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ASSESSMENT OF MAIZE HYBRID PERFORMANCE AND RAINFALL DISTRIBUTION INFLUENCE ON YIELD UNDER WESTERN ROMANIAN CONDITIONS (BOGSIG, 2024)

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Abstract. *The present study examines the combined influence of genetic and climatic factors on maize yield under the agroecological conditions of Bogsig, Romania, during the 2024 growing season. Eleven maize hybrids representing various FAO maturity groups were cultivated under uniform technological conditions to evaluate the effects of genotype and rainfall distribution on grain productivity and harvest moisture. Over the last century, maize cultivation technology has undergone profound transformation, shaped by genetic progress, technological innovation, and climate adaptation. Genetic improvement remains the foundation of yield advancement. Considerable yield variability was recorded among the tested hybrids, ranging from 4,406 kg ha⁻¹ for SY Pandoras to 9,835 kg ha⁻¹ for SY Atos, revealing a yield amplitude of 5,429 kg ha⁻¹. This variability underscores both the genetic potential of the studied materials and the risk associated with selecting hybrids insufficiently adapted to water-limited environments. The analysis highlights the strong influence of rainfall distribution on yield formation, with summer drought exerting a significant negative impact on less tolerant hybrids. Conversely, drought-resilient genotypes demonstrated superior stability and productivity under the same environmental stress. Overall, the findings emphasize the importance of hybrid selection as a key adaptive strategy for sustainable maize production in regions facing increasing climatic variability. The study provides valuable insights for optimizing hybrid choice to enhance resilience and productivity under changing rainfall regimes typical of continental agroecosystems.*

Keywords*: maize, hybrid performance, rainfall distribution, yield stability, drought stress.*

INTRODUCTION

Maize (*Zea mays* L.) represents a cornerstone of global agriculture due to its versatility, high yield potential, and capacity to adapt to diverse pedoclimatic conditions. As both a strategic food and industrial crop, maize contributes significantly to food security, livestock feeding, and renewable bioresource systems (Shiferaw et al., 2011; Rusu et al., 2022). In Romania, maize occupies more than 2.5 million hectares annually, ranking the country among the largest European producers (INS, 2023).

Over the last century, maize cultivation technology has undergone profound transformation, shaped by genetic progress, technological innovation, and climate adaptation. Genetic improvement remains the foundation of yield advancement. Transitioning from local landraces to hybrid maize led to dramatic increases in productivity, uniformity, and resilience. Breeding programs today focus on developing drought tolerant hybrids with superior water and nutrient use efficiency, disease and pest resistance, and broad adaptability to variable management systems (CAMPOS et al., 2004; BÄNZIGER et al., 2006). Advanced tools such as marker assisted selection, functional genomics, and genome editing (CRISPR/Cas9) have accelerated genetic gains, enabling precise improvement of complex traits associated with yield stability and stress tolerance (SCHEBEN et al., 2017).

Beyond genetics, agronomic innovation has revolutionized maize production systems. Modern crop management integrates conservation tillage, optimized seeding density, balanced fertilization, and precision irrigation practices designed to maximize input efficiency and mitigate environmental degradation (EDGERTON, 2009; RUSU et al., 2019). The introduction of notillage and striptill systems has enhanced soil organic matter, reduced erosion, and improved long-term fertility (DERPSCH & FRIEDRICH, 2009; Lal, 2015). These conservation practices also enhance the soil's capacity to retain water, which is increasingly critical under the erratic rainfall patterns induced by climate change.

Fertilization strategies have evolved toward sustainability and efficiency. Rational nutrient management based on soil testing and crop demand reduces losses and environmental impact. Split nitrogen application (part at sowing and part during the 6–8 leaf stage) has proven optimal for nitrogen uptake. The use of controlled release fertilizers, biostimulants, and microbial inoculants enhances nutrient-use efficiency and soil biological activity while lowering pollution risks (CHEN et al., 2018). Moreover, organic and microelement fertilization improve crop resilience and support long-term soil health.

Water management remains a decisive factor in maize productivity. The crop is highly sensitive to moisture deficits during pollination and grain filling (CAMPOS et al., 2004). In the context of increasing drought frequency, precision irrigation systems (sprinkler, drip) and soil moisture sensors enable real time adjustment of water supply (LI et al., 2020). Simultaneously, soil moisture conservation practices such as mulching and reduced tillage help maintain rhizosphere humidity. Studies indicate that soils covered with crop residues can retain 20–30% more water, significantly improving plant survival under drought (LAL, 2015).

The choice of hybrid plays a fundamental role in yield performance and stability. Selection criteria include adaptation to local pedoclimatic conditions, appropriate FAO maturity group, yield potential, stability across environments, and tolerance to abiotic stress (Bänziger et al., 2006). Modern testing platforms, such as the International Maize and Wheat Improvement Center (CIMMYT), provide valuable multi-environment data supporting hybrid selection (CAIRNS et al., 2013). Highquality certified seed with >95% germination, properly treated with fungicides and insecticides, ensures uniform emergence and early vigor. Recent seed technologies coating with microbial inoculants, growth stimulants, and mycorrhizae enhance nutrient absorption and resilience under stress (GARCÍA-LÓPEZ et al., 2021).

Weed, pest, and disease management remains integral to sustainable maize production. Weed competition severely limits yield through competition for water, nutrients, and light. Integrated weed management combines pre- and post-emergence herbicide applications with crop rotation and mechanical control, maintaining effectiveness while reducing herbicide resistance risks (HEAP, 2023). Similarly, diseases such as fusarium ear rot, smut, and helminthosporiosis, as well as pests like Ostrinia nubilalis and Agriotes spp., are managed through integrated pest management (IPM) combining resistant hybrids, seed treatments, biological control, and targeted pesticide use (OERKE, 2006). These approaches align with EU policies promoting reduced pesticide dependence and environmental protection.

At harvest, ensuring optimal grain moisture (22–25%) is critical to minimize losses and reduce drying costs. Post-harvest management rapid drying to 13–14% moisture, aerated storage, and continuous monitoring preserves grain quality and prevents mycotoxin contamination (*Aspergillus*, *Fusarium*) (MUNKVOLD & HELLMICH, 2018).

From an environmental perspective, sustainable maize systems seek to balance productivity with ecosystem preservation. Conservation tillage, crop rotation, cover crops, and reduced nitrogen leaching are fundamental pillars of this balance. The transition toward low-carbon, resource-efficient systems supports the objectives of the European Green Deal and the Farm to Fork Strategy (EUROPEAN COMMISSION, 2020).

Finally, precision agriculture and digitalization are reshaping the future of maize cultivation. Advanced technologies GPS-guided machinery, drones, satellite imagery, and AIdriven data analytics enable real time crop monitoring and site-specific management (Gebbers & Adamchuk, 2010; Virk et al., 2021). These tools improve decision making and optimize the use of water, fertilizers, and pesticides. Meanwhile, biotechnologies and genome editing techniques (CRISPR/Cas9) open new avenues for breeding resilient, resource efficient hybrids with improved nutritional and agronomic traits (SCHEBEN et al., 2017).

In summary, sustainable intensification of maize cultivation depends on the synergistic integration of genetic progress, precision management, and environmental responsibility. These innovations form the foundation for future agricultural resilience, ensuring both productivity and sustainability under the evolving challenges of climate change and global food demand.

MATERIAL AND METHODS

Experimental Site and Climatic Conditions - The field experiment was carried out in the agricultural year 2024 at the experimental site of Bogsig, located in Arad County, Western Romania (46°16' N, 21°54' E), within the western part of the Banat–Crișana plain. The area is representative of the temperate continental climate, characterized by mild winters, warm summers, and variable precipitation patterns. The mean annual temperature in this region is approximately 10.8°C, while the long-term annual precipitation averages 560–580 mm, unevenly distributed during the vegetation period. Meteorological data recorded during 2024 showed a non-uniform rainfall regime, with an excess of precipitation during spring (March–May: 153.4 mm) followed by a significant deficit in July (30.5 mm) and August (9.7 mm). The total rainfall during the growing season (April–September) reached only 268.9 mm, which classified the year as moderately dry. These climatic conditions induced varying levels of water stress during the maize reproductive stages, particularly during tasseling and grain filling, allowing a realistic evaluation of hybrid drought tolerance.

The experiment was conducted on a chernozem soil, typical of the western Romanian Plain. The soil profile exhibited the following characteristics:

- Texture: clay loam, with balanced sand, silt, and clay fractions;
- Humus content: 3.2–3.8%;
- pH: slightly acid to neutral (6.4–7.1);
- Total nitrogen: 0.18–0.22%;
- Available phosphorus (P_2O_5): 34–38 mg kg^{-1};
- Exchangeable potassium (K_2O): 180–220 mg kg^{-1}.

The soil is deep, fertile, well-aerated, and characterized by good water-holding capacity. The field was uniform in fertility and topography, providing suitable conditions for evaluating the performance of maize hybrids.

The study included 11 maize hybrids belonging to different FAO maturity groups (250–440). The hybrids tested were: SY Pandoras, SY Pamplona, SY Torino, SY Evident, SY Helenor, SY Craft, SY Stacio, SY Atos, SY Marengo, SY Fabio, and SY Minerva.

These hybrids, developed by Syngenta Seeds, represent a wide genetic diversity and maturity spectrum, from early to late hybrids. Their selection was based on commercial importance, genetic variability, and claimed drought tolerance.

The experiment was organized as a randomized complete block design (RCBD) with four replications. Each experimental plot measured 25 m² (5 m × 5 m), and plant density was adjusted according to hybrid maturity class, averaging 70,000 plants ha^{-1} for early hybrids and 65,000 plants ha^{-1} for medium and late hybrids. The field was prepared through autumn plowing (25 cm depth), followed by spring disking and leveling before sowing. Sowing was performed mechanically in mid-April, under optimal soil moisture conditions. Fertilization was carried out based on the nutrient requirements of maize and soil fertility: 120 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, and 60 kg K_2O ha^{-1}, applied in two stages — 50% before sowing and 50% at the 6–8 leaf stage (V6–V8).

Weed control involved the application of pre-emergence herbicides (acetochlor + terbuthylazine) and post-emergence herbicides (nicosulfuron) depending on weed spectrum and crop tolerance.

The crop was maintained under rainfed conditions, without irrigation, allowing for the evaluation of natural hybrid response to water stress.

During the growing season, no major pest or disease outbreaks occurred. The crop was protected through standard prophylactic measures, and no insecticides were required.

At physiological maturity, ears were harvested manually from the central rows of each plot to avoid border effects. The following parameters were measured:

- Grain yield (kg ha^{-1}), corrected to 14% moisture;
- Grain moisture at harvest (%);
- Yield differences and significance relative to the experimental mean.

Grain yield was determined using standard agronomic protocols. Data were subjected to analysis of variance (ANOVA) to test the significance of hybrid effects. Mean separations were performed using Least Significant Difference (LSD) at $p = 0.05$, 0.01, and 0.001 levels.

The statistical analyses were performed using STATISTICA v.13.5 and Microsoft Excel for descriptive and comparative evaluation.

All results were expressed as means of four replications. The experimental error was maintained within acceptable limits, and the coefficient of variation (CV%) confirmed the homogeneity and reliability of the experimental data.

RESULTS AND DISCUSSIONS

Grain yield performance of maize hybrids - The 2024 experimental year in Bogsig was characterized by significant climatic variability, which strongly influenced the yield performance of the maize hybrids.

Grain yield values ranged from 4,406 kg ha^{-1} for the early hybrid SY Pandoras to 9,835 kg ha^{-1} for the high-performing SY Atos, resulting in a yield amplitude of 5,429 kg ha^{-1} (Table 1).

Table 1

Table 1. Grain yield of maize hybrids and statistical significance (Bogsig, 2024)

Hybrid	FAO Group	Yield (kg ha^{-1})	Difference vs. Mean (kg ha^{-1})	Significance
SY Pandoras	250–290	4,406	–3,371	000
SY Pamplona	250–290	7,543	–234	0
SY Torino	300–340	7,854	+77	ns
SY Evident	400–440	8,334	+557	xx
SY Helenor	250–290	8,313	+536	xx
SY Craft	300–340	8,707	+930	xxx
SY Stacio	350–390	8,987	+1,210	xxx
SY Atos	300–340	9,835	+2,058	xxx

SY Marengo	350–390	7,854	+77	ns
SY Fabio	400–440	8,758	+981	xxx
SY Minerva	400–440	8,485	+708	xxx
Field average	—	7,777	—	—
LSD 5% = 189 kg ha⁻¹; LSD 1% = 287 kg ha⁻¹; LSD 0.1% = 576 kg ha⁻¹				

The statistical analysis showed highly significant differences ($p < 0.001$) among hybrids. The hybrids SY Atos, SY Craft, SY Fabio, SY Stacio, SY Helenor, and SY Minerva yielded significantly above the field average, confirming superior genetic adaptability to moderate drought stress.

Conversely, SY Pandoras and SY Pamplona exhibited reduced productivity, demonstrating their limited adaptability under water-limited conditions.

These results are consistent with previous research highlighting that hybrid selection strongly determines yield stability under environmental constraints (CAMPOS et al., 2004; BÄNZIGER et al., 2006).

Influence of FAO maturity group on yield stability - Yield performance by FAO maturity group revealed a clear trend (Figure 1).

Early hybrids (FAO 250–290) recorded lower yields (mean: 6,400 kg ha^{-1}) compared to intermediate (FAO 300–340; 8,000 kg ha^{-1}) and late hybrids (FAO 350–440; >8,400 kg ha^{-1}).

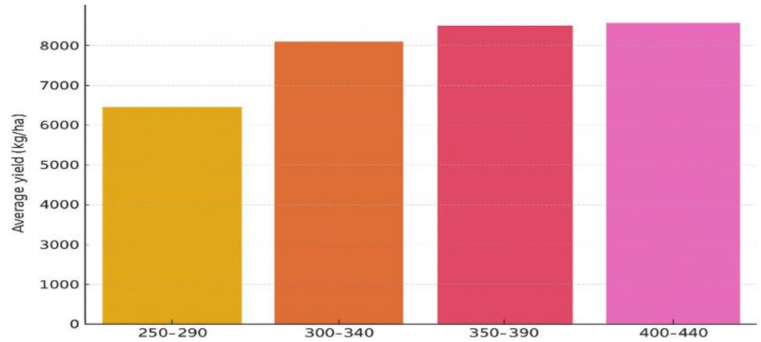

Figure 1. Average maize yield by FAO group

The yield increase with hybrid maturity is attributed to the longer vegetation period and extended grain filling phase, which allow superior biomass accumulation and kernel weight. However, under severe summer drought, late hybrids may face challenges in completing grain maturation, leading to potential yield penalties (CAIRNS et al., 2013).

In 2024, climatic conditions allowed full maturation even for late hybrids, favoring the highest yields for SY Atos, SY Stacio, and SY Fabio. These findings confirm that hybrid maturity must be aligned with local climatic risk to optimize both yield potential and harvest stability.

Grain moisture at harvest - Grain moisture at harvest is a key technological and economic indicator. Values ranged between 9.3% and 11.6%, with a field average of 10.1% (Table 2).

Hybrids such as SY Fabio, SY Atos, and SY Minerva achieved optimal grain moisture below 10%, representing favorable traits for mechanized harvesting and reduced post-harvest drying costs. Conversely, SY Pandoras had the highest moisture level (11.6%), correlating with its lower yield and early maturity. Similar patterns were reported by MIHĂIESCU et al. (2019), who found that high-yielding maize hybrids often maintain lower grain moisture at harvest, indicating efficient water remobilization and physiological maturity synchronization.

Table 2

Table 2. Grain moisture content at harvest by hybrid and FAO group

Hybrid	FAO Group	Maize moisture
Y Pandoras	250–290	11.6
SY Pamplona	250–290	10.3
SY Torino	300–340	9.8
SY Evident	400–440	9.8
SY Helenor	250–290	9.6
SY Craft	300–340	10.0
SY Stacio	350–390	10.3
SY Atos	300–340	9.7
SY Marengo	350–390	10.3
SY Fabio	400–440	9.3
SY Minerva	400–440	9.6

Relationship between rainfall distribution and yield - The rainfall pattern in 2024 exhibited pronounced irregularity, with adequate rainfall during vegetative growth followed by severe deficits in mid-summer. The cumulative precipitation between June and August was only 115.7 mm, a critical threshold for maize reproduction. Yield losses during this period were primarily associated with pollination stress and incomplete kernel development.

Figure 2 illustrates that July and August rainfall deficits coincided with the reproductive stages (VT–R3), causing significant yield differentiation among hybrids.

Hybrids with enhanced drought tolerance (SY Atos, SY Stacio, SY Fabio) maintained higher productivity due to improved root system efficiency and stay-green characteristics — traits also emphasized by CAMPOS et al. (2004) and FAROOQ et al. (2014).

The correlation between rainfall and yield confirms that maize production in this area is highly dependent on seasonal rainfall distribution, not only total precipitation. This underlines the need for region-specific hybrid recommendations and potential irrigation strategies in dry years.

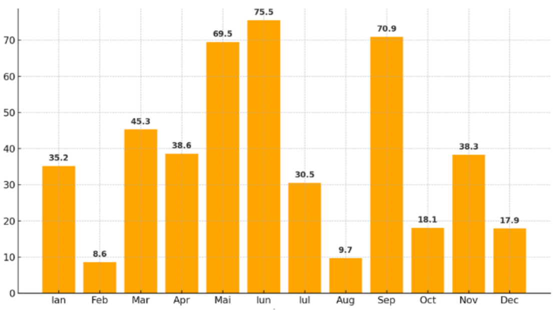

Figure 2. Monthly rainfall distribution, at Bocsig 2024

The performance of maize hybrids under the 2024 conditions aligns with the broader literature on genotype × environment interactions in maize.

Studies across Eastern Europe and the Mediterranean basin report yield reductions of 30–50% under similar drought conditions when non-adapted hybrids are used (ROTARU et al., 2023).

CAIRNS et al. (2013) emphasized that hybrids with drought-tolerant traits can maintain 70–80% of their potential yield under moderate water stress, consistent with the yield resilience observed in SY Atos and SY Fabio.

Likewise, research by CIULCA et al. (2019) and ROTARU et al. (2023) highlighted that hybrid adaptability depends on both genetic stability and agronomic plasticity—traits clearly visible in the top-performing hybrids of this study.

Overall, the findings confirm that hybrid selection and rainfall pattern are the dominant factors influencing maize yield variability under the climatic conditions of Western Romania. Integrating drought-tolerant hybrids, conservative soil management, and precision fertilization can significantly improve yield stability and sustainability in maize-based systems.

CONCLUSIONS

The findings of the field experiment conducted in 2024 at Bogsig, Arad County (Western Romania), clearly demonstrate that the interaction between hybrid genotype and climatic conditions is a determining factor in maize productivity under rainfed conditions.

The experimental year was characterized by a non-uniform rainfall distribution, with excessive precipitation during spring followed by severe moisture deficits in July and August. This pattern significantly influenced yield variability, highlighting the decisive role of water availability during the critical growth stages of pollination and grain filling.

Among the eleven hybrids evaluated, substantial differences were observed in grain yield performance, with values ranging from 4.4 t ha^{-1} (SY Pandoras) to 9.8 t ha^{-1} (SY Atos). Statistical analysis (ANOVA) confirmed that these differences were highly significant ($p < 0.001$), reflecting the contrasting genetic potential and adaptability of the tested genotypes.

The hybrids SY Atos, SY Stacio, SY Fabio, and SY Craft demonstrated superior drought tolerance, maintaining high yields despite the water deficit, whereas early-maturing hybrids (SY Pandoras, SY Pamplona) recorded lower yields, indicating limited adaptability to the dry summer conditions.

The analysis of yield by FAO maturity group revealed a consistent trend of increasing yield with hybrid maturity. Late hybrids (FAO 350–440) produced the highest average yields (8,400–8,500 kg ha^{-1}), benefiting from a longer vegetative period and extended grain-filling phase. Early hybrids matured faster and showed lower grain moisture at harvest (below 10%), which may represent a technological advantage for mechanized harvesting and post-harvest management in cooler or shorter growing seasons.

Soil fertility and uniformity across the experimental field ensured that yield differences were mainly attributable to genotypic variation and climatic influence, not edaphic heterogeneity. The experimental chernozem soil, with balanced nutrient supply and high water-holding capacity, provided a favorable base for hybrid differentiation.

Grain moisture content at harvest ranged from 9.3% to 11.6%, with the lowest values recorded for SY Fabio and SY Minerva. These results emphasize that high-yielding hybrids can simultaneously achieve lower grain moisture at harvest—a valuable trait that reduces drying costs and improves economic efficiency.

The correlation between rainfall distribution and yield confirmed that seasonal rainfall patterns, rather than total annual precipitation, represent the critical determinant of maize performance. Rainfall shortages during July–August coincided with a reduction in grain set and kernel filling in early hybrids. This supports the need to recommend region-specific hybrid assortments—combining early and late genotypes—to mitigate climatic risks and ensure yield stability across variable growing seasons.

From a broader perspective, the study highlights the importance of genetic progress and technological adaptation in sustaining maize productivity under the emerging challenges of climate change.

Future improvements in hybrid breeding—particularly for drought tolerance, stay-green traits, and efficient nutrient use—should be combined with conservation tillage, precision fertilization, and water-saving irrigation practices to enhance resource efficiency and environmental sustainability.

In conclusion, the 2024 Bogsig experiment confirms that: hybrid genotype is the main source of yield variability under rainfed conditions; FAO maturity group strongly influences both yield potential and grain moisture content; rainfall distribution, especially during reproductive stages, is the primary climatic constraint on yield stability; the adoption of drought-tolerant hybrids combined with sustainable management practices (minimum tillage, balanced fertilization, and timely sowing) can ensure consistent maize yields and improve resilience to climatic stress.

The outcomes of this research provide valuable insights for maize breeding programs, regional hybrid recommendation systems, and sustainable crop management strategies in Western Romania and similar agro-climatic regions of Central and Eastern Europe.

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