

MULTI-ANNUAL ANALYSIS OF THE PERFORMANCE OF MAIZE HYBRIDS CULTIVATED UNDER A MINIMUM TILLAGE SYSTEM IN IRRIGATED CONDITIONS IN DOBROGEA (2022-2025)

Traian Ciprian STROE^{1,2}, Liliana PANAITESCU^{1,2}

¹University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd,
District 1, Bucharest, Romania

²Ovidius University of Constanta, Universitatii Alley, Campus Building B, 900470,
Constanta, Romania

Corresponding author email: str_ciprian@yahoo.com

Abstract

The paper presents the results of a field experiment conducted between 2022 and 2025 in the Dobrogea region, under an irrigation system, evaluating the behavior of three maize hybrids (P9911, P9889, and MAS43P) cultivated under a minimum tillage system. The study aimed to assess the influence of the technological itinerary on grain yield, thousand kernel weight (TKW), test weight (TW), plant height, and plant density at harvest. Weed control was achieved through an integrated management system using pre- and post-emergence herbicides (Callisto and Clinic Xpert), in order to reduce weed infestation and preserve soil moisture. The data were statistically analyzed using the ANOVA method, highlighting significant differences among hybrids regarding average yield, which ranged from 7.8 to 9.2 t/ha. Hybrid P9889 showed the highest adaptability and yield stability under irrigated conditions. The combination of minimum tillage, irrigation, and effective weed control contributed to maintaining soil fertility and increasing the energy efficiency of maize cultivation. The results indicate that thermal stress during the May-July period represents the main limiting factor for maize productivity in Dobrogea, even under irrigated conditions, while hybrid-specific adaptability plays a decisive role in ensuring yield stability under increasing climate stress.

Key words: hybrids, irrigation system, maize, minimum tillage, weed control.

INTRODUCTION

Maize (*Zea mays* L.) is one of the most strategic crops globally, ranking third worldwide by cultivated area after wheat and rice, while being of primary importance for the livestock and energy sectors due to its versatility and high economic value (Erenstein et al., 2022). In Europe, Romania consistently ranks among the leading countries in terms of cultivated area and total maize production, with maize playing a key role in national food security and agricultural competitiveness (Botoș et al., 2025; Stroe & Panaitescu, 2026). In recent years, increasing research attention has focused on adapting maize production technologies to the growing frequency and intensity of drought and aridity episodes associated with climate change (Habibur-Rahman et al., 2022).

Climate change has expanded the agricultural areas exposed to severe heat stress, particularly in southern and south-eastern Romania, where summer temperatures frequently reach or

exceed the critical physiological thresholds for row crops (Prăvălie et al., 2014; Popescu et al., 2023). Dobrogea is considered one of the most climatically vulnerable agricultural regions of the country, being characterized by low annual rainfall, high evapotranspiration rates and recurrent heat waves during July and August (Smuleac et al., 2020; Dumitru et al., 2023). Under these conditions, soil-conservation technologies become essential for preserving soil moisture and preventing structural degradation.

Minimum tillage systems have been increasingly adopted in arid and semi-arid regions due to their capacity to reduce evaporation losses, improve water-use efficiency and limit soil disturbance (Stroe & Panaitescu, 2025). The use of conservative tillage practices, often complemented by cover crops, contributes to soil protection and improves water availability during critical growth stages (Filip & Marin, 2018). Nevertheless, even when water losses are

reduced, maize crops remain highly sensitive to extreme temperatures during reproductive stages, particularly during flowering, when elevated thermal thresholds impair fertilisation and reduce kernel number per ear (Yanev, 2023). Dobrogea is frequently affected by extreme temperatures during maize pollination, with numerous days exceeding 32-35°C, a condition that substantially reduces grain yield even under irrigated conditions (Mircea et al., 2023). In the Topraisar area, where both pedological and atmospheric drought are pronounced, irrigation represents an indispensable technological component; however, its efficiency is strongly constrained by the intensity of heat stress affecting key physiological processes (Risnoveanu et al., 2023). Similar responses to heat stress during flowering have been reported in other southern regions of Romania, where high temperatures during pollination resulted in reduced kernel set and lower yields (Simionescu et al., 2016; Zafiu & Mihalache, 2021). Several studies conducted in south-eastern Europe have demonstrated that the performance of maize hybrids under arid conditions is strongly dependent on their adaptability to high temperatures during flowering (Haraga & Ion, 2022). Consequently, hybrid selection should account not only for drought tolerance but also for sensitivity to extreme thermal conditions, which has become increasingly relevant in the context of climate change and the intensification of heat-wave events (Kirchev, 2025). In this framework, the effectiveness of conservative tillage systems is closely linked to the genetic adaptability of the hybrids cultivated under specific pedoclimatic conditions (Dunăreanu & Bonea, 2022; Aedin et al., 2024). Irrigation systems remain a key technological tool for mitigating water stress in spring crops such as maize, which exhibits maximum water demand during grain formation and filling (Filip & Marin, 2018). However, recent studies indicate that irrigation cannot fully compensate for the negative effects of extreme temperatures on pollen viability and fertilisation, making thermal stress during pollination a major determinant of yield variability in south-eastern Romania (Zhang et al., 2021). In this context, minimum tillage systems have expanded considerably in Dobrogea, contributing to improved soil structure, reduced evaporation

and enhanced resilience to drought, although their long-term effectiveness depends on hybrid response to heat stress during flowering (Amuza & Ilie, 2023; Manole et al., 2023; Dumitru et al., 2023).

Recent research has highlighted the importance of optimizing technological components in maize cultivation systems under irrigation and arid conditions. The interaction between agronomic practices, such as fertilization management and hybrid selection, plays a decisive role in improving yield performance and stability in water-limited environments. For instance, optimizing nitrogen application timing has been shown to significantly enhance grain yield in maize-based systems under arid conditions (Hu et al., 2020). At the same time, quantitative models have been developed to assess the combined influence of technological factors on maize productivity under irrigation, emphasizing the complexity of yield formation processes (Vozhehova et al., 2023). In addition to yield-related aspects, increasing attention has been given to the biochemical and nutritional quality of maize cultivars, which is influenced by both genetic background and cultivation technology (Popoviciu et al., 2024). These findings underline the need for integrated approaches that combine technological optimization with hybrid adaptability in order to ensure stable maize production under conditions of increasing climatic stress.

The aim of this study was to evaluate the multi-annual performance of drought-tolerant maize hybrids cultivated under minimum tillage and irrigation in the specific climatic conditions of the Topraisar area, southern Dobrogea. The objectives were to assess yield stability and key productivity components under contrasting climatic conditions and to identify hybrids with superior adaptability to thermal stress, using ANOVA-based statistical approaches to support technological decision-making in semi-arid regions.

MATERIALS AND METHODS

The research was carried out between 2022 and 2025 in south-eastern Romania, in the Topraisar area (Dobrogea), a region characterized by frequent episodes of pedological and atmospheric drought and high sensitivity of

agricultural crops to heat stress (Dumitru et al., 2023; Smuleac et al., 2020). The experimental site is representative of the Dobrogea Plateau, where moderate soil fertility and a permanent climatic water deficit justify the use of conservative tillage systems and irrigation for spring crops (Filip & Marin, 2018; Dunăreanu & Bonea, 2022).

The biological material consisted of three maize hybrids with high tolerance to drought and elevated temperatures (P9911, P9889 and MAS43P), selected based on their recent performance in south-eastern European environments (Haraga & Ion, 2022; Călugăr et al., 2024). The experiment was organized as a randomized complete block design, with hybrid as the single experimental factor, and was conducted under identical technological conditions for all variants, including sowing date, plant density, fertilization scheme and irrigation regime, in order to allow a realistic comparison of genetic performance (Mircea et al., 2023; Stroe & Panaiteanu, 2025).

Each experimental plot covered an area of 1 ha, and three replications were used for each hybrid in each experimental year. This experimental layout allowed both intra-annual comparisons among hybrids and interannual evaluation of climatic effects under uniform management conditions.

The cultivation technology was based on minimum tillage, involving shallow stubble operations and a reduced number of soil interventions, according to recommendations for areas affected by severe aridity (Dumitru et al., 2023; Risnoveanu et al., 2023). In all vegetation cycles, irrigation was applied using sprinkler systems, ensuring an adequate water supply for crop development, although without eliminating the impact of extreme temperatures during the pollination period, which represents the main limiting factor for maize productivity in Dobrogea (Zafiu & Mihalache, 2021; Kirchev, 2025). Weed control was performed through the application of pre- and post-emergence herbicide treatments based on mesotrione and glyphosate, following technological recommendations for maize cultivated under minimum tillage systems (Yanev, 2023).

The assessed parameters included average grain yield, thousand-kernel weight (TKW), test weight (TW), plant height and plant density at

harvest. Experimental data were statistically analysed using analysis of variance (ANOVA), in accordance with methodologies commonly applied in studies addressing the effects of heat stress, genotype and cultivation system on maize production in south-eastern Europe (Prăvălie et al., 2014; Habib-ur-Rahman et al., 2022).

In addition to ANOVA, correlation and regression analyses were applied to evaluate the relationships between grain yield and the main biometric and quality parameters (TKW, TW, plant height and plant density). Pearson correlation coefficients were calculated and tested for statistical significance at $p < 0.05$ and $p < 0.01$. Linear and polynomial regression models were used to assess the dependence of grain yield on thermal conditions during the flowering period and on selected productivity components. Prior to statistical analysis, data distribution and variance homogeneity were verified in accordance with standard biometric requirements for agricultural field experiments. Statistical processing and graphical interpretation were performed using standard statistical software packages commonly employed in agronomic research, following methodological approaches reported in recent maize studies from south-eastern Europe (Haraga & Ion, 2022; Kirchev, 2025).

The aim of this study was to evaluate the performance of the maize hybrids P9911, P9889 and MAS43P under the pedoclimatic conditions of the Topraisar area and to identify technological solutions applicable to agriculture in south-eastern Romania under conditions of intensifying heat stress (Popescu, 2023). The main objectives were the comparative analysis of key productivity elements, the assessment of the impact of high temperatures on yield components, and the identification of hybrids with superior yield stability under irrigation and minimum tillage conditions.

RESULTS AND DISCUSSIONS

Maize was grown each year after winter wheat, a dominant crop rotation system in south-eastern Dobrogea, considered technologically suitable for the land-use structure of the region. At the preceding crop, swine manure was applied as organic fertilization, contributing to improved soil structure and nutrient availability under the

moderate fertility conditions typical of the Dobrogea Plateau. Basal fertilization of maize included annual applications of nitrogen (200 kg/ha as ammonium nitrate), phosphorus (100 kg/ha as superphosphate) and potassium (80 kg/ha as potassium sulfate), supplemented by a top-dressing of urea (80 kg/ha, 46% N) at the 6-8 leaf stage. The combined use of organic amendments and moderate mineral fertilization is recommended for arid regions and has been reported as an efficient strategy for sustaining crop productivity under limited natural nutrient supply (Filip & Marin, 2018; Dumitru et al., 2023; Stroe & Panaitescu, 2025).

Maize was sown annually between 12 and 17 April at a uniform density of 68,000 plants/ha, ensuring a consistent basis for genetic comparison among hybrids. Weed control followed an integrated management approach, combining mechanical cultivations with pre- and post-emergence herbicide applications based on mesotrione (0.4 L/ha) and glyphosate (3 L/ha), reducing both weed competition and soil moisture losses. Pest control targeted mainly *Ostrinia nubilalis* and *Helicoverpa armigera*, while fungicide treatments were applied in years with favourable conditions for foliar diseases, particularly *Cercospora zeae-maydis*. Similar technological approaches have been widely reported for maize cultivation in south-eastern Romania, where organic fertilization, integrated weed management and irrigation are essential components of conservative tillage systems (Simionescu et al., 2016; Haraga & Ion, 2022; Manole et al., 2023; Yanev, 2023; Kirchev, 2025).

Irrigation was applied through sprinkler systems during all vegetation cycles, ensuring adequate water supply during critical growth stages. However, even under regular irrigation, high temperatures during pollination remained the main limiting factor for grain production, negatively affecting fertilisation and kernel set. The uniform application of the cultivation technology across the four experimental years allowed a clear assessment of hybrid performance against the background of pronounced interannual climatic variability and increasing thermal stress typical of the Dobrogea region (Zafiu & Mihalache, 2021; Mircea et al., 2023). The climatic data recorded in the Topraisar area during 2020-2025 indicate a pronounced

positive deviation of monthly mean temperatures relative to the long-term climatic normal (1980-2019), particularly during the agricultural season (Figure 1). Across all experimental years, the April-September period showed temperature increases of approximately 2.0-4.0°C above the multiannual average, highlighting the intensification of thermal stress characteristic of arid regions. The highest positive deviations were consistently recorded in June, July and August, in agreement with recent studies reporting a marked increase in summer temperatures in south-eastern Europe (Prăvălie et al., 2014; Smuleac et al., 2020; Haraga & Ion, 2022; Mircea et al., 2023). In July, mean temperatures ranged between 26.7 and 28.5°C, substantially exceeding the multiannual average of 22.6°C and approaching or surpassing the physiological thresholds considered limiting for maize pollination and fertilisation (Yanev, 2023). Elevated temperatures persisted in August, with mean values 3-4°C above the climatic normal, indicating prolonged thermal stress during the reproductive phase. Under these conditions, even in irrigated systems, temperature emerged as the primary limiting factor for yield formation in the analysed experimental years, confirming observations previously reported for south-eastern Romania (Dumitru et al., 2023; Zafiu & Mihalache, 2021).

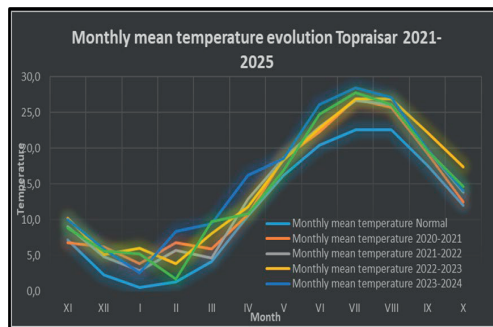


Figure 1. Monthly mean temperature evolution (Topraisar, 2020-2025)

The analysis of absolute maximum and minimum temperatures recorded during March–September confirms the occurrence of pronounced thermal extremes with direct effects on crop establishment and reproductive development in the Topraisar area. In several

years, April registered minimum temperatures below the biological tolerance threshold of maize, reaching values as low as -2.6°C and -11.1°C , which delayed emergence and reduced early seedling vigour. Similar early-season cold events have been reported in Dobrogea and are considered disruptive for uniform crop establishment under conservation tillage systems (Dumitru et al., 2023).

During the reproductive period, absolute maximum temperatures in July-August frequently exceeded $36-39^{\circ}\text{C}$, confirming the presence of severe heat stress during pollination. Such values surpass the thresholds considered critical for pollen viability and fertilisation and are associated with reduced kernel set even under irrigated conditions (Yanev, 2023). The occurrence of temperatures above 35°C as early as June indicates an advancement of heat stress towards the beginning of summer, potentially limiting biomass accumulation during stem elongation, while low minimum temperatures recorded in May ($0.8-3.4^{\circ}\text{C}$) reveal a high thermal amplitude during early vegetative stages.

Overall, the combination of extreme minimum temperatures in early spring and extreme maximum temperatures during July-August demonstrates that maize phenological success in the Topraisar area is jointly constrained by early-season and reproductive heat stress. Consequently, even under irrigation, thermal stress remains the main limiting factor of crop performance in the analysed agricultural years,

in agreement with previous findings from south-eastern Romania (Haraga & Ion, 2022; Mircea et al., 2023) (Figure 2).

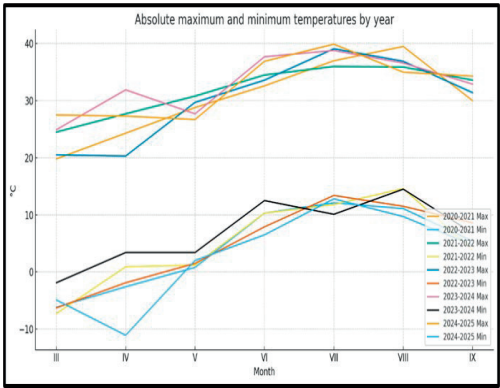


Figure 2. Absolute temperature extremes in Topraisar during the vegetation season (2020-2025)

The analysis of precipitation distribution during the 2020-2025 interval reveals pronounced interannual variability, with large positive and negative deviations from the multiannual climatic norm of 436 mm (Table 1). The agricultural year 2020-2021 was the wettest of the analysed period, recording 629 mm (approximately 44% above the norm), with precipitation surplus concentrated mainly in winter and early spring (January-April), which favoured soil water reserve accumulation at the beginning of the vegetation period, an uncommon situation for southern Dobrogea (Dumitru et al., 2023).

Table 1. Analysis of precipitation distribution during the 2020–2025

Month/year	Precipitation (mm)					
	Normal	2020-2021	2021-2022	2022-2023	2023-2024	2024-2025
XI	40.4	20.6	40.8	39.5	85.0	56.6
XII	34.0	72.0	69.6	20.3	28.0	92.8
I	31.0	89.0	14.8	45.2	14.4	17.4
II	33.0	30.4	27.2	10.8	1.2	5.4
III	21.7	59.7	19.2	23.6	22.0	4.6
IV	33.5	51.8	30.7	99.5	27.6	23.4
V	50.2	66.0	19.8	11.4	26.2	52.4
VI	53.2	100.4	45.0	28.4	11.2	0.2
VII	35.6	33.5	41.6	27.8	7.4	20.8
VIII	31.6	6.8	5.4	3.6	17.0	21.0
IX	41.6	20.8	64.2	0.2	86.2	47.4
X	30.2	78.4	5.4	7.8	79.6	95.0
Total per year	436.0	629.4	383.7	318.1	405.8	437

In contrast, the years 2021-2022 and 2022-2023 were characterised by marked pluviometric deficits, with total precipitation values 12-27% below the multiannual average, reflecting a typical semiarid climatic regime. The year 2022-2023 was particularly severe, with extremely low spring precipitation (March-May), totalling only 36 mm compared to the normal 105 mm, leading to the early onset of water stress during crop establishment.

The 2023-2024 agricultural year also exhibited a dry character, despite total precipitation close to the norm, due to its uneven seasonal distribution, with higher values in autumn and pronounced deficits during the critical May-July period. Similarly, although total precipitation in 2024-2025 (437 mm) was close to the multiannual average, rainfall scarcity during May-July directly affected soil moisture availability during panicle emergence and pollination. These patterns confirm that, under the climatic conditions of south-eastern Romania, total annual precipitation is not a reliable indicator of climatic risk, as crop performance is primarily determined by rainfall distribution during critical phenophases (Zafiu & Mihalache, 2021; Mircea et al., 2023).

Beyond its impact on yield formation, precipitation distribution during the vegetation period also plays an important role in determining grain quality parameters. Adequate water availability during grain filling contributes to proper kernel development, influencing both grain consistency and the accumulation of bioactive compounds. Variations in moisture conditions during this stage may lead to changes in kernel structure and nutritional composition, as reported in studies evaluating maize quality traits under different environmental conditions (Popoviciu et al., 2024). Therefore, irregular precipitation patterns not only affect yield levels but may also influence the qualitative attributes of maize production under semiarid conditions.

Overall, only the 2020-2021 season can be considered favourable in terms of rainfall, while the remaining years were characterised by moderate to severe hydric deficits during the vegetation period, a situation typical of highly arid regions such as Dobrogea (Smuleac et al., 2020; Popescu et al., 2023).

During the vegetation period (March-September), precipitation amounts were below the multiannual norm (267.4 mm) in most of the analysed years, confirming the semiarid character of the Topraisar region (Figure 3). Only the 2020-2021 season recorded precipitation above the normal level (339 mm), whereas the remaining years exhibited marked hydric deficits, with values ranging between 169.8 and 225.9 mm, corresponding to reductions of 15-36% relative to the climatic average.

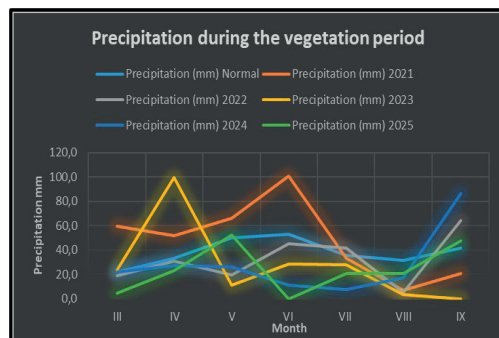


Figure 3. Precipitation during the vegetation period (March-September) in Topraisar (2020-2025)

The hydric deficit was most pronounced during the critical months for yield formation, June and July, when precipitation dropped in some seasons to as little as 0.2-11 mm, far below the physiological water requirements of maize during peak demand. Consequently, except for the first experimental year, crop development relied almost entirely on irrigation inputs.

These results confirm that total annual precipitation is not a reliable indicator of hydric stress, as maize productivity in Dobrogea is primarily determined by rainfall distribution during critical phenological stages rather than by cumulative annual amounts (Smuleac et al., 2020).

Plant density at harvest showed marked interannual variation, reflecting the influence of early-season climatic conditions, particularly spring drought and low minimum temperatures occurring between emergence and the 6-8 leaf stage. Years characterised by higher precipitation during March-May and the absence of severe early frosts favoured uniform emergence and higher final plant densities, whereas reduced rainfall and low minimum

temperatures led to delayed emergence and substantial stand losses.

Against this variable climatic background, clear and consistent differences among hybrids were observed. In the favourable year 2020-2021, average harvest density reached approximately 61,800 plants/ha, with hybrid P9889 recording the highest values ($\approx 62,500$ plants/ha), followed by MAS43P ($\approx 58,700$ plants/ha) and P9911 ($\approx 56,200$ plants/ha). In less favourable years, such as 2021-2022 and especially 2022-2023, when spring precipitation was reduced and minimum temperatures dropped below -1.9°C , average densities declined to approximately 52,600-54,200 plants/ha. Even under these stress conditions, P9889 maintained a clear advantage, exceeding the other hybrids by 3,000-8,000 plants/ha.

In 2023-2024, improved precipitation during June partially compensated early-season stress and resulted in higher final densities ($\approx 58,500$ plants/ha), while in 2024-2025, despite extremely low minimum temperatures in April (-11.1°C), irrigation and partial rainfall recovery during summer enabled stand recovery. In both cases, P9889 consistently recorded the highest plant density at harvest ($\approx 60,800$ - $61,000$ plants/ha), followed by MAS43P and P9911.

These results indicate that, although early-season climatic stress, particularly drought, strongly influences plant establishment, hybrid response plays a decisive role in determining final stand density. The ability of P9889 to maintain higher and more stable plant populations under contrasting hydro-thermal conditions highlights its superior tolerance to early water and thermal stress. This establishment stability constitutes a key physiological advantage, directly contributing to the observed differences in yield performance under irrigated conditions in Dobrogea (Figure 4).

Plant height was strongly influenced by hydro-thermal conditions during May-July, the period of maximum vegetative growth, but consistent differences among hybrids were observed across all experimental years. In seasons characterised by near-normal precipitation and moderate summer temperatures (e.g. 2020-2021 and 2024-2025), average plant height ranged between 200 and 210 cm, with hybrid P9889 consistently exhibiting the highest values (≈ 215 - 218 cm).

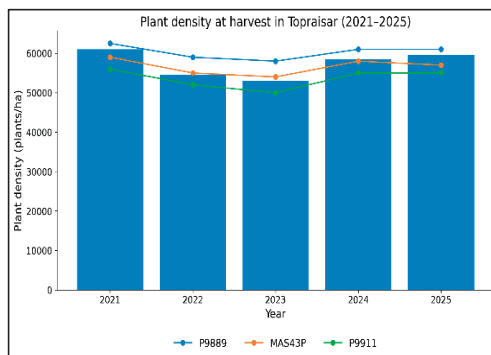


Figure 4. Plant density at harvest in Topraisar (2021-2025)

In contrast, years affected by spring-summer drought and elevated temperatures (2021-2022 and 2022-2023) showed reduced vegetative growth, with average heights declining to approximately 185-195 cm. Even under these stress conditions, P9889 maintained a clear advantage, exceeding P9911 and MAS43P by 8-15 cm, indicating enhanced tolerance to thermal and hydric stress during the peak growth period. Despite strong interannual climatic variability, the genetic ranking of hybrids for plant height remained stable ($\text{P9889} > \text{P9911} > \text{MAS43P}$), highlighting the dominant role of hybrid adaptability in determining vegetative vigour. Across the four experimental years, P9889 consistently recorded the greatest plant height (≈ 205 - 220 cm), confirming its high genetic potential and superior adaptability to the pedoclimatic conditions of Dobrogea.

Ear insertion height followed a similar pattern, being jointly influenced by hydro-thermal conditions during June-July and hybrid genetic characteristics. Under favourable moisture conditions, ear insertion ranged between 102 and 111 cm, while under drought and high-temperature stress it declined to 93-100 cm. In all years, hybrid P9889 maintained the highest ear insertion values (≈ 100 - 111 cm), followed by P9911 and MAS43P, indicating a stable morphological response even under pronounced thermal stress.

The combined stability of plant height and ear insertion observed for P9889 reflects a superior capacity to sustain vegetative growth under contrasting climatic conditions, a trait of particular importance for irrigated maize production systems in south-eastern Dobrogea.

These differences, clearly illustrated by the multiannual means in Figure 5, support the interpretation that morphological vigour

contributes to the higher yield stability of this hybrid under conditions of intensifying heat stress.

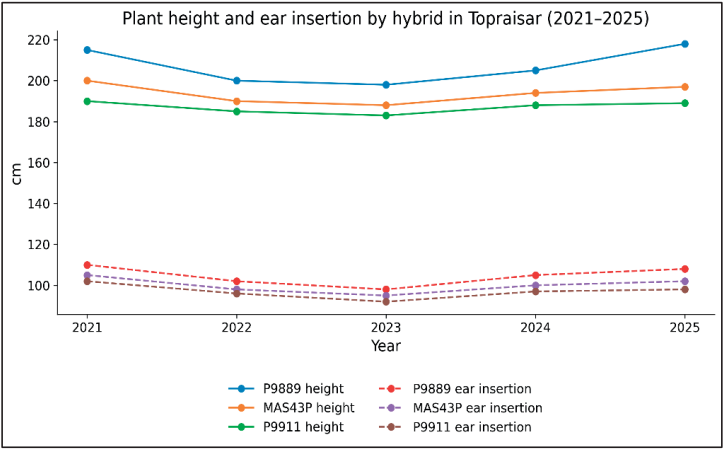


Figure 5. Plant height and ear insertion height of maize hybrids under contrasting climatic conditions in Topraisar (2021-2025)

The determinations regarding kernel weight per ear (without cob) showed clear differences among hybrids, with P9889 recording the highest multiannual mean value (161.29 g), ranging between 172.62 g in 2021 – the year with above-average spring precipitation – and 152.71 g in 2023, strongly affected by heat stress during grain filling. MAS 43P recorded intermediate values, with a mean of 141.14 g, ranging between 162.22 g (2021) and 129.13 g (2023), whereas P9911 exhibited the lowest values (mean 126.67 g), decreasing to 114.42 g in 2023 under severe water deficit conditions. The two-factor ANOVA (hybrid × year), followed by LSD test at $p<0.05$, confirmed significant differences among hybrids as well as a significant hybrid × year interaction, indicating combined influences of genetic potential and yearly climatic variability in the specific conditions of Dobrogea (Filip & Marin, 2019). To obtain a robust estimation of year effect, the statistical analysis was conducted within a mixed model framework, in which hybrid was considered as a fixed effect and year as a random effect, allowing inter-annual climatic variability to be properly integrated in the experimental model. The results regarding total ear mass (kernels + cob) further confirmed the superiority of hybrid P9889, which recorded a mean value of 198.2 g,

followed by MAS 43P (163.14 g) and P9911 (167.56 g). Significant differences ($p<0.05$) were detected within the mixed model ANOVA, confirming physiological differences related to ear development and biomass accumulation, as previously reported for drought-tolerant maize hybrids under arid environments (Haraga & Ion, 2022). For both parameters (kernel weight per ear and total ear mass), hybrid P9889 achieved the highest values, confirming its superior genetic performance and adaptability under irrigation and heat stress conditions specific to Dobrogea (Figure 6).

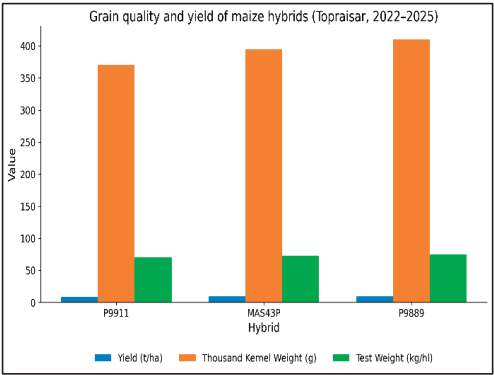


Figure 6. Grain quality parameters and yield for the evaluated maize hybrids (Topraisar, 2022-2025)

The consistently higher ear biomass observed for P9889 indicates a superior capacity to sustain assimilate accumulation during grain filling under heat stress, which represents a key physiological mechanism underlying its higher yield stability in irrigated systems of southern Dobrogea.

Pearson correlation analysis based on multi-annual averages revealed a significant negative relationship between mean temperatures during May–July and grain yield ($r = -0.73$; $p < 0.05$), with a determination coefficient of $R^2 \approx 0.54$, indicating that more than half of the yield variation can be explained by the intensity of thermal stress occurring during the reproductive phase (Figure 7A). This result is consistent with previous findings showing that elevated temperatures during flowering reduce pollen viability and kernel set, leading to substantial yield penalties even under irrigated conditions (Yanev, 2023).

In contrast, cumulative precipitation during April–June showed only a weak positive correlation with grain yield ($r \approx 0.27$; $R^2 \approx 0.07$), suggesting a secondary role of natural rainfall under the experimental conditions (Figure 7B). This limited relationship can be attributed to the use of irrigation, which partially compensated for early-season water deficits. Under rainfed conditions, a stronger precipitation–yield relationship would be expected, as reported for semiarid maize systems (Zafiu & Mihalache, 2021).

Two-way ANOVA (hybrid $\times$ year), followed by LSD/Tukey post-hoc tests at $p < 0.05$, confirmed significant effects of both hybrid and year for all productive traits, highlighting the strong influence of interannual climatic variability. The mixed-model approach, with hybrid treated as a fixed effect and year as a random effect, further emphasized the dominant role of environmental factors under the arid conditions of southern Dobrogea, while allowing reliable discrimination among hybrid responses.

Hybrid $\times$ year interactions demonstrated that maize performance is highly dependent on the intensity of thermal stress during reproductive stages. In this context, hybrid P9889 consistently exhibited the highest interannual yield stability, accompanied by superior thousand-kernel weight and test weight values, reflecting enhanced genetic adaptability and

water-use efficiency. These results are in agreement with previous studies conducted in semiarid regions of south-eastern Europe (Filip & Marin, 2018) and represent a key contribution of the present multi-year, field-based evaluation under minimum tillage and irrigation.

Overall, maize productivity under the analysed conditions was primarily controlled by thermal stress during May–July and only secondarily by early-season water availability. Although irrigation mitigated rainfall deficits, it could not offset the negative effects of extreme temperatures during flowering. Consequently, the adoption of thermotolerant hybrids such as P9889 is essential for maintaining yield performance under the intensifying climatic stress characteristic of Dobrogea.

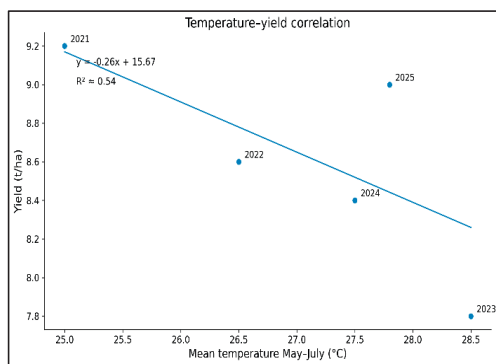


Figure 7A. Temperature-yield correlation for irrigated maize (Topraisar, 2022-2025)

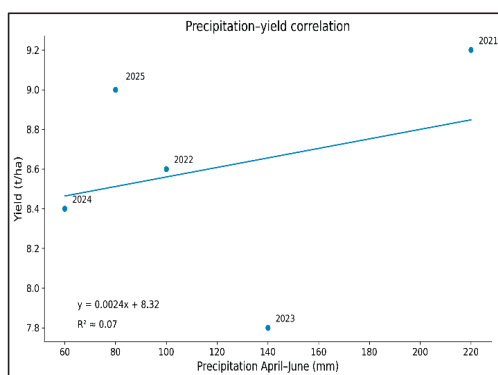


Figure 7B. Precipitation-yield correlation for irrigated maize (Topraisar, 2022-2025)

The results confirm that maize yield under the pedoclimatic conditions of Dobrogea is primarily driven by the thermal regime during

May–July, particularly during flowering and grain filling, in line with findings from other arid regions of south-eastern Europe. Hybrid P9889 showed superior yield stability, supporting previous evidence that genetic traits can mitigate thermal stress effects. Thousand-kernel weight and test weight values were within the range reported for semiarid-adapted hybrids, although lower than those observed in central Romania, where thermal stress during pollination is less severe. Overall, minimum tillage combined with irrigation proved suitable for maize production, although its effectiveness remains constrained under extreme temperature conditions.

The originality of this study lies in its multi-year comparative assessment of thermotolerant maize hybrids under minimum tillage and irrigation in the Topraisar area, one of Romania's most climatically vulnerable regions. The findings demonstrate that yield variability is primarily controlled by May–July temperatures, with hybrid performance shaped by both genetic potential and interannual climatic variability, as confirmed by mixed models and two-factor ANOVA. The superior adaptability of hybrid P9889 supports its inclusion in maize production systems of southern Dobrogea.

A key limitation is the single-location experimental design, which may reflect site-specific pedoclimatic effects, while irrigation partially buffered natural precipitation variability. Future research should expand to multi-location trials, include non-irrigated or controlled water-stress conditions, higher plant densities, a broader hybrid pool, and alternative tillage systems. Integrating predictive thermal-stress models would further improve the assessment of hybrid adaptability under climate change.

CONCLUSIONS

The multi-year study (2022–2025) conducted under the pedoclimatic conditions of the Topraisar area demonstrated that thermal stress during May–July represents the main limiting factor for maize yield, even under irrigated conditions. Interannual climatic variability strongly influenced crop performance, confirming that yield formation in southern Dobrogea is primarily controlled by temperature during the reproductive period rather than by cumulative water availability.

The results highlight that hybrid response to heat stress plays a decisive role in determining yield stability under semi-arid conditions. Differences among hybrids were consistently observed for yield components and biometric traits, indicating that genetic adaptability can partially buffer the negative effects of extreme temperatures. In this context, hybrid P9889 exhibited superior performance across years, reflecting an enhanced capacity to maintain plant density, vegetative growth and ear development under contrasting hydro-thermal conditions.

From a methodological perspective, the combined use of multi-year field experimentation and mixed-model statistical analysis proved essential for separating genetic effects from environmental variability. The significant hybrid $\times$ year interactions underline the importance of long-term evaluations when assessing hybrid adaptability under climate stress, particularly in regions characterized by high interannual climatic fluctuations.

Although minimum tillage combined with irrigation can sustain high yield levels, its effectiveness remains constrained by extreme temperatures during flowering and grain filling. Irrigation mitigates water deficit but cannot fully compensate for the physiological limitations induced by thermal stress, emphasizing the need to integrate technological solutions with appropriate hybrid selection.

For farms located in southern Dobrogea, the adoption of thermotolerant hybrids such as P9889 is recommended to improve yield stability under increasingly frequent heat-wave conditions. Moderate plant densities, together with sprinkler irrigation and soil-conservation technologies, represent suitable management strategies for reducing yield risks in years characterised by pronounced thermal stress.

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