Agronomy Research **20**(X), xxx–ccc, 2022
https://doi.org/10.15159/AR.22.028

Adaptation of various maize hybrids when grown for biomass

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Received: January 10th, 2022; Accepted: May 1st, 2022; Published: May 10th, 2022

Abstract. The aim of this research is to optimize growth and development of maize for biomass by selecting maize hybrids to fulfill their productivity potential. The following maize hybrids were the subject of research: Forteza, DM Native, DM Skarb. The greatest height of plants was formed in the interphase period of milk-wax maturity of grain in hybrid Forteza - 286.4 cm. In hybrid DM Native the height of plants was - 271.2 cm, hybrid DM Skarb - 263.6 cm. Weight of one plant of hybrids studied during the maize growing season ranged from 442 g to 760 g. Thus, the largest mass of maize plants was recorded in the milk-wax maturity stage. It was the largest at the hybrid Forteza and amounted to 760 g, that is more than at the hybrid DM Native for 3.4% (26 g) and at the hybrid DM Skarb for 6.6% (50 g). The average crop yield of the hybrid Forteza for the period of research was 55.1 t ha^{-1}. Hybrids DM Native and DM Skarb provided this indicator at the level of 50.6 and 45.7 t ha^{-1} respectively. Hybrid Forteza provided a maximum crop yield 55.1 t ha^{-1} with plant height 286.4 cm, assimilation surface of one plant and a crop 0.59 m^2; 42.8 thousand m^2 ha^{-1} and plant weight 760 g.

Key words: hybrid, leaf surface, plant, cob, crop yield.

INTRODUCTION

Among the high-yielding spring crops, maize occupies a leading position as unsurpassed in terms of potential yield of grain and silage. It is one of the main sources of forage and energy resources. In many regions of the world of the temperate climate, maize is the main forage crop. The area of maize cultivation for silage has shifted significantly to the north. Today, this subtropical plant is widely used in the main agroclimatic zones of Ukraine (Knyazyuk, 2018).

Over the past few years, maize cultivation areas in Ukraine have grown several times and now amount to 4.3–4.7 million hectares. This is due to the comprehensive use of maize as forage, food and industrial crops (Palamarchuk, 2018). At the present stage, agricultural producers in Ukraine are faced with the task of significant increasing the productivity of maize for needs of the national economy. This problem can be solved by using highly productive hybrids, advanced energy-saving technologies, high-quality seeds, etc. are used (Bagan, 2015).

On the basis of many years of research, the scientific developments and practical experience in growing maize using intensive energy-saving technology have been generalized. Much attention has been paid to improving the basic elements of technology for growing maize used for grain, silage, green fodder, as well as for food purposes and promising directions for increasing maize production in Ukraine (Chandiposha & Chivende, 2014; Haddadi & Mohseni, 2016).

The increase in the area under maize became possible thanks to creation of new hybrids with a shorter maturity period. It made possible to increase the area under this crop in the northern regions. The fundamental direction of increasing the yield of maize is the introduction of intensive type hybrids of different maturite groups. Not all hybrids respond equally to specific agroecological and technological conditions of cultivation, therefore, their potential productivity is different. Highly productive hybrids take a large amount of nutrients from soil, consume a lot of water, so they require appropriate agricultural technology. If such conditions are not created, then a potentially more productive hybrid may yield its position in harvesting capacity to another less productive, but also less demanding hybrid (Lavrynenko et al., 2018; Butenko et al., 2019; Kadyrov & Kharitonov, 2019).

The continuous work of crop breeders on improving the architectonics of a maize plant focuses on the components that determine the formation of productivity and resistance to stress factors - the size and angle of inclination of the leaves, the architectonics of the root system and more. Maize genotypes vary in their response to the full range of possible temperatures by not always clear signs (Lynch, 2007; Kolisnyk et al., 2019). Therefore, we need a differentiated approach to the selection of hybrids of the corresponding group of maturity and purpose. To increase the level of realization of the yield potential of modern hybrids and protect crops from negative abiotic and biotic environmental factors, in addition to agrotechnical measures, the development of morphological and heterosis models and selection of hybrids on this basis with specific adaptability to agroecological factors is important (Troyer, 2014; Horváth et al., 2021).

First-grade maize silage should contain 40–50% of maizecobs in green mass and 25–35% of dry matter, which is provided during harvesting plants in wax maturity phase (Lipovy et al., 2003).

In the period of wax maturity, maize also has negative qualities relating to silage: the lower parts of maizestalks and cut cobs get coarse; only 15–18% of the grain reach physiological or technical maturity. At the same time, in full maturity of maize, the stalks turn yellow and coarse and contain practically no carotene. The yield of dry matter and its nutrition are reduced by 5–6% due to an increase in the amount of fiber and cobs.

Taking in consideration the above, the duration of the wax maturity phase of maize must be prolonged in order to have time to harvest the mass for silage. It is problematic to suspend or slow down the physiological processes that take place in a maize plant during the grain filling period. Therefore, to obtain the maximum productive yield of maize in the wax maturity phase, it is necessary to extend the cropping period by sowing hybrids of different prematureness. This way it becomes possible to create an appropriate feed conveyor for harvesting silage with a total harvesting period of 20–30 days (Yamkova, 2014; Babkov & Zhelobkova, 2019).

To obtain high and stable maize yields in each farm, it is necessary to have a range of hybrids with a different type of reaction to the variability of environmental conditions, including the intensive type (to obtain maximum yields on a high agricultural background), medium plastic hybrids, which have a wide adaptive potential (to obtain relatively stable yields in fields with an unstable agricultural background), and highly stable (for a guaranteed yield under conditions of variable meteorological factors on poorly nutrient soils). The ability to economically and efficiently use life-giving factors is a property of highly adaptive genotypes (Kitayova et al., 2013).

For maize, it is important that the seeds are sown evenly both across the length and width of the row. The uniformity of their distribution creates favorable conditions for the emergence of even and proper sprouts, high evenness of plants in height and development, simultaneous maturation, the same density and quality of grain in the corncob (Sun et al., 2009; Weidong & Matthijs, 2009; Li et al., 2012).

Taking into account the above, it is necessary to analyze the seeding machinery and sowing units produced by the industry, with due regard for the technological properties of the machine, the agrobiological characteristics of the crop and soil and climatic conditions (Ipsilandis & Vafias, 2005; Farsiani et al., 2011; Saberi et al., 2012).

The purpose of research is to optimize the growth and development of silage maize by selecting maize hybrids to realize their productivity potential.

MATERIALS AND METHODS

The researches for study of varietal features of maize for silage were conducted during 2017–2021 in the Educational, Scientific and Production Complex of Sumy National Agrarian University. The researches were conducted according to research methods of Dospehov (1985), Pidoprygora & Pysarenko (2003).

The following corn hybrids were the subject of the research: Forteza, DM Native, DM Skarb. The receding crop was winter wheat. Sowing was carried out after beginning of physical soil maturity at the temperature of 10–12 °C at the depth 10 cm by wide-row sowing with row spacing 70 cm and sowing rate 85 thousand of seeds per ha^{-1}.

In modern agricultural industry, the main method of maize sowing is a single-grain one with 70 cm spacing, which ensures maximum productivity of machines with minimal labor, costs and energy expenditures during sowing and care of crops (Amanullah et al., 2009; Tang et al., 2013).

The sown area of the plot was 50 m^2. Variants of the research were placed in triplicate. The alternation of variants was consistent. Before sowing maize, mineral fertilizers were applied: nitroammophoska 150 kg ha^{-1} and carbamide 200 kg ha^{-1}. Nitroammophoska is a triple physiologically neutral fertilizer - concentrated, nitrogen-phosphorus-potassium, granular with the content and ratio of mineral nutrients N:P:K = 16:16:16. Carbamide is a concentrated amide fertilizer. Mass fraction of nitrogen (N) is 46.2%. Form of fertilizer - granular.

During the phenological observations, the beginning of the developmental stage of maize plants was assumed when it was present in at least 10% of plants, and the complete developmental stage in 75%. The average height was determined from 25 plants in two non-adjacent rows of the plot by measuring with a rail from the ground to the longest of the upper leaves. To determine the growth of aboveground part of the plant, samples were taken from each plot of 20 plants and were weighed in laboratory in the raw state. The structure of crops (length and cob diameter, the number of rows and grains in a row, the number of grains from a cob) was determined by selected samples. The leaf area was determined by calculation. The calculation method is based on determining the area of a separate leaf by multiplying the length by the width and the verified coefficient, which for cereals with linear (oblong) leaf shape is 0.67. The yield of biomass maize was calculated by total harvesting and weighing from each plot. Processing and generalization of research results were carried out according to Dospehov (1985) using Microsoft Excel.

The soil of experimental field is a typical powerful heavy-loamy and medium humus black soil, which is characterized by the following indices: humus content in arable layer (according to I.V. Tiuryn) - 4.0%, reaction of soil solution is close to neutral (pH 6.5), the content of easily hydrolyzed nitrogen (according to I.V. Tiuryn) 9.0 mg, movable phosphorus and exchangeable potassium (according to Ph. Chyrikov), accordingly, 14 mg and 6.7 mg per 100 g of soil.

Table 1. Weather conditions of vegetative seasons for 2017–2021

Year	Average daily air temperature, °C		Amount of precipitation, mm	
	annual air temperature, °C	± to the long-tern indicator, (7.4 °C)	for the reporting year, mm	± to the long-term norm, (593.0 mm)
2017	8.1	+ 0.7	449.0	– 144.0
2018	9.4	+ 2.0	539.0	– 54.0
2019	9.6	+ 2.2	409.0	– 184.0
2020	10.2	+2.8	466.0	– 127.0
2021	9.4	+ 2.0	453.0	– 140.0

Weather conditions in 2018 and 2020 are more favorable for formation of maximum yields. The climatic conditions of 2017, 2019 and 2021 are extreme for growing crops due to low precipitation and significant deviations in air temperature during the growing season.

RESULTS AND DISCUSSION

To obtain high yields of quality products, it is important to timely obtain and maintain even and proper sprouts of optimal density. Maize requires increased moisture supply and adequate soil temperature for seed germination. Therefore, under adverse weather conditions, maize seeds have a longer germination period. This usually results in a significant decrease in field germination and crop productivity. Cold resistance is the ability of seeds to sprout at a positively low (threshold) temperature of 6–8 °C, and sprouts - actively photosynthesize at low temperatures. This trait is genetically determined and manifests at all levels of biological organization - cellular, population. High level of cold resistance ensures sprouts and development of young hybrid plants in early sowing of maize in overmoistened soil at a positively low temperature (Wijewardana et al., 2016).

The highest field germination of seeds was observed in Forteza hybrid - 92.3%, and the lowest in DM Skarb hybrid - 85.5%. Depending on the hybrid, a plant density on average ranged from 7.27 to 7.85 pcs m^2. The highest index of a plant density was observed in Forteza hybrid - 7.85 pcs m^2 (Table 2).

Table 2. Degree of maize density depending on the variety characteristics (average for 2017–2021)

Cultivar (hybrid)	Ground germination capacity, %	Degree of plant density, pcs m^2	Preservation of the plants during the vegetation season	
			pcs m^2	%
DM Native	89.6	7.62	6.90	90.6
Forteza	92.3	7.85	7.25	92.4
DM Skarb	85.5	7.27	6.44	88.6
LSD_{05}	0.99	0.078	0.12	1.69

The highest plant safety in Forteza hybrid was 7.25 pcs m^2 (92.4%), the lowest in DM Skarb hybrid - 6.44 pcs m^2 (88.6%).

Morphometric indicators and their ratios become important for development of the optimal morphotype of maize hybrid plants (Cherchel et al, 2014).

Maize plants, like other non-perennial crops, have their limited height, that is, at the time of maturation, they stop their linear growth in any combination of agrotechnical and meteorological conditions. Fluctuations of daily gain of plants in height in the interstage periods and in general during the vegetation season can aid in determination of the influence of various factors on the productional processes of plants (Mazur et al, 2018).

Hybrids have been found to significantly affect the linear growth of maize. At the beginning of the development stage of maize (7–8 leaves), the highest plant height was observed in the hybrid Forteza - 77.3 cm, in DM Native hybrid this indicator was 72.0 cm, and in DM Skarb hybrid - 69.1 cm.

The obtained experimental data indicate that the increase in the linear height of plants occurs before the ear emergence phase, and their maximum value was observed in the interstage period of milky-wax maturity of the grain. The greatest height of plants was formed in the interphase period of milk-wax maturity of grain in hybrid Forteza - 286.4 cm. In hybrid DM Native the height of plants was - 271.2 cm, hybrid DM Skarb - 263.6 cm (Table 3).

Table 3. Dynamics of maize plant height depending on the variety characteristics (average for 2017–2021), cm

Cultivar (hybrid)	Phenological phases		
	7–8 leaves	Ear emergence	Milk-wax maturity
DM Native	72.0	198.5	271.2
Forteza	77.3	208.3	286.4
DM Skarb	69.1	188.0	263.6
LSD_{05}	2.09	4.18	3.81

Physical and physiological processes that transform solar energy into organic matter in the atmosphere - leaf - plant - agrocenosis system have an important influence on quantitative and qualitative indicators of crop yielding capacity formation. The intensity of this process depends greatly on the characteristics and spectral composition of sunshine, energy balance between energy absorbed and costs of photosynthesis, transpiration, thermal and moisture circulation, the availability of nutrients and readily available moisture, etc. To optimize production processes and form the maximum possible maize yield, the size of a plant leaf apparatus is important that accumulates solar radiation during photosynthesis and provides the creation of organic matter (Andriyenko, 2003).

Thanks to the type C4 photosynthesis, which leads to rapid accumulation of organic matter in plants, maize has the highest dry matter yield per 1 ha of crop area (Ruile et al., 2015).

The researches allowed to investigate the response of maize plants to varietal characteristics by determining their indicators of photosynthetic activity. The area of leaf surface of the sowing is quite variable and depends both on weather conditions during the years of research and on the factors studied (Table 4).

Table 4. Dynamics of leaf area growth depending on the variety characteristics (average for 2017–2021)

Cultivar (hybrid)	Leaf-area duration, m^2					
	7–8 leaves		Ear emergence		Milk-wax maturity	
	on the plant	thousand m^2 ha^{-1}	on the plant	thousand m^2 ha^{-1}	on the plant	thousand m^2 ha^{-1}
DM Native	0.038	2.6	0.51	35.2	0.54	37.3
Forteza	0.045	3.1	0.55	39.8	0.59	42.8
DM Skarb	0.039	2.5	0.48	31.0	0.50	32.2
LSD_{05}	0.0026	-	0.031	-	0.030	-

At the beginning of vegetation season (7–8 leaves), on average over the years of research, the area of the leaf apparatus fluctuated within 2.5–3.1 thousand m^2 ha^{-1} in all plots. In the ear emergence phase, the largest area of the assimilation area of one plant and the crop was in Forteza hybrid (0.55 m^2; 39.8 thousand m^2 ha^{-1}), slightly smaller - in DM Native hybrid (0.51 m^2; 35.2 thousand m^2 ha^{-1}), in the variant with DM Skarb hybrid - 0.48 m^2; 31.0 thousand m^2 ha^{-1}, accordingly. In the milky-waxy maturity phase, the largest area of the assimilation area of one plant and the crop was in Forteza hybrid (0.59 m^2; 42.8 thousand m^2 ha^{-1}), slightly smaller - in DM Native hybrid (0.54 m^2; 37.3 thousand m^2 ha^{-1}), in DM Skarb hybrid - 0.50 m^2; 32.2 thousand m^2 ha^{-1}, accordingly.

Analyzing the data in Table 5, it is fair to say that the weight of one plant in the hybrids studied during the maize growing period ranged between 442 and 760 g. Thus, the largest mass of maize plants was recorded in the milk-wax maturity phase. In Forteza hybrid, it was the largest and amounted to 760 g. In the DM Native hybrid - 734 g, DM Skarb hybrid 710 g.

Table 5. Influence of variety characteristics on the weight of one maize plant (average for 2017–2021), g

Cultivar (hybrid)	Phenological phases		
	7–8 leaves	Ear emergence	Milk-wax mturity
DM Native	447.0	653.0	734.0
Forteza	471.0	686.0	760.0
DM Skarb	442.0	641.0	710.0
LSD_{05}	4.90	8.63	14.31

An important characteristic of the productivity of maize hybrid plants is the biometric characteristics of maizecobs such as number of rows, number of grains in the row, number of grains per corncob, length and diameter of the cob. Providing maize plants with favorable conditions for growth and development led to an increase in the biometric indicators of maizecobs.

The highest values of maizecob length and diameter were obtained using Forteza hybrid and were 16.2 cm and 4.5 cm, respectively (Table 6).

The number of rows in the maizecob and the grains in the row tend to increase depending on the variety characteristics. Thus, according to the variants of the experiment, the number of rows ranged between 14.0 and 16.0 pieces. The number of grains in the row ranged between 31.4 and 34.2 pcs (LSD_{05} = 0.55). The researches have shown that the impact of different maize hybrids on the number of rows and the number of grains in a row was insignificant The highest of those indicators were observed on the plots with Forteza hybrid - 16.0, 34.2 pcs, accordingly. The lowest of those indicators were observed on the plots with DM Skarb hybrid - 14.0, 31.4 pcs, accordingly.

Table 6. Maizecob biometrics depending on the variety characteristics (average for 2017–2021)

Cultivar (hybrid)	Length, cm	Diameter, cm	No. of rows, pcs	No. of grains in the row, pcs
DM Native	15.7	4.1	16.0	33.5
Forteza	16.2	4.5	16.0	34.2
DM Skarb	14.7	3.9	14.0	31.4
LSD_{05}	0.56	0.26	2.30	0.55

The obtained data indicate that the maximum number of grains from one maizecob have been obtained in the variants with Forteza hybrid - 540.4 pcs. (Fig. 1).

So, the hybrids increased the values on average from 34.5 to 85.1 pcs. of grains from one maizecob or by 6.4–15.7% (LSD_{05} = 19.5).

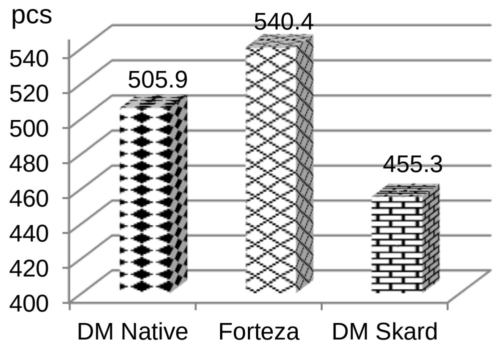

Figure 1. Number of grains from one maizecob depending on the variety characteristics (average for 2017–2021), pcs.

The main indicators of the productivity of crops are their yield, which in terms of production characterizes the amount of the produce. The ultimate goal of maize cultivation for biomass is to get the highest yield with high quality. The crop formation and the accumulation of its economic value is an important result of complex biochemical and physiological processes. The plant best reveals its potential under optimal environmental conditions, which depend on specific soil and climatic conditions of the year and varietal specificity.

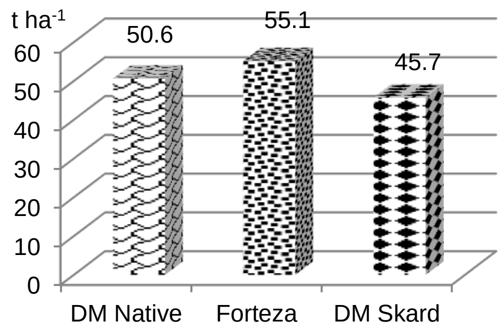

Figure 2. Maize biomass yield depending on the variety characteristics (average for 2017–2021) t ha^{-1}

For modern cultivation of stable crops of maize such biological properties of modern hybrids as plasticity and stability acquire great importance and characterize the adaptive properties of the organism, reveal the dynamics of changes in the genotype response to variations in environmental conditions, allow for their functions to stay relatively constant (Taran et al., 2018; Hlisnikovský et al., 2020). The data obtained by us, which characterize the magnitude of maize biomass, fully confirm the above point (Fig. 2).

The graph data indicate that the yield of hybrids of different maturity averaged between 45.7 and 55.1 t ha^{-1} (LSD_{05} = 3.85). The maximum yield, on average, during the researches period was formed by Forteza hybrid of 55.1 t ha^{-1}. DM Native and DM Skarb hybrids provided 50.6 and 45.7 t ha^{-1}, accordingly, for that indicator (Fig. 2).

CONCLUSIONS

The obtained experimental data of researches testify that the best indicators of productivity of maize for biomass are received at sowing of the hybrid Forteza. This hybrid provided the maximum height of a plant - 286.4 cm with assimilation surface of one plant and sowing 0.59 m^2; 42.8 thousand m^2 ha^{-1} and plant weight 760 g. The number of rows in a cob is 16.0 pcs and of grains in a row is 34.2 pcs. The average crop yield of the hybrid Forteza for the period of research was 55.1 t ha^{-1}. Hybrids DM Native and DM Skarb provided this indicator at the level of 50.6 and 45.7 t ha^{-1} respectively.

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