

Evaluation of dry matter accumulation of maize (*Zea mays* L.) hybrids

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SUMMARY

The increase of the grain yield of maize is closely correlated with its seasonal dry matter accumulation. Dry matter is accumulated into the grain yield during the grain filling period. The following maize hybrids were involved in the experiment: Armagnac FAO 490, Loupiac FAO 380 and Sushi FAO 340. In order to determine dry matter content, two samples per week were taken on the following days: 22nd, 25th, 28th, 31st August, 4th, 7th, 14th, 18th, 22nd, 25th, 29th September and 2nd, 6th, 9th, 13th October. In the course of sampling the weight of 100 grains from the middle section of 4 ears was measured in 4 replications. Dry matter content was determined after drying to constant weight in a drying cabinet at 60 °C. Harvesting was performed on 13th October 2017.

The daily precipitation sum was determined by local measurements, while the daily radiation and temperature data were provided by the Meteorological Observatory Debrecen of the National Meteorological Service in Budapest. Among the agrometeorological parameters, an analysis was made of the precipitation during the growing season, effective heat sums during the vegetative and generative phase, and the water supplies. The daily heat sums were determined using the algorithm proposed.

The amount of precipitation in the winter period before the 2017 growing season was 210 mm. The soil was saturated until its field capacity. The rather dry and warm March and April had a favourable effect, but there was no worthy amount of precipitation until May (51 mm) due to the condition of the dried seedbed. Sowing was performed on the 5th of May 2017 in a randomised small plot experiment. There was favourable precipitation and temperature during the growing season, thereby providing ideal conditions for maize development, growth and yield formation. There was near average amount of precipitation in each year. The total amount of precipitation in the summer period is 342 mm. Temperature was mostly above the average, but there was no long and extremely warm period.

The Armagnac hybrid reached its highest dry matter mass 126 days after emergence. Physiological maturity was reached sooner (on the 119th day) in the case of Loupiac, and even sooner in the case of Sushi (116th day).

The thousand grain weight of Sushi (which has the shortest ripening period) was 286 g at the time of physiological maturity, while that of Loupiac was 311 g. Compared to Sushi, Armagnac showed 12 g more dry matter accumulation (306 g). In the case of all three examined hybrids, physiological maturity was preceded by an intensive phase, when the dynamics of dry matter accumulation was rather quick. On average, Sushi gained 2.8 g dry matter per day between 103 days following emergence and physiological maturity, while the same values were 3.2 g for Armagnac and 3.3 g for Loupiac.

The aim of the regression line slope is to predict the behavior of the dependent variable with the knowledge of the values and characteristics of the independent variables using the regression line equation. Furthermore, to determine how the location affected the dynamic of dry matter accumulation in the Armagnac, Loupiac and Sushi hybrids. In regression analysis, the coefficient of explanation showed that the effect of day in the Armagnac was 97%, in the Loupiac 94%, in the Sushi 90 %. The determination coefficient (R^2) is useful in determining how the regression equation fits. But, as we have seen, the determination coefficient alone is not sufficient to verify the model's accuracy, in addition to the determination coefficient (R^2), the normality of the data or the residuals, the variance of the variables at different levels, the independence of the data relative to time and non-oblique. Observations are evaluated for the correctness of the fitted model.

Dry matter values decreased evenly and slightly following physiological maturity. According to our research results, it was established that physiological maturity is followed by a moderate dry matter loss. Until harvesting, Armagnac lost 40 g of its thousand mass weight in 29 days, while the same value pairs were 69 g in 36 days for Loupiac and 29 g in 39 days for Sushi. Loupiac – which had the highest weight at the time of physiological maturity – lost the most of its dry weight; therefore, Armagnac and Sushi had higher values at the time of harvesting.

Keywords: maize, genotype, dry matter accumulation, physiological maturity

INTRODUCTION

The 43–49% of the total organic dry matter of the maize plant is stated in the kernel. The process of filling the kernels in is closely correlated with the loss of moisture content and both are influenced by a host of factors (Bellini and Fusi 1961).

Maize hybrids have different genetic background; therefore, they react differently to the effect of agrotechnical and ecological factors. There are significant differences between the natural nutrient extraction and nutrient conversion ability of hybrids (Sárvári and Bene 2015).

Yield increase is the result of physiological processes. The grain yield increase of maize is in close correlation with seasonal dry matter accumulation. Dry matter is incorporated into the grain yield during the grain filling period. Only a smaller part of dry matter incorporated before the silking period is remobilised into the grains. Hybrids with short ripening period accumulate half of all dry matter until silking and nearly the same amount until grain filling. Also, there is a difference between parental inbred lines in terms of phasal development. Compared with inbred lines, the grain filling period is longer in the case of hybrids (Berzsenyi 2009).

Carter and Polenit (1973) claim that the maximum dry matter of the kernel ensues when the black layer appears in the kernel was a sign of physiological maturity.

The long-term experiment results of Pepó et al. (2016) show that maize is sensitive to environmental conditions (weather, soil). The temperature and water supply are significant conditions for the successful development of kernels (Kiesselbach 1950). The temperature and speed of kernel development are positively correlated (Duncan et al. 1965). A similar positive correlation was registered by Ragland et al. (1965) between temperature and ear development. Low temperature and unfavourable supply of organic compounds stimulate the development of the black layer (Daynard and Duncan 1969). At the period of kernel filling, the high temperature and defective accumulation of sugar (saccharose), the black layer appears earlier at a low maximum of dry matter and a high moisture content (Afuakwa et al. 1984, Hanft et al. 1986). Temperature and provision of organic compounds are also decisive in determining the time of physiological maturity (Wilson et al. 1973, Máthéné 1989). Cool weather delays (Hallauer and Russel 1961), high temperature (>30 °C) shortens the time of maturity (Badu-Apraku et al. 1983, Tollenaar and Bruulsema 1988). Low temperature is also unfavorable for dry matter accumulation (Bunting 1976), and the yield is more or less reduced (Jones et al. 1981). Water deficiency reduces the speed of accumulation of dry matter and delays the time of maturity (Quattar et al. 1987ab). After physiological maturity, weather is the most important condition. (Aldrich 1975). The filling of kernels is connected with the loss of moisture content. Until physiological maturity, active physiological process prevail (Afuakwa et al. 1984). Kang et al. (1986) showed by means of path-analysis a positive interaction between kernel filling and speed of decline in water content %, which means that if the speed of kernel filling increase, water loss ensues at a higher rate (% loss per day). The process of drying from the appearance of the black layer until harvest, Schmidt and Hallauer (1962) observed that the daily rate of water loss depends on the season. On the contrary, Hicks et al. (1976), Dobos (2003), Dobos and Szabó (2005) were unable to show the specificity of hybrids from this point of view.

MATERIAL AND METHODS

Samples were taken in location in Debrecen. The Experimental Station is situated on the Hajdúság Loess Ridge, and the soil is a lowland chernozem with lime deposits and a deep humus layer, formed on loess. It has medium hard loam texture. The soil type is a solonetz, strongly calcareous, meadow chernozem, with loam or sandy loam texture.

The following maize hybrids provided by KITE Plc. were involved in the experiment: Armagnac FAO 490, Loupiac FAO 380, Sushi FAO FAO 340. In order to determine dry matter content, two samples were

taken per week on the following days: 22nd, 25th, 28th, 31st August, 4th, 7th, 14th, 18th, 22nd, 25th, 29th September and 2nd, 6th, 9th, 13th October. In the course of sampling the weight of 100 grains from the middle section of 4 ears was measured in 4 replications. Dry matter content was determined after drying to constant weight in a drying cabinet at 60 °C. Harvesting was performed on 13th October 2017.

The daily precipitation sum was determined by local measurements, while the daily radiation and temperature data were provided by the Meteorological Observatory Debrecen of the National Meteorological Service in Budapest. Among the agrometeorological parameters, an analysis was made of the precipitation during the growing season, effective heat sums during the vegetative and generative phase, and the water supplies. The daily heat sums were determined using the algorithm proposed.

The amount of precipitation in the winter period prior to the 2017 growing season was 236 mm. The soil was saturated until its field capacity. The rather dry and warm March and April had a favourable effect, but there was no worthy amount of precipitation until May (51 mm) due to the condition of the dried seedbed. Sowing was performed on the 5th of May 2017 in a randomised small plot experiment at a plant density of 70 000 plants per hectare. There was favourable precipitation and temperature during the growing season, thereby providing ideal conditions for maize development, growth and yield formation. There was near average amount of precipitation in each year. The total amount of precipitation in the summer period is 342 mm. Temperature was mostly above the average, but there was no long and extremely warm period. The positive temperature difference in July and August was close to 2 °C. The mean value in August was in accordance with the multiple-year-average (*Figure 1*).

Thus the computation of the sum of temperature should be performed according to Gilmore and Rogers (1958), Arnold (1959, 1960), moreover, to Cross and Zuber (1972) by the following formula:

$$\sum_{T}^a T_a = \left(\frac{Max - Min}{2} \right) - T_B \quad ^\circ C$$

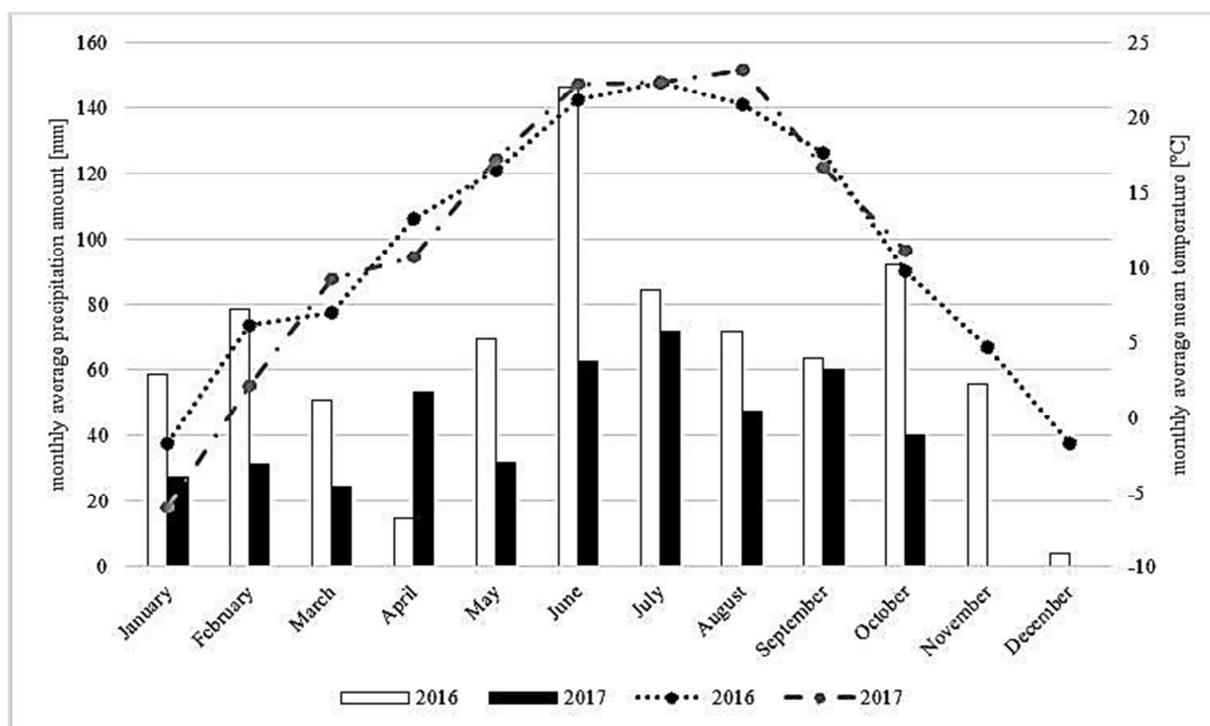
$$T_B = 10 \quad ^\circ C$$

where ΣT_a is the sum of the active temperatures throughout the growing season, the expression of the fraction corresponds to the mean value of daily mean temperature, and the T_B is the basic temperature. The value of the degree-day is obtained by the formula:

$$\text{degree - day} = \left[\left(\frac{Max - Min}{2} \right) - T_B \right] \quad ^\circ C \text{ day}^{-1}$$

$$T_B = 10 \quad ^\circ C$$

Figure 1: Monthly mean temperature and precipitation in 2016 and 2017



The most accepted one is proposed by Gilmore and Rogers (1958) based on a regression analysis, which postulates that the growth is linear during the first phase of development – being demonstrated relatively well – and the horizontal axis of the graph is the temperature. The vertical axis is assigned to the volume or height of the plants. The intersection of (linear) growth with the horizontal axis (x) indicates the base temperature.

Another method using a more reliable database is proposed by Szász and Nagy (unpublished). The distribution of probability of growth over temperature gives an asymmetric β -distribution, hence the β -model of the distribution.

As far as the lower value of the daily variation of temperature is above the base temperature, in order to establish the active values of temperature, we must know the temperature below which the values ought to be omitted when making the sum. This value is generally found by statistical methods from the database of climatological observations applying a cubic equation, which describes the variation of the latter value until the end of the flowering period (Tollenaar et al. 1979, Ritchie et al. 1994).

In Hungary, 10–12 °C daily variation is nearly constant at least from the point of view of the phenological phases of maize; according to our studies this is the case also in other regions. Detailed investigations were performed in Canada, USA, in Western and Eastern Europe. Extended climatological analyses revealed that in the region of 40–46° latitude of North America the daily variation of the

temperature during the vegetative phase of vegetative development of maize (May–July) was around 12 °C, and the difference between the regions referred to was some tenth of degrees only, whereas in Western Europe – e.g. England, where maize is grown – daily variation is 6.5 °C. In Western Europe the variation is 10.0–11.0 °C, in Southern Europe 6.0–8.0 °C, respectively. After all, the question of base temperature ought to be solved by different approaches in those regions.

Evaluation statistics used by Minitab and MS Excel software.

RESULTS AND DISCUSSION

Phenological measurements were performed on hybrids of various height and their most typical characteristics were collected (Table 1). The average height of Armagnac was 236 cm, while Loupiac was 10 cm taller. Based on our measurements, Sushi was the tallest (250 cm). The number of leaves were 13 in the case of the two smaller hybrids and 12 in the case of Sushi. Based on the results measured in our experiment, the average ear length of Armagnac is 15 cm. The ears of Loupiac and Sushi were significantly longer (21 cm and 20 cm, respectively).

Maize hybrids of different genotype can be considered mature from the physiological aspect once dry matter accumulation reaches its maximum value. The connection between grain and cob, as well as water and nutrient transport disappears with the formation of the black layer. The Armagnac hybrid

reached its highest dry matter weight on the 126th day following emergence. The physiological maturity was sooner in the case of Loupiac (119th day) and even sooner in the case of Sushi (116th day).

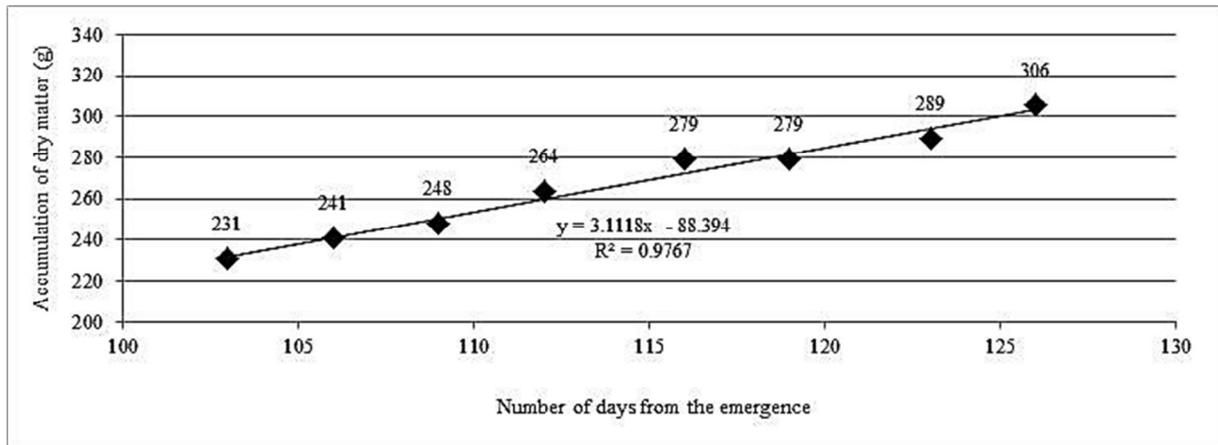
Table 1
Phenological indexes of maize hybrids of different genotype (Debrecen, 2017)

	Armagnac	Loupiac	Sushi
Height (cm)	236	245	250
Number of nodes	13	13	13
Stem diameter (mm)	14	15	13
Number of leaves	13	13	12
Ear length (cm)	15	21	20
Ear diameter (mm)	35	45	45
Number of rows per ear	17	16	15
Number of grains per row	25	36	38

Armagnac is a mid-ripening dent maize hybrid (FAO 490) for grain use purpose. The average plant height of Armagnac is 236 cm. Armagnac is a mid-tall hybrid. The ear is connected to the stem at an average height of 91 cm. The ears are elongated and they

develop 16 rows of grain and the developed ears are fully covered with grains. The initial development (at the age of 2–4 leaves) of the hybrid is weaker than average and its early development (5–8 leaves) can be considered average. The hybrid has strong foliage and stem. Its roots are strong and its stem calls for attention in the late phase of the season (especially if the predominant conditions were favourable in the flowering period). Stem breaking can be minimised with early harvesting. This hybrid has high grain quality. The pistil has no antocyanic coloration, while the cob has antocyanic colour. The hybrid has a high thousand grain weight of 350 g. It is a flexible hybrid recommended to be sown early. Its agronomical traits are adequate and its hectolitre weight is higher than the average. The hybrid has outstanding nutrient reaction and it is recommended for intensive production. It has good water losing characteristics and its grain moisture content at harvesting is 18.1%. Armagnac can be characterised by high yield level, stability and drought resistance. The hybrid's yield potential is similar to that of DKC5276 both at low and high yield levels. Armagnac has outstanding dynamics of dry matter accumulation and the range of accumulation dynamics is wide (Figure 2).

Figure 2: Dynamics of dry matter accumulation of Armagnac until physiological maturity (Debrecen, 2017)



Loupiac is a dent maize hybrid for grain use purpose. The hybrid belongs to the late end of the mid-ripening group (FAO 380). Loupiac is a favourable hybrid in terms of its phenotype and its flowering takes place one day later than the group average of FAO 380 hybrids. It has a compact structure: its average plant height is 245 cm, which makes it shorter than the average. The ear is connected to the stem at a relatively short position at 78 cm. This hybrid develops large, elongated, cone-shaped ears with 16 rows of grain and the ear end is properly covered with grains. Its root and stem provides proper stability and its stamina is above average. Its early development is average. Loupiac is not a stay-green type of maize and the stem may have antocyanic coloration by the end of the season. The agronomical

characteristics of Loupiac are good and its hectolitre weight is higher than the average. Early and optimal sowing dates are recommended. Its grain weight is above average: its thousand grain weight is around 419 g. The hybrid's grain moisture content at harvesting is 15.8%. It has good yield potential and drought resistance, similarly to hybrids DKC4795 and PR37N01. The intensive phase of the grain filling of Loupiac started off from a high value (258 g) and it lasted for 16 days (Figure 3).

Sushi is a dent maize hybrid for grain use purpose belonging to the early ripening group (FAO 340). Sushi is a strong, mid-tall hybrid of an average height of 250 cm with a strong stem. The ear is connected to the stem at an average height of 101 cm. The hybrid has a stable structure and develops elongated, flexible,

cone-shaped ears with 16 rows of grain properly covered with grains. Sushi has favourable root and stem characteristics. The initial development of the hybrid is outstanding. The agronomical characteristics of the hybrid can be considered average, its emergence rate, early development and hectolitre weight are adequate. The hybrid can be characterised by especially high thousand grain weight of 361 g on average. Due to its flexible ear type and average

drought resistance, it is recommended to set crop density lower. The compensation ability of Sushi is favourable. Its grain moisture content is 18.8%. Sushi has especially high yield potential, similarly to DKC4014. It is not among the best hybrids in terms of drought resistance. Its dry matter accumulation interval is the shortest (13 days) and its exposure to drought is also the lowest (Figure 4).

Figure 3: Dynamics of dry matter accumulation of Loupiac until physiological maturity (Debrecen, 2017)

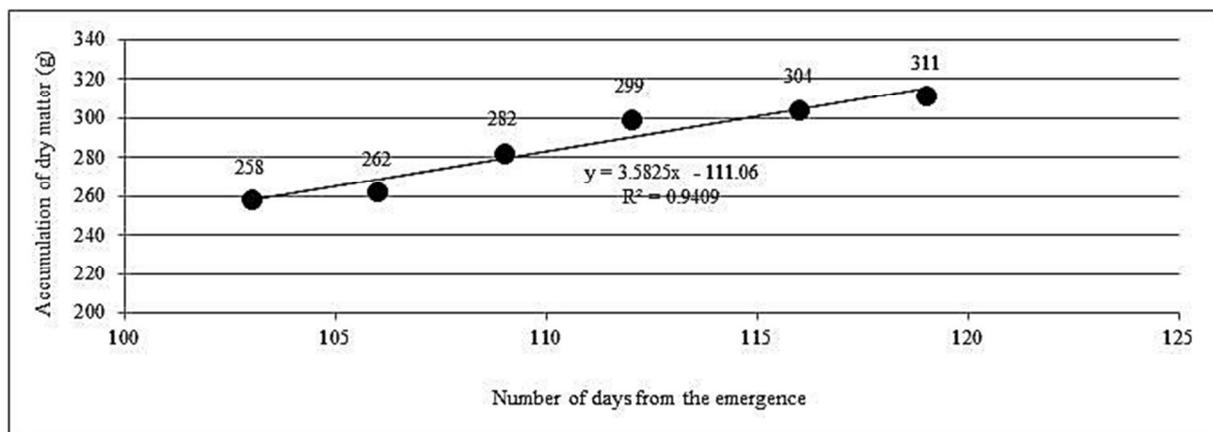
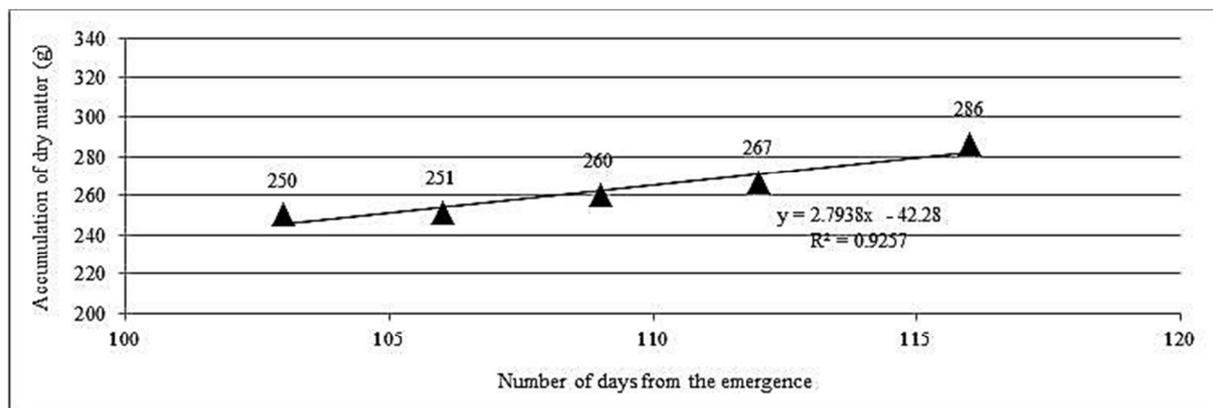


Figure 4: Dynamics of dry matter Accumulation of Sushi until physiological maturity (Debrecen, 2017)



The thousand grain weight of Sushi (which has the shortest ripening period) was 286 g at the time of physiological maturity, while that of Loupiac was 311 g. Compared to Sushi, Armagnac showed 12 g more dry matter accumulation (306 g). In the case of all three examined hybrids, physiological maturity was preceded by an intensive phase, when the dynamics of dry matter accumulation was rather quick. On average, Sushi gained 2.8 g dry matter per day between 103 days following emergence and physiological maturity, while the same values were 3.2 g for Armagnac and 3.3 g for Loupiac. In other words, hybrids reached the highest dry matter content with different intensity (Table 2).

The aim of the regression line slope is to predict the behaviour of the dependent variable with the knowledge of the values and characteristics of the independent variables using the regression line equation. Furthermore, to determine how the location affected the dynamic of dry matter accumulation in the Armagnac, Loupiac and Sushi hybrids. In regression analysis, the coefficient of explanation showed that the effect of day in the Armagnac was 97%, in the Loupiac 94%, in the Sushi 90%. The determination coefficient (R^2) is useful in determining how the regression equation fits. But, as we have seen, the determination coefficient alone is not sufficient to verify the model's accuracy, in addition to the determination coefficient (R^2), the normality of the

data or the residuals, the variance of the variables at different levels, the independence of the data relative to time and non-oblique Observations are evaluated for the correctness of the fitted model (Table 3).

Table 2

Maximum dry matter and moisture content of the thousand grain weight of maize hybrids of different genotype at the time of physiological maturity (Debrecen, 2017)

Hybrid	FAO No.	Maximum dry matter (g)	Day of physiological maturity since emergence	Moisture (%)
Armagnac	490	306	126	28.7
Loupiac	380	311	119	30.4
Sushi	340	286	116	33.3

Table 3

Thousand grain dry matter weight of maize hybrids of different genotype with a regression equation (Debrecen, 2017)

Hybrid	FAO No.	Regression equation	R ²
Armagnac	490	3.118x-88.394	0.97
Loupiac	380	3.552x-111.06	0.94
Sushi	340	2.7938x-42.28	0.91

Dry matter values decreased evenly and slightly following physiological maturity. According to our research results, it was established that physiological maturity is followed by a moderate dry matter loss. Until harvesting, Armagnac lost 40 g of its thousand mass weight in 29 days, while the same value pairs were 69 g in 36 days for Loupiac and 29 g in 39 days for Sushi. Loupiac – which had the highest weight at the time of physiological maturity – lost the most of its dry weight; therefore, Armagnac and Sushi had higher values at the time of harvesting.

The harvested yield of Sushi was 10.98 t ha⁻¹, that of Loupiac was 12.09 t ha⁻¹ and the yield of Armagnac was 12.16 t ha⁻¹ (14% moisture content). The grain

moisture content at harvesting was 16.3, 15.9 and 18.1%, respectively (Table 4).

Table 4

Physiological maturity time, yield elements and results of maize hybrids of various genotype (Debrecen, 2017)

	Armagnac	Loupiac	Sushi
Time of physiological maturity	14/9	7/9	4/9
Thousand grain weight (g)	306	311	286
Grain weight per ear (g)	158.9	254.3	210
Number of grains per ear (pcs)	429	578	572
Yield at 14% moisture content (t ha ⁻¹)	12.16	12.09	10.98
Grain moisture at harvesting (%)	18.1	15.9	16.3
Cob weight (g)	31	38.9	35.2
Corn/cob ratio (%)	80.5	84.7	83.2

CONCLUSIONS

Dry matter values decreased evenly and slightly following physiological maturity. According to our research results, it was established that physiological maturity is followed by a moderate dry matter loss. Until harvesting, Armagnac lost 40 g of its thousand mass weight in 29 days, while the same value pairs were 69 g in 36 days for Loupiac and 29 g in 39 days for Sushi. Loupiac – which had the highest weight at the time of physiological maturity – lost the most of its dry weight; therefore, Armagnac and Sushi had higher values at the time of harvesting.

The aim of the regression line slope is to predict the behavior of the dependent variable with the knowledge of the values and characteristics of the independent variables using the regression line equation. Observations are evaluated for the correctness of the fitted model.

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