, where an increased risk of water deficit and a longer dry season in Central Brazil were observed. In contrast, in the South, a reduction in the risk associated with extremely low temperatures was noted. These changes directly affect planting windows and intensify agricultural climate risks, especially in regions that are more prone to water deficits. The study highlights the importance of continuously updating the climate baselines used in Zarc, enabling more accurate risk assessments and supporting strategic decision-making in agricultural planning.

Key-words: climate trend, planting window, risk assessment.

Introdução
In Brazil, the Agricultural Climate Risk Zoning (Zarc) is a key tool for identifying climate risks and recommending crop suitability by integrating crop-specific requirements with local soil and weather constraints. Established in the 1990s, Zarc has been instrumental in supporting risk mitigation programs, such as *Proagro* and the *Subsidy Program for Rural Insurance* (PSR). However, the growing influence of climate change and increasing interannual

variability have posed significant challenges to maintaining precise, reliable, and up-to-date climate risk assessments (Regoto *et al.*, 2021).

The accuracy of agrometeorological assessments heavily depends on long-term, high-quality weather datasets, ideally spanning a 30-year climatological reference period. In regions with limited ground-based weather observations, Earth observation datasets play a crucial role in addressing data gaps, offering broader spatial coverage and complementing existing measurements. The continuous updating and integration of these datasets are essential, as recent studies have identified critical trends across Brazil, such as rising temperatures and shifting rainfall patterns (Tomasella *et al.*, 2023).

In this context, the Zarc climatic baseline was updated from the 1984-2013 period to 1993-2022, utilizing a robust, continuous, and spatially representative weather database for Brazil. To assess ongoing climatic changes, we conducted a trend analysis using the Mann-Kendall method over the extended period (1984-2022), focusing on key climate variables. Furthermore, the impacts of these trends on agricultural risk were evaluated by analyzing shifts in risks linked to drought and low temperatures. By highlighting significant trends and their implications for updated climate risk assessments, this study provides a comprehensive foundation for future agricultural climate risk assessments.

Material e métodos

The weather database was prepared using the same criteria as Zarc, prioritizing long, continuous, and high-quality weather records. Rainfall data came mainly from ANA's SNIRH network (ANA, 2024), supplemented by other national or state networks. Stations with more than 30% missing data were excluded. The rainfall data quality was ensured through comparison with CHIRPS (Funk *et al.*, 2015), flagging and correcting anomalies, and filling gaps. For selected stations, daily data for radiation, minimum (Tmin) and maximum (Tmax) temperature, wind, and humidity were sourced from NASA POWER to calculate reference evapotranspiration (ETo) via the FAO-56 Penman-Monteith method (Allen *et al.*, 1998). Additionally, Tmin and Tmax were obtained from BR-DWGD (Xavier *et al.*, 2022), which better represents temperature extremes. NASA POWER ensures consistent spatial-temporal coverage, while BR-DWGD enhances thermal risk assessment-essential for current Zarc applications. With a denser dataset than the previous Zarc database, remaining rainfall gaps in the North, Northeast, and Central-West regions were filled using CHIRPS v2.0 virtual stations.

To assess the implication of updating the climate database, two analyses were conducted. First, a trend analysis was performed using only the stations common to both periods. Then, a climate risk assessment was performed-initially using this same common set for both periods: P1 (1984-2013) and P2 (1993-2022) and subsequently incorporating the expanded set of stations available in the second period, referred to as V2.

The calculated statistic Z-score (Zs) was based on Mann-Kendall test (Kendall, 1938; Mann, 1945), applied to each study site using monthly and annual time series data (1984-2022), on rainfall, Tmax, Tmin and ETo.

Crop climate risk (focusing on drought and low temperatures), was estimated using the usual Zarc methodology but simplified for this assessment considering one soil type and a hypothetical maize crop (110-day cycle, 47 mm of soil water capacity, Kc 0.4-1.2). Drought risk was evaluated using the Water Requirement Satisfaction Index (WRSI), calculated from crop evapotranspiration (outputs from the SARRA model, Baron et al., 1996). Water deficits

were defined when WRSI fell below 0.60 or 0.50 during establishment and grain filling, respectively. Low-temperature risk was determined by the frequency of minimum daily temperatures below 5°C from emergence to 100 days post-emergence.

Crop cycles were simulated across all data series in both P1 and V2, considering three sowing dates per month - one every 10 days - through each year of the 30-year period. After, the risk or frequency of adverse weather events, drought and low temperatures, was classified and spatialized into four categories: up to 20%, 30%, 40%, and greater than 40%. Comparisons between P1 and V2 were based on differences in average risk, as well as on changes in the duration of the planting windows identified for each municipality.

Resultados e discussão

Table 1 shows the monthly and annual Zs values from the Mann-Kendall test for all climate variables. Rainfall trends are non-significant throughout the months, but between March and September, negative trends predominate, with more pronounced declines in April (Zs = -0.60) and September (Zs = -0.76); the annual trend shows a Zs value of -0.08. Tmin shows a consistent positive trend throughout the months, with the highest significant monthly Zs values occurring in October (2.31), September (2.12), and June (2.02). Tmax displays the strongest warming signals, particularly in September (3.42) and August (2.35). The annual Zs of 2.25 for Tmin and 3.01 for Tmax reflects a widespread and statistically significant temperature increase. ETo also reveals a general upward trend across most months, significant from July to September, with Zs values of 1.75, 1.88 and 1.87, respectively. The annual Zs of 1.33 supports evidence of rising atmospheric water demand.

Tabela 1. Monthly and annual Zs values of the Mann-Kendall test for rainfall, minimum and maximum temperature (Tmin and Tmax), and evapotranspiration (ETo), averaged across all evaluated sites in Brazil over the period 1984-2022. *Bold values-larger than 1.65 or lower than -1.65-denotes significance at a confidence level of 90%.

	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	
Rainfall	0.03	0.12	-0.08	-0.60	-0.30	0.21	-0.28	-0.41	-0.76	0.38	0.40	0.02	-0.08
Tmin	1.44	1.37	1.36	0.71	0.70	2.02	1.50	1.19	2.12	2.31	1.22	1.58	2.25
Tmax	1.15	1.33	1.71	1.65	0.90	1.73	2.24	2.35	3.42	2.21	1.15	1.62	3.01
ETo	0.03	0.30	0.98	1.35	1.02	1.27	1.75	1.88	1.87	0.32	-0.59	-0.02	1.33

The increasing temperatures may have positive and negative agricultural implications. In the South and Southeast, the reduction in frost frequency will benefit crops and potentially extend planting windows. Despite not shown, a spatial trend pattern revealed a decline in rainfall, mainly at the onset of the rainy season (August-September) across Central Brazil. This reduction coincides with significant increases in temperature and evapotranspiration, contributing to an extended dry season. These findings support the observed rise in agricultural climate risk depicted in Figure 1a and reflect broader global climate trends-including the warmest decade on record-and national observations, with Brazil experiencing its hottest year since 1961 in 2024, likely intensified by recent El Niño events (INMET, 2025).

Table 2 and Figure 1b, presents a comparison of maize planting windows between the P1 and V2 datasets, which reveals a regional pattern across Brazil. The Southeast was the most impacted, with 58% (1,211 kha) of the area showing reductions-especially losses of 1 (28%, 585 kha), 2 to 3 (24%, 499 kha), and less than 4 ten-day (6%, 127 kha) periods. The Central-West showed 30% (3,615 kha) of its area with reductions, most of them with 1 ten-day period losses (25%, 2,988 kha) and 16% with gains, while 54% remained stable. In contrast, the South exhibits greater area with increased planting windows (49%, 1,965 kha), most of them with 1 ten-day periods (38%, 1,505 kha).

These considerable portions of maize areas in Southeast experiencing a reduction in suitable planting periods may force farmers to operate under higher risk conditions, which compromises productivity and harvest security, being particularly challenging for double-cropping systems.

Tabela 2. Maize cultivated areas (kha) showing decrease, stability, or increase in the number of ten-day periods in the viable planting window, comparing baselines P1 and V2.

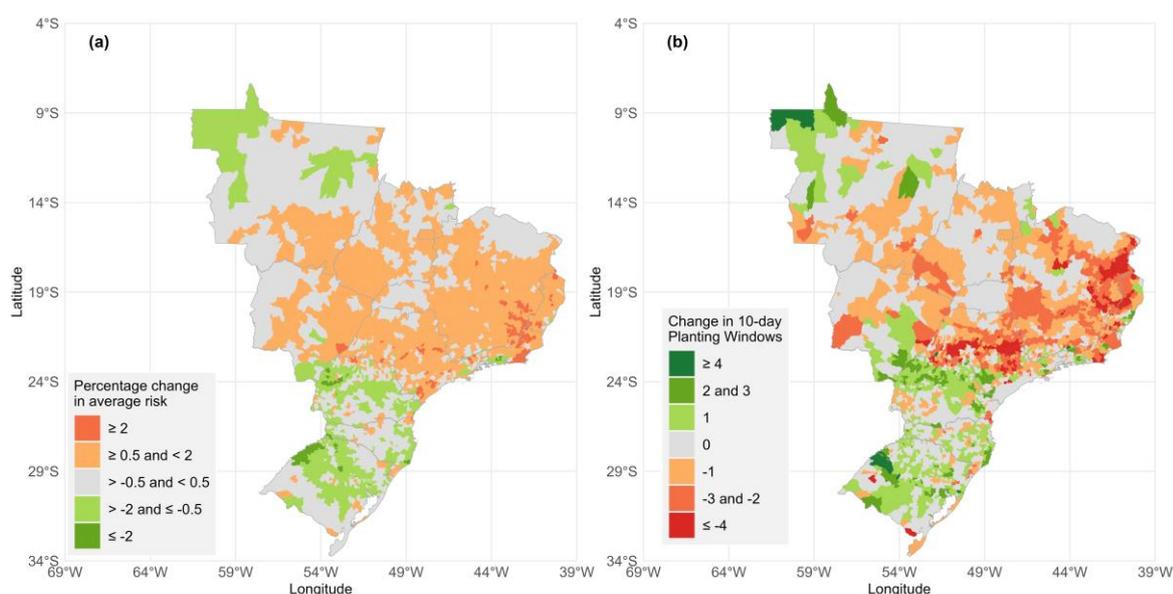| Region	Total	Change in the number of ten-day periods in the viable planting window						
		-4 or less	-3 and -2	-1	0	1	+2 and +3	+4 or more
Central-West	12,063	7	620	2,988	6,497	1,551	395	3
	100%	0%	5%	25%	54%	13%	3%	0%
Southeast	2,076	127	499	585	661	110	94	1
	100%	6%	24%	28%	32%	5%	5%	0%
South	3,955	46	153	449	1,342	1,505	410	50
	100%	1%	4%	11%	34%	38%	10%	1%

Figura 1. Municipal areas showing decrease, stability, or increase in average risk (a) and the number of ten-day periods (b) in the viable planting window for maize across Brazil in V2 (1993-2022) relative to P1 (1984-2013).

Conclusões

1. Warming temperatures, increasing evapotranspiration, and region-specific rainfall reductions underscore the intensification of the dry season, particularly in Central Brazil, posing a growing challenge for agricultural water resources.

2. The identified climate shifts significantly impact agricultural risk assessments and planting windows, increasing water deficit risks in the Southeast and Central-West, while reducing low-temperature risks in the South of Brazil.

3. The integration of an updated, robust, and denser weather database in Zarc contributes to a more realistic and precise agricultural risk assessment, which is essential for adapting to and mitigating the impacts of climate change.

Referências

AGÊNCIA NACIONAL DE ÁGUAS E SANEAMENTO BÁSICO (Brasil). **Sistema Nacional de Informações sobre Recursos Hídricos: Hidroweb**. Available at: <https://www.snirh.gov.br/hidroweb/apresentacao>. Accessed on: Nov. 01 2024.

ALLEN, R.G.; PEREIRA, L.S.; RAES, D.; SMITH, M. **Crop evapotranspiration: guidelines for computing crop water requirements**. Rome: FAO, 1998. (FAO Irrigation and Drainage Paper, 56).

BARON C., CLOPES A., PEREZ P., MULLER B., MARAUX F. Manuels d'utilisation de SARRAMET 45 p, SARRABIL 35 p et SARRAZON 29 p., CIRAD, Montpellier: CIRAD. 1996.

FUNK, C.; PETERSON, P.; LANDSFELD, M.; PEDREROS, D.; VERDIN, J.; SHUKLA, S.; HUSAK G.; ROWLAND, J.; HARRISON, L.; HOELL, A.; MICHAELSEN, J. The climate hazards infrared precipitation with stations - A new environmental record for monitoring extremes. **Scientific Data**, v.2, art.150066, 2015. DOI: https://doi.org/10.1038/sdata.2015.66.

INMET. Instituto Nacional de Meteorologia. Available at: <https://portal.inmet.gov.br/noticias/2024-%C3%A9-o-ano-mais-quente-da-s%C3%A9rie-hist%C3%B3rica-no-brasil>. Accessed on Apr. 07 2025. KENDALL, M.G. A New Measure of Rank Correlation. **Biometrika**, v.30, p.81-93, 1938. DOI: https://doi.org/10.2307/2332226.

MANN, H.B. Nonparametric tests against trend. **Econometrica**, v.13, p.245-259, 1945. DOI: https://doi.org/10.2307/1907187.

REGOTO, P.; DERECZYNSKI, C.; CHOU, S.C.; BAZZANELA, A.C. Observed changes in air temperature and precipitation extremes over Brazil. **International Journal of Climatology**, v.41, p.5125-5142, 2021. DOI: https://doi.org/10.1002/joc.7119.

TOMASELLA, J.; CUNHA, A.P.M.A.; SIMÕES, P.A.; ZERI, M. Assessment of trends, variability and impacts of droughts across Brazil over the period 1980-2019. **Natural Hazards**, v.116, p.2173-2190, 2023. DOI: https://doi.org/10.1007/s11069-022-05759-0.

XAVIER, A.C.; SCANLON, B.R.; KING, C.W.; ALVES, A.I. New improved Brazilian daily weather gridded data (1961-2020). **International Journal of Climatology**, v.42, p.8390-8404, 2022. DOI: https://doi.org/10.1002/joc.7731.