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IMPACT OF THERMAL REQUIREMENT ON GROWTH AND GRAIN YIELD OF MAIZE HYBRIDS UNDER RAINFED CONDITIONS

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Abstract

In Oltenia region, maize productivity is highly affected by increasing average temperature and the uneven distribution of rainfall. The suitable hybrid is one of the main adaptation strategies for maize crop for managing the climatic changes. In this study, a field experiment was conducted in rain-fed conditions during 2018 and 2019 at ARDS Simnic to evaluate the accumulated growing degree days (GDD), phenothermal index (PTI) and heat use efficiencies (HUE) at different phenological stages (emergence, tasseling, silking and physiological maturity) and grain yield (GY) of three maize hybrids. The results revealed that among different thermal indices, GDD, PTI and HUE at physiological maturity stage better explained the variations in grain yield across the different growing seasons (96.6%, 93.1% and 99.7%, respectively). Therefore, these thermal indices could be used as the best indices for selection of heat tolerant hybrids for this region. Among the studied hybrids, Pioneer P0216 and Monsanto DK 5068 produced higher yields while accumulated maximum GDD, PTI and HUE at different phenological stages.

Key words: *growing degree days, heat use efficiencies, phenological stages, phenothermal index.*

INTRODUCTION

Maize (*Zea mays* L.) is the second most important cereal crop in the world after wheat and is mainly grown for food, feed and as an industrial raw material. Global climate changes are increasingly affecting maize yield and raising future food security concerns.

In Romania, maize occupies around 2,442 thousand hectares with total production of 18,664 thousand tons and grain yield of 7 641 kg/ha (Bonea, 2020a). In the central part of the Oltenia region, drought and heat stresses causes substantial yield reductions of up to 60.5% in maize (Bonea & Urechean, 2017).

Characterizing and better understanding crop phenology is crucial for field crop management practices. Adaptation strategies, such as the use of suitable cultivars can help in reducing impacts of climate change (Aggarwal, 2008).

The phenological stages could be used to indicate whether a cultivar can be grown commercially in a certain area (Tojo-Soler et al., 2005). The rate of crop growth through the different phenological stages is a function of its response to temperature and rainfall (Bonea, 2020b; Kamal et al., 2017; Urechean & Bonea, 2017).

Temperature, photoperiod and genetic response to the environmental factors, greatly influence growth, development and production of a crop. The knowledge on the calculation of the heat unit requirement under field conditions, mostly called the growing degree days (GDD) and their further mathematical derivations like phenothermal index (PTI) and heat use efficiencies (HUE) are the basic principles to describing and understand the phenological behaviour of different crops in specific environment (Fealy and Fealy, 2008; Matzarakis et al., 2007; Rajput et al. 1987; Sreenivas et al., 2010; Tojo-Soler et al., 2005). The PTI helps in evaluating relative performance of different cultivars under high temperature conditions (Rathod & Chimmad, 2016). Pramanik & Sikder (2020) reported that for evaluation of crop yield potential in different growing conditions, quantification of HUE is necessary.

Thus, due to climatic changes, is crucial to have knowledge of exact duration of phenological stages in a particular crop growing environment and their impact on yield of crop (Dangi & Shrestha, 2018). Also, little is known about the relationship between thermal

indices and maize yield under current environmental conditions of the Oltenia region.
In present study, investigation was carried out to evaluate the performances of different maize hybrids in relation with duration of phenological stages, thermal indices and grain yield, as well as to select the most suitable hybrids for this region.

MATERIALS AND METHODS

The field experiments were conducted during growing seasons of 2018 and 2019 at Agricultural Research and Development Station (ARDS) Simnic, Craiova. The study area is located at $44^{0}19'$ N latitude, $23^{0}48'$ E longitude, and 182 m altitude in the central part of the Oltenia region, Romania.
The experiment was laid out in a randomized block design with three replications. Three semi-late maize hybrids: Fundulea F 376, Pioneer P0216 and Monsanto DK 5068 were used in this study. These maize hybrids are among the most cultivated ones in this region due to high productivity. The crop was sown on 24 April 2018 and 17 April 2019, respectively. The soil of the experiment area is a reddish preluvosoil with pH=5.8. All the recommended agronomic practices for this area were followed.
Whole growth cycle of maize hybrids was categorized into four different phenological stages *viz*., emergence stage, tasseling stage (appearance of tassels in 75% of the plants in each plot), silking stage (appearance of silks in 75% of the plants in each plot) and physiological maturity stage (appearance of a black layer at base of the grain).
The daily weather data records were collected from the Craiova Meteorological Station.
The thermal indices at different phenological stages based on grain yield were calculated according to the following formulas (Amgain, 2011):

Growing degree days (GDD):

$$GDD = \sum_{i=1}^{n}\left(\frac{Tmax+Tmin}{2}\right) - Tb$$

were Tmax =Daily maximum temperature (°C);
Tmin = Daily minimum temperature (°C);
Tb = Base temperature = 10°C

Phenothermal index (PTI):

$$PTI = \frac{GDD}{growth\ days}$$

Heat use efficiency (HUE):

$$HUE = \frac{GY}{GDD}$$

were GY = grain yield (kg/ha)
The recorded data for grain yield were subjected to Fisher's analysis of variance technique (ANOVA) and means were compared for significance using Duncan's multiple range tests at 5% level of probability. The relationship between the thermal indices with the grain yield was described by Pearson's correlation coefficients and by linear regression.

RESULTS AND DISCUSSIONS

Weather conditions

The weather data showed more favorable environmental conditions for the growth and development of maize in 2018 as compared to 2019 (Table 1). In 2018, April, May and August were dry, but June and July were wet with frequent rainfall. Temperature in July was below multiannual average (-1.2°C), but in the rest of the growing season it was significantly warmer than the multiannual average, especially in April (+4.4°C). The growing season ended with a surplus of rainfall (+38.5 mm) and was 1.6°C warmer than the multiannual average. In 2019, the rainfall deficiency was of -49.6 mm as compared to multiannual average, largely pronounced in April, May, July and August. The mean monthly temperatures were over the multiannual average in August (+2.6°C).

Table 1. Rainfall distribution and average temperature for 2018 and 2019 at ARDS Simnic

Item	Year	April	May	June	July	August	Sum/average 1.04 – 31.07
Rainfall (mm)	2018	-42.0	-20.7	+67.4	+52.8	-19.0	366.1
	2019	-11.1	-39.7	+62.4	-23.2	-38.0	278.0
	Multiannual average	53.1	71.7	73.6	82.2	47.0	327.6
Temperature (°C)	2018	+4.4	+1.7	+0.1	-1.2	+1.2	21.1
	2019	-0.3	-1.3	-1.2	-0.9	+2.6	19.8
	Multiannual average	12.2	17.5	21.5	23.8	22.5	19.5

Phenology of maize hybrids

The duration of phenological stages over two-year observations are presented in the Table 2. The results indicated that the duration of the growing cycle (number of days from sowing to physiological maturity) was affected by the growing conditions of the years, but also by the hybrids.

In the growing conditions of 2018, the time from sowing to emergence was similar in two hybrids, Fundulea F 376 and Pioneer P0216 (16 days).

Relatively more days to tasseling (72) and silking (74 and 73) were recorded by Fundulea F 376 and by Pioneer P0216, while lesser days were taken by Monsanto DK 5068 (69 and 70 days, respectively). Monsanto DK 5068 required the highest number of days for physiological maturity (130 days) followed by Pioneer P0216 (129 days), while Fundulea F376 required the lowest number of days (125 days).

In 2019, the time from sowing to tasseling and the time from sowing to silking were similar in hybrids Fundulea 376 and Monsanto DK 5068 (83 and 85 days, respectively), while Pioneer P0216 required 91 and 90 days, respectively.

On average, the number of days from sowing to plant emergence was 16.3 for 2018, and was slightly increased to 17.0 days for 2019.

However, the greatest effect of growing conditions was observed in the number of days from sowing to tasseling and in the number of days from sowing to silking, which have increased from 71.0 days and from 72.3 days in 2018, to 85.66 days (21% increase) and to 86.66 days, respectively (19.8% increase) for 2019. Also, the number of days from sowing to physiological maturity was reduced from 128 days in 2018, to 124.33 days in 2019.

The drought and heat stresses during July and August 2019, hastened physiological maturity reducing the duration of phenological development during grain filling period (from silking to physiological maturity). Similar results for maize under high temperatures conditions were reported by Castro-Nava et al. (2011) and Bonea (2020b). High temperatures accelerates growth rate shortening growth stages and reducing grain yield (Hamid et al., 2020). White and Reynolds (2003) found that reduction in the length of the growth cycle, especially the grain-filling period, is the most important factor in explaining reduced yields at warmer temperatures.

Table 2. Phenological calendar of maize hybrids (days)

Year	Hybrids	Emergence	Tasseling	Silking	Physiological maturity
2018	Fundulea F 376	16	72	74	125
	Pioneer P0216	17	72	73	129
	Monsanto DK 5068	16	69	70	130
	Mean	16.3	71.0	72.3	128.0
2019	Fundulea F 376	16	83	85	123
	Pioneer P0216	18	91	90	126
	Monsanto DK 5068	17	83	85	124
	Mean	17	85.7	86.7	124.3

Growing degree days (ºC days)

The accumulated heat units (GDD) of maize at different phenological stages by different hybrids are presented in Table 3. The GDD was increasing from early stages to late stages. Similar results were reported by Amgain (2011) and Bonea (2020b).

In 2018, the Monsanto DK 5068 had the highest GDD requirement for attaining physiological maturity (1483.5 ºC day) followed by Pioneer P0216 (1469.5 ºC day) and Fundulea F 376 (1415.5 ºC day), but had the lowest GDD requirement for tasseling (685.0 ºC day) and silking (698.0 ºC day).

Due to the large deficit of rainfall and temperatures above the multiannual average in May and April, the germination and emergence of plants were severely affected, thus leading to an increase in GDD requirement for all hybrids. In 2019, the highest GDD requirement for attaining all the phenological stages was observed in Pioneer P0216 (82.5 ºC day for emergence, 804.5 ºC day for tasseling, 795.5 ºC day for silking and 1263.5 ºC day for physiological maturity).

On average, the greatest effects of growing conditions were observed in the GDD requirement for emergence, which have reduced from 159.5 in 2018, to 75.7 for 2019 (52% reduction) and in the GDD requirement for physiological maturity which have reduced from 1456.2 in 2018, to 1240.8 for 2019 (15% reduction).

The lower heat units (GDD) requirement for attaining the physiological maturity in the growing condition of 2019 as compared to 2018 were due to drought and heat stresses which shortened the period from silking to physiological maturity (grain-filling period). Pramanik and Sikder (2020) also reported that stress condition reduced GDD requirement in wheat genotypes.

Table 3. Growing degree days (GDD) at different phenological stages of maize hybrids

Year	Hybrids	Emergence	Tasseling	Silking	Physiological maturity
2018	Fundulea F 376	156.5	716.0	741.0	1415.5
	Pioneer P0216	165.5	716.0	727.5	1469.5
	Monsanto DK 5068	156.5	685.0	698.0	1483.5
	Mean	159.5	705.7	722.2	1456.2
2019	Fundulea F 376	69.0	735.0	753.5	1222.5
	Pioneer P0216	82.5	804.5	795.5	1263.5
	Monsanto DK 5068	75.5	735.0	753.5	1236.5
	Mean	75.7	758.2	767.5	1240.8

Phenothermal index (°C days/day)

Among the different phenological stages, the highest PTI was observed during sowing to physiological maturity, while the PTI was lowest during sowing to emergence (Table 4). Similar results were observed by Amgain (2011) at maize planted during spring.

In the growing conditions of 2018, the maximum PTI was observed at physiological maturity stage in Monsanto DK 5068 (11.41) followed by Pioneer P0216 (11.40), while Fundulea F 376 required the minimum PTI (11.32).

In the growing conditions of 2019, the maximum PTI was also observed at physiological maturity in Pioneer P0216 (10.03) followed by Monsanto DK 5068 (9.97).

On average, the greatest effect of growing conditions was observed in the PTI requirement for emergence, which have reduced from 9.76 in 2018, to 4.44 for 2019 (55% reduction). These results indicate that, even for a short period, changes in the air temperature are reflected in the PTI during the individual growth stages.

The higher PTI in 2018 suggested a longer growing period of each phenophase which led to the accumulation of more thermal units and therefore, a higher GY.

Similar results were noted in wheat by Ram et al. (2016). Sikder (2009) and Gill et al. (2014) also mentioned that the PTI is affected by the growing conditions and the studied cultivars.

Table 4. Phenothermal index (PTI) at different phenological stages of maize hybrids

Year	Hybrids	Emergence	Tasseling	Silking	Physiological maturity
2018	Fundulea F 376	9.78	9.94	10.01	11.32
	Pioneer P0216	9.73	9.94	9.96	11.40
	Monsanto DK 5068	9.78	9.93	9.97	11.41
	Mean	9.76	9.94	9.98	11.38
2019	Fundulea F 376	4.31	8.85	8.86	9.94
	Pioneer P0216	4.58	8.84	8.84	10.03
	Monsanto DK 5068	4.44	8.85	8.86	9.97
	Mean	4.44	8.85	8.85	9.98

Heat use efficiency (t/ha/°C days)
The quantification of HUE is important for determination of grain yield performance in different growing conditions. It was observed that all the hybrids were more heat use efficient in 2018 (Figure 1).
In the growing condition of 2018, Pioneer P0216 had highest HUE (6.73) followed by Monsanto DK 5068 (6.61), while Fundulea F 376 had the lowest HUE (5.85).
In the growing condition of 2019, Monsanto DK 5068 had highest HUE (4.90) followed by Fundulea F 376 (4.73), while Pioneer P0216 had the lowest HUE (4.51).

On average, the value of HUE at physiological maturity has reduced from 6.40 in 2018, to 4.71 for 2019 (26% reduction).
This result indicates that the thermal indices were more favorable in 2018 as compared to 2019 when plants increased the physiological activities through more efficient use of accumulated heat units, which resulted in a higher HUE and a higher GY, respectively. Pramanik and Sikder (2020) confirmed that the stress conditions reduced HUE in wheat.

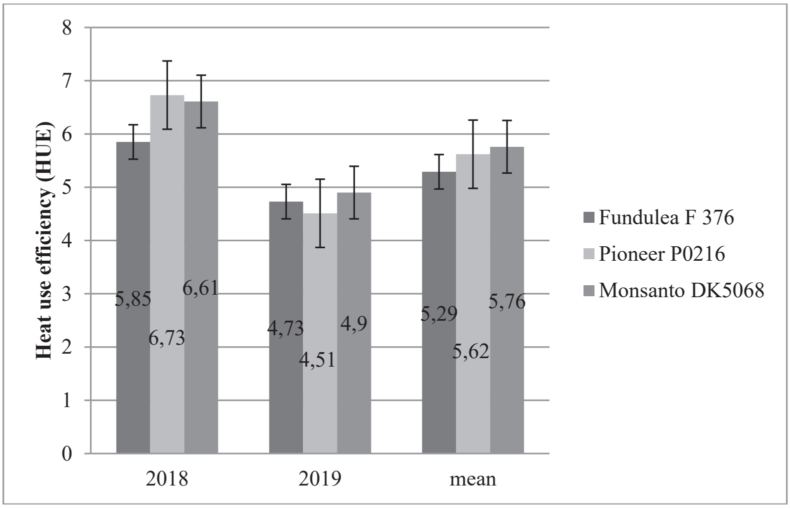
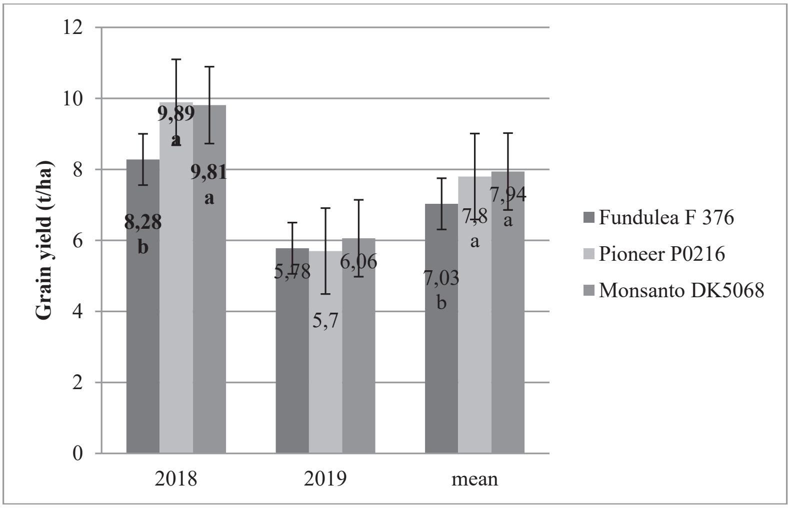


Figure 1. Heat use efficiency (HUE) of maize hybrids

Maize grain yield
Drought and heat stresses at different phenological stages have caused an array of morphological, physiological and biochemical changes that have reduced GY of maize hybrids.
In 2018, the GY was significantly higher ($P \leq 5\%$) in Pioneer P0216 (9.89 t/ha) and Monsanto DK 5068 (9.81 t/ha), while the minimum GY was recorded in Fundulea F 376 (8.28 t/ha).
The same ranking of hybrids was observed for the average of the two-years (Figure 2).

In 2019, non-significant differences ($P \leq 5\%$) were observed between hybrids for GY.
On average, the GY has reduced from 9.33 t/ha in 2018, to 5.85 t/ha for 2019 (37% reduction) due to the drought and heat stresses during grain–filling period.
According to Shao et al. (2008) the yield loss depends not only on the severity and duration of the stress, but also on when the stress occurs. Bonea and Urechean (2020) mentioned that air temperatures during grain-filling period are correlated strongly negative with the level of maize yield.



Means followed by different latters in each column are significantly different from each other at 5% level of significance

Figure 2. Grain yield (GY) of maize hybrids

Relationship between thermal indices and grain yield

The Pearson correlations of GY with GDD (Table 5) were highly significant positive (p=1%) at emergence stage (+0.958) and at physiological maturity stage (+0.983).

The significant negative relationship (p=5%) between GY and GDD at silking stage (-0.841) revealed that with increase in GDD requirement in this stage, the yield of maize decreased.

The relationship of GY with PTI was highly significant positive (p=1%) at all the phenological stages of maize hybrids (+0.954, +0.955, +0.948 and +0.965 respectively). It showed that as thermal indices are increased the grain yield is also linearly increased.

On the contrary, Singh et al. (2014) observed negative correlation between seed yield of mustard and PTI at anthesis stage and at maturity stage.

GY and HUE was registered a strongly positive relationship (+0.997). The results revealed that GY increased with the increased of HUE. Similar results were reported by Pramanik and Sikder (2020) in wheat.

Singh et al., (2014) reported significant positive correlations between seed yield of mustard and GDD (at emergence, anthesis, 50% flowering and at maturity) and between seed yield and HUE (at maturity), therefore they recommended these thermal indices for use in selection of genotypes for high temperature tolerance.

The linear regression equations were developed between the thermal indices and GY to find out the extent of variability in GY (Table 5).

It was observed that GDD at different phenological stages was able to explain the variability of GY from 56.3% at tasseling stage, to 96.6% at physiological maturity stage; PTI was able to explain the variability of grain yield from 89.9% at silking stage, to 93.1% at physiological maturity stage, and HUE (at maturity) was able to explain 99.3% variation in GY.

Choudhary et al. (2018) reported that GDD and PTI at maturity of mustard was able to explain variation in seed yield to the value of 83.2% and 85.3% respectively, while HUE could explain 72.5% of variation.

Also, Srivastava et al. (2011) observed that 66% variation in yield of oilseed *Brassica* could be explained through the accumulated GDD when crop was sown in variable weather conditions.

Table 5. Correlation and regression results between grain yield (GY) and thermal indices at different phenological stages (mean two-years)

Item	Regression equation	R^2	r
GDD at emergence	Y = 23.23x – 51.09	0.959	0.958**
GDD at tasseling	Y = -15.04x + 846	0.563	-0.750
GDD at silking	Y = -13.63x + 848.3	0.707	-0.841*
GDD at physiological maturity	Y = 59.56x +896.6	0.966	0.983**
PTI at emergence	Y = 1.394x – 3.477	0.910	0.954**
PTI at tasseling	Y = 0.286x + 7.22	0.912	0.955**
PTI at silking	Y = 0.293x + 7.189	0.899	0.948**
PTI at physiological maturity	Y = 0.370x + 7.865	0.931	0.965**
HUE	Y = 0.488x + 1.846	0.993	0.997**

*, ** significant 0.05 and 0.01 levels

CONCLUSIONS

Drought and heat stresses in maize for Oltenia region can be mitigated in two ways: agronomical practices or the development of the tolerant hybrids. Breeding for genotypes that are tolerant to stress at grain-filling period is an effective strategy to overcome this problem.

The present study showed that, the stress conditions of 2019 during grain-filing period lowered the GDD requirement and PTI at physiological maturity stage and reduced the HUE and GY in all the hybrids.

Among different thermal indices, GDD, PTI and HUE at physiological maturity stage better explained the variations in GY across two growing conditions (96.6%, 93.1% and 99.7%, respectively). Therefore, these thermal indices could be used as the best indices for selection of heat tolerant hybrids.

The hybrids Pioneer P0216 and Monsanto DK 5068 which have had highest GDD, PTI, HUE and GY, are the most suitable hybrids for the cultivation in this region and can be recommended for breeding programme for developing of tolerant genotypes.

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