Scientific Papers. Series A. Agronomy, Vol. LXVIII, No. 1, 2025
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

EFFECT OF METEOROLOGICAL CONDITIONS ON THE PRODUCTIVITY OF MAIZE HYBRIDS OF DIFFERENT MATURITY GROUPS

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Abstract

The work aimed to study the productivity of maize hybrids from maturity groups FAO 300 to 600 under different conditions. A four-year experiment was carried out at Maize Research Institute Knezha, Bulgaria. The hybrids Kneja 310, Kneja 461, Kneja 565 and Kneja 683 A were grown under non-irrigation conditions and with approval for the regional agricultural technology. Two-factor analysis of variance was used to find the effect of both hybrid and environment on the grain yield. In addition, Stability Yield Index (SYI) was calculated. The amount of rainfall per growing season varied from 199.8 to 316.1 mm/m^2, and grain yield averaged for the tested hybrids by years varied from 859.7 to 1040.7 kg/da. The highest average grain yield over the period was obtained from Kneja 565 (1003.9 kg/da) and the lowest - from Kneja 310 (900.3 kg/da), respectively. Kneja 683 A hybrid showed the low Stability Yield Indices, 0.685 followed by Kneja 565 0.729 values, respectively. Relatively high and stable yields were obtained from Kneja 310 (900.3 kg/da) and Kneja 461 (925.9 kg/da) with SYI 0.937 and 0.841, respectively.

Key words*: grain yield, maize, Stability Yield Index.*

INTRODUCTION

The climate changes we are all witnessing are affecting maize productivity (Christensen et al., 2013; Elbehri et al., 2015). Some model projections identify grain maize as one of the crops most vulnerable to climate change in Europe (https://www.actualno.com/climate/klimatichni-promeni-kak-shte-povlijajat-na-uslovijata-za-otglejdane-na-carevica-u-nas-news_2073706.html). The growing season of maize is located in spring and summer when the daylight hours are longest, the maximum temperatures are highest, and rainfall is unevenly distributed with an annual maximum in May and June. Prolonged droughts are common occurrence in July, August and September. The crop's productivity is very dependent on temperature and rainfall during the growing season and especially during the critical stages of its development. Later in its development, it is less demanding of moisture, but highly sensitive in the silking and flowering stages, when it uses up nearly 50% of the water required for the entire growing season. Lack of moisture during flowering has a negative effect on pollination, and the water deficit during grain formation and filling affects grain size.

Current research and models are bringing to the fore resistant and adaptable varieties and hybrids, as well as the right choice of vegetation group of maturity suitable for each region (Cairns et al., 2013). The preference is for hybrids with early flowering (before the intense heat) and short growing season, also suitable as second crops, with a vigorous start, resistant to stress and disease, and diversity in the crop for better pollination. During flowering, the optimum temperature is 25-28°C, values of 30-35°C, combined with low atmospheric humidity, adversely affect pollen viability.

Productivity is important, but also yield stability. High and stable yield is a very important characteristic of maize cultivars. A stable cultivar yield means that its rank relative to other cultivars remains unchanged in a given set of one environment during several years. Some results revealed that high-yielding cultivars also can be stable cultivars (Abera et al., 2006).

Our study aimed to establish the performance of maize hybrids of FAO 300 to FAO 600 maturity group under different agrometeorological conditions.

MATERIALS AND METHODS

The experiment was carried out at the experimental field of Maize Research Institute - Knezha, Bulgaria under non-irrigated conditions during the period from 2020 to 2023. Four hybrids from FAO 300 to FAO 600 maturity groups were tested as follows: Kneja 310, Kneja 461, Kneja 565 and Kneja 683A, all of them part of the breeding collection of the Institute. A block method was used, 4 replications, the size of the experimental plot was 10 m^2 and the density of 5300 plants/da. The soil type was typical chernozem. The standard technology of growing of maize was applied.

Meteorological conditions, viz. rainfall and daily average temperature of growing seasons, were recorded. In addition, the meteorological conditions for a long-term period (1991-2020) were shown. Hydrothermal Coefficient (HTC) was calculated for the reproductive stage (sum of precipitation and accumulated sum of daily temperature from last decade of June and all days of July) for each year of study. To calculate the Hydrothermal coefficient the next formula, as suggested Selyaninov, was applied: HTC= $\Sigma x / \Sigma t \times 10$; where Σx and Σt – accordingly sum of precipitations and temperatures in the period. The interpretation of the hydrothermal coefficient according to Selyaninov was based on the following: HTC from 1.0 till 2.0 – humidity is sufficient; HTC > 2.0 – immoderately humid; HTC < 1.0 – insufficient humidity; HTC from 1.0 till 0.7 – dry; HTC from 0.7 till 0.4 – very dry.

The grain yield was calculated in kg/da and it was reported at moisture content of 14%. Factorial regression was performed to obtain a biological explanation of the hybrid, environment, and hybrid - environment interaction for the yield. Stability yield index (SYI) was applied to determine hybrid yield stability. The formulae as suggested Singh et al. (1990) was used: SYI (Sustainable yield index) = (Ym - Sd)/Ymax, where Ym – mean yield; Sd – standard deviation; Ymax – the maximum yield. Statistical analysis of the experimental data using ANOVA without and with replication processing was performed using the SPSS 20.0 software product for Windows.

RESULTS AND DISCUSSIONS

The agrometeorological conditions during the growing season are a very important factor significantly affecting the growth, development and productivity of maize. The meteorological conditions comprising the growing season of maize over a long-term period (30 years) are presented in Figure 1. From the data, it can be seen that the mean daily temperature increases gradually from April to July and August. The most significant temperature difference was found between April and May (4.1°C), while between May, June and July it was about 3°C. The highest monthly mean daily temperatures were recorded in the typically summer months of July and August, with values very similar.

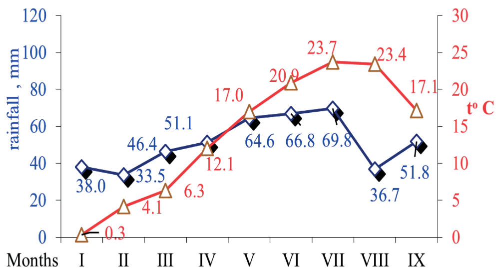

Figure 1. Meteorological conditions including the growing seasons of maize for the long term 30 years period 1991-2020

Monthly rainfall totals increase from the beginning of the growing season in April to July, again with the most significant difference between April and May (about 14 mm), while between May, June and July (65, 67 and 70 mm), the difference ranged from 2 to 5 mm. A significant decrease in the rainfall total for this long-term average period was recorded in August (37 mm), with a total for the growing season of 289.0 mm.

For the 2020-2023 study period, the meteorological conditions during the maize growing season by year are presented in Table 1. A gradual increase in mean daily temperature occurs from April to July and August. In May and June the temperature was above 16°C and above 20°C, respectively, with higher values of 17.4°C and 21.6°C only in 2022.

Comparing the differences of the monthly mean daily temperatures of April and May over the long-term period with those of the study years, the differences were found to increase from 4.1°C to 5.0°C, 6.0°C, 6.2°C and 5.0°C for 2020, 2021, 2022 and 2023, respectively. This accelerated warming at the beginning of the growing season in four consecutive years is indicative of a change in the environmental conditions during the vegetative stage of crop development. In addition, July 2023 was 0.25°C above the record - since measurements began in the world at large.

The temperatures were found highest in July, with only 2020 recording a higher value for August (23.5°C). The average temperature for the growing season was about 19.0, with only that in 2022 close to 20°C. The highest average daily temperature values were in July (24.1°C) and in August (23.9°C). Maitaha et al. (2021) found that yield was negatively correlated with temperatures in July and August. The high temperatures in July coincide with the reproductive stage of maize development, which can have an extremely negative effect on the yield as also suggested by Shiduo et al. (2024).

In terms of precipitation, over the four-year study period, precipitation amounts ranged from 199.8 to 316.1 mm for 2020 and 2021, respectively (Table 1).

Table 1. Agrometeorological conditions during the growing seasons of maize for the period 2020-2023

Months/ Years	2020	2020	2021	2021	2022	2022	2023	2023
	mm	to °C	mm	to °C	mm	to °C	mm	to °C
IV	8.9	10.7	46.9	9.15	67.3	11.0	45.6	10.9
V	38.7	16.7	82.0	16.9	35.1	17.4	71.5	16.1
VI	75.7	20.7	95.4	20.6	75.1	21.6	92.6	20.4
VII	49.4	22.9	35.2	24.3	7.5	24.7	71.3	24.6
VIII	27.1	23.5	56.9	23.9	74.8	24.2	23.8	24.2
Sum/av	199.8	18.9	316.4	19.0	259.8	19.8	304.8	19.2
CV%	62.5	28.1	39.3	32.9	57.4	28.8	43.7	30.1

The month with the highest monthly rainfall amount was June and has the least variation during the period 2020-2023, while the month with the lowest amount was July and has the highest variation. On average over the period, the highest rainfall amount was recorded in the months of May and June, while in the remaining months the rainfall amount values were similar (above 40 mm).

It is evident the precipitation was very irregularly distributed by months. The total precipitation amounts for the growing season fluctuated by year. The coefficient of variation (CV%) for precipitation ranged from 39.3 to 62.5% and was significantly higher than that for mean daily temperature, which ranged from 28.1 to 32.9%. The smallest amount of precipitations was recorded in 2020, being 26% less than the average for the period. The highest precipitations as a sum were recorded during 2021 and 2023, exceeding the average for the period by 17 and 13%, respectively.

Undoubtedly, precipitation is the most important factor influencing the maize grain yield (Huang et al., 2015). How this precipitation both by month and as total sum, influenced the maize growing and development and also the yield of grain is not so clear. To clarify the importance of precipitation, we calculate the hydrothermal coefficient as suggested by Selyaninov (1928) for the main stages of the reproductive period of maize (Figure 2). For the location of Knezha this period begins relatively from June 20th and continues throughout the whole month of July. The calculation of the ratio of the average daily temperature sum and the precipitation through HTC characterizes in more detail the conditions in which this important reproductive stage of development of maize occurs (Qiao et al., 2025).

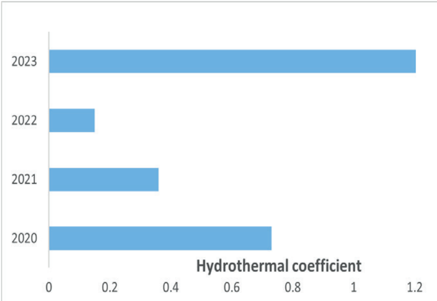

Figure 2. Hydrothermal coefficient of Selyaninov for the vegetation period of maize

It is evident from the HTC calculated values by year that they do not correspond to the rainfall amounts during the growing season. For example, the 2020 growing season has the least amount of rainfall (199.8 mm), but this during the reproductive stage together with the temperature amount formed a coefficient of 0.73, while the 2021 growing season has the highest amount of rainfall (316.4 mm), the HTC coefficient was twice as low (0.36). The lowest hydrothermal coefficient for the reproductive stage was recorded in 2022 (0.15), despite the close precipitation amount to the average for the growing season (259.8 mm). This is mainly due to the scanty rainfall in July of 2022. The highest value of HTC was recorded in 2023 due to significant rainfall during the last ten days of June and the whole month of July.

Weather conditions affect the formation of grain yield of maize. The reported grain yields of maize hybrids are presented in Table 2. Many authors confirm the influence of weather conditions on maize grain productivity (Wei et al., 2021; Rajičić et al., 2024). In the last 25 years, grain yield has become increasingly dependent on weather conditions during the maize growing season, which have often involved "extreme climate events" (Bekavac et al., 2010).

Table 2. Grain yield from maize hybrids (kg/da)

Hybrid/ Year	2020	2021	2022	2023	Average	SYI
Kn 310	831.3	911.1	893.1	965.8	900.3	0.937
Kn 461	911.4	901.6	898.5	992.4	925.9	0.841
Kn 565	894.4	1058.7	893.4	1168.9	1003.9	0.729
Kn 683A	905.1	802.3	753.9	1035.8	874.3	0.685
Average	885.6	918.4	859.7	1040.7	926.1	
CV%	4.16	11.51	8.21	8.67	6.04	
LSD 0.05	38.9	110.5	114.3	138.9	68.9	

Grain yields in the first experimental year varied within a relatively narrow range (from 831.3 to 911.4 kg/da for Kneja 310 and Kneja 461, respectively). The HTC value was 0.73, which defines the conditions of the year at the generative stage of maize development as dry. In such a year, our data showed that the variation of grain yields was low (CV% 4.16). Under very dry conditions in this period, such as those of the experimental year 2022 (HTC 0.13), yield variation was also low (CV% 8.21) and all hybrids tested (except for Kneja 683A) had similar yields. In 2021 at HTC 0.36, yield variation was average in strength (CV% 11.51), with the highest yield recorded in Kneja 565 (1058.7 kg/da). In the fourth year, which was meteorologically the most favourable, the highest yields were also recorded. For the Kneja 565 hybrid the yield reached 1168.9 kg/da.

On average for all hybrids, the highest yield was obtained in 2023 (1040.7 kg/da), which is 12.4% more than the average yield obtained over the entire four-year experimental period. This was followed by the yield in 2021 (918.4 kg/da), with the lowest yields in 2022 and 2020. Then the amount of grain obtained is 859.7 and 885.6 kg/da, or 7.2 and 4.4% lower than the average for the period in the absence of statistical evidence.

Comparing the average yields of the tested hybrids by year with the recorded rainfall during the maize growing season (April-August), there is some correspondence of the amount of rainfall with the average yields obtained. For example, the highest average yields in 2023 and 2021 were consistent with the highest amounts of rain recorded during the growing seasons, 304.8 and 316.4 mm, respectively. The rainfall totals of 259.8 and 199.8 mm in 2022 and 2020 produced the lowest average yields.

The highest average yields in 2021 and 2023 were with a difference of more than 120 kg. In 2023, rainfall amounts are very similar.

Looking at the rainfall amounts by month of the growing season, it is clear that the amounts in April, May and June are very close. However, the differences in July and August are significant. In July of 2021, the rainfall is twice that of 2023 (35.2 and 71.3 mm), while in August it is the opposite - twice the amount in 2021 (56.9 mm) compared to 23.8 mm in 2023.

In April of 2020, rainfall was only 8.9 mm, while that in 2022 was 67.3 mm. In May and June the amounts were similar, but in July the amount in 2020 was many times greater at 49.4 mm (over 5 times) compared to 2022's amount of only 7.5 mm. In August, the amount of precipitation in 2020 was over 2 times less than in 2020.

In 2022, the lowest average yield was obtained (859.7 kg/da) with a sum of rainfall during the growing season of 259.8 mm, while the yield in 2020 was 885.6 kg/da and the sum of rainfall (199.8 mm) was the lowest for the entire study period.

The yields of the tested maize hybrids over the years were influenced by the meteorological conditions during the growing season and especially during the period of pronounced formation of the reproductive organs; therefore, to enrich the discussion, we monitored the amounts of rainfall and the average daily temperature sum during the last ten days of June and the whole month of July, expressed by the

Selyaninov's hydrothermal coefficient (mentioned above). This coefficient helps to explain the results obtained in yields more thoroughly than the sum of rainfall over the whole growing season. For example, the highest average yield in 2023 is a consequence of a large amount of rainfall during the growing season. The next highest average yield is in 2021 and with the highest amount of rainfall (316.4 mm), but with an HTC of 0.36.

It is confirmed that the yields of the tested hybrids over the years depend on the weather conditions. Relating the yields to the values of the calculated HTC, it is evident that the highest results were obtained in 2023, when the sum of precipitation was 204.8 mm and the HTC during the generative period was 1.26, while the lowest yields were obtained from the hybrids in 2022, with a sum of precipitation during the growing season of 259.8 mm and the lowest HTC value of 0.15. In this experimental year, it is noteworthy the insignificant decrease in the yield of hybrid Kneja 310 (893.14 kg/da), compared to the average yield for the period (only 0.8%), while for the other hybrids the decrease was 3% for Kneja 461, 11% for Kneja 565 and 13.8% for Kneja 683A.

The productivity exhibited under specific climatic conditions during a particular period with different weather conditions can be estimated by the Sustainable Yield Index (SYI) calculated by a formula proposed by Singh et al. (1990). Though only a four-year study period, but with distinctly different agrometeorological conditions, we can estimate the yield stability of the tested hybrids. The reported values for this index reflected in Table 2 show the least deviation from the period average yield for hybrid Kneja 310 at 0.937, followed by the index of Kneja 461 at 0.841. With a lower stability index is hybrid Kneja 565 - 0.729 as a consequence of the larger range of yield variation from 893.4 kg/da in 2022 to 1168.6 kg/da in 2023. The lowest yield stability index is Kneja 683A - 0.685. Impressively, as the FAO maturity group advanced, the yield stability index decreased. This suggests that earlier hybrids have more stable yields. Our results are in agreement with Božović et al. (2020).

The analysis shows that the greatest influence on maize grain yields is the amount of rainfall during the generative stage.

From the bivariate analysis of variance (Table 3), it is evident that the largest proportion of the total variance (102618.8) is due to the conditions of the year. The specific genotypic responses exhibited by plants of different maize hybrids also showed high variation due to selection of different maturity group (FAO 300 to 600). The magnitude of the effect of the interaction of species and year traits was better manifested at $P<0.01$. Productivity was more determined by the factor of year conditions but also by the FAO group of the hybrid. The studied interaction of the two factors conditions of the year and hybrid appears to be a useful estimate of the adaptability of the hybrid depending on the realized productivity potential of its years of the period. A reliable interaction of year conditions and hybrid was found.

Table 3. Analysis of variance of the grain yield (ANOVA)

Source of Variation	SS	Df	MS	F	P-value	F crit	Factor influence
Year	307856.3	3	102618.8	24.8	8E-10	2.8	37.823
Hybrid	150371.4	3	50123.8	12.1	5E-06	2.8	18.474
Interaction	157277.3	9	17475.2(	4.2	0.0005	2.1	
Within	198444.1	48	4134.25				
Total	813949.1	63				Error	43.703

The analysis shows that the greatest influence on maize grain yields is the amount of rainfall during the generative stage.

The two-factor analysis of variance applied to the maize hybrids tested revealed an interaction of the two factors (FAO conditions of the year and hybrid type) that significantly influenced maize productivity. The data showed a stronger influence of the year conditions factor compared to hybrid type on productivity.

CONCLUSIONS

The highest average grain yield over a four-year study period was shown by the hybrid Kneja 565 (1003.9 kg/da) with a high yield stability index SYI 0.729. Relatively high and stable yields were obtained from Kneja 310 (900.3 kg/da, SYI 0.937) and Kneja 461 (925.9 kg/da, SYI 0.841), respectively. The factor of year conditions had a stronger influence on grain yield of maize compared to hybrid.

In years with favorable conditions during the maize growing season, higher yields were obtained from hybrids in the mid- and late maturity groups, and in unfavorable years from those in the early and mid-early maturity groups.

ACKNOWLEDGEMENTS

This research work was carried out with the support of the Agricultural Academy – Sofia, Bulgaria.

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