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Productivity of Corn Hybrids in the Conditions of the Western Forest-Steppe of Ukraine

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Abstract. The relevant scientific justification for the western region of Ukraine is the comprehensive assessment and selection of maize hybrids with wide environmental plasticity to ensure high and stable grain yield under the influence of specific weather factors. The increase in gross maize yields is possible due to the effective use of the genetic capabilities of new hybrids and is vital for the Western Forest-Steppe where this crop is not selected, and agricultural producers use hybrids of other originator institutions. The purpose of this study was to establish the grain productivity of hybrids of early-maturing and mid-early maturing groups in the soil and climatic zone of Ukraine under study. Generally accepted and special methods were used in this study, such as field, measurement and weight, statistical methods. Based on the obtained research results for 2019-2021, changes in weather conditions in the soil and climate zone under study were confirmed. The duration of the growing season of maize is determined depending on weather factors and the hybrid. The area of the leaf surface in the flowering stage (BBCH 61-69) – development of fruit (BBCH 71-79) and the net productivity of photosynthesis were found. The resistance of hybrid plants to diseases was substantiated and the highest percentage of their damage was found in 2021 with a large amount of precipitation during June-September. The dependence between hybrids and their biological properties was proved to effectively use the existing soil and climatic conditions, which affected grain productivity and the range of variability over the years. The results of this study suggest that changes in weather factors, namely an increase in the sum of active temperatures and sufficient precipitation during the growing season, enable high grain yields of maize hybrids of early-maturing and medium-early maturing groups. Recommendations were given for farms of various legal forms to introduce Ukrainian hybrids into agricultural production: DN Meotyda and Orzhitsa 237 MV

Keywords: FAO, BBCH development stages, leaf area duration, net photosynthesis productivity, diseases, yield

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INTRODUCTION

Currently, an urgent issue is the strategic grain sector of the agricultural sector of Ukraine, which forms food for the population and provides foreign exchange incomes of the state. As described in the article by Hadzalo & Luzan (2020), the conditions of an open economy will bring along an intensive competition with much more advanced foreign firms, and not just with each other. Therefore, more effective measures are required to protect the domestic agricultural market, to adapt the legislation to its European counterparts as much as possible.

M. Cherny (2017) believes that Ukraine has all the opportunities, both in terms of natural factors and the organisational structure of agricultural enterprises, to take a prominent place in the global grain market. However, there are also threats, according to Sabluk & Luzan (2019), which include the lack of reliable safeguards to prevent the shadow economy, unblocking the development of exchange trading as a tool for objectively determining prices in the agricultural sector of the Ukrainian economy.

The leader in grain production is maize – a crop of a wide range of application, used in 60% for animal feed, 25% for nutrition, and the rest – for industrial processing, as described in the studies of Dziubetskyi *et al*. (2020), Belov (2018) and Vozhegova *et al*. (2018). The leading role of maize lies not only in the efficiency of grain production, but also in the economic growth of the livestock industry, as Mason *et al*. (2019), Jareš *et al*. (2019) and Marchenko *et al*. (2021) note.

Ya. Nagy (2012) believes that the crop has recently gained considerable popularity among Ukrainian farmers due to the prominent biological potential of productivity, its demand in the internal and external markets, simplicity of cultivation technologies, low cost of grown products, which contributed to an increase in sown areas.

Currently, the maize collection in Ukraine is represented by 6,340 samples, including 548 local varieties, 532 breeding varieties, 211 synthetic populations, 4,584 self-pollinated lines and 465 lines with a genetically determined genotype. Kuzmyshyna *et al*. (2019) outlined self-pollinated lines of promising hybrids with a complex of valuable economic characteristics, which will improve the breeding process and ensure its acceleration by 4-5 years. Marković *et al*. (2017) indicates a considerable difference between hybrids in terms of productivity indicators due to genetic features.

Voloshchuk *et al*. (2021) concluded that the Western Forest-Steppe of Ukraine is a specific region, since it includes several zones: forest-steppe, Polissia, foothills, and mountains – all with differing soils, sums of effective temperatures, and precipitation. Therefore, to reduce the risks of the negative phenomena from the range of varietal resources of maize, it is advisable to adhere to the approximate ratio of hybrids: for the Forest-Steppe zone – 35% of the early-maturing group, 50-55% – mid-early maturing, 10-15% – mid-late maturing; for the Polissia zone – 100% of the early-maturing group.

Proper selection of hybrids as an effective factor in using their genetic capabilities plays an important role in increasing the gross grain yield of this crop. The desired result can be achieved by considering the biological requirements of the hybrid to the proposed cultivation technology, which includes sowing seeds of high generations, placement according to the best predecessors, sowing dates, seeding rates, plant nutrition system, and protection from diseases and pests, as indicated in the studies of Mazur & Shevchenko (2018), Lemic *et al*. (2019) and Marchenko (2019).

The climate of the Western Forest-Steppe, which has changed towards increasing active temperatures and reduced precipitation in the summer-autumn period, is favourable for growing maize. However, depending on the biological characteristics, the hybrid's response to the same factors is different, which requires identifying the most productive ones based on the principles of adaptability and ecological plasticity to respond positively to weather factors and proposed elements of cultivation technology. The expansion of the assortment of early-maturing hybrids (FAO 100-200) and medium-early (FAO 201-300) allows farms to obtain the required amount of grain and feed products, to sow and harvest at an earlier time, increase the density of agrocenosis and move away from conventional crop rotations, but leads to a slower accumulation of dry matter and accelerated moisture recovery at the final stages of grain maturation. Therefore, establishing the variability of morpho-biological signs under the influence of weather factors, maturity groups, the growing season, grain moisture loss and resistance to major diseases is an urgent issue of scientific research for practical recommendations for production.

The purpose of this study lies in figuring out the duration of interstage periods, leaf area duration, net photosynthetic productivity, disease resistance, and grain yield of maize hybrids of different maturing groups in the Western Forest-Steppe zone of Ukraine.

MATERIALS AND METHODS

Experimental work was performed during 2019-2022 in the Western Forest-Steppe zone. The experiments were conducted on grey forest surface-water gley, light loamy soil, which is the most common in the area under study and occupies over 50%. It has a shallow humus horizon (20-30 cm) with a humus content of 1.7% and is acidic (pH – 5.4). It is characterised by (per 100 g of soil, mg): nitrogen – 8.96, mobile and metabolic phosphorus – 6.95 and potassium – 6.80.

The hybrids of the state institution – the Institute of Grain Crops of the National Academy of Agrarian Sciences of Ukraine FAO 150-199 and FAO 200-299 were used as the source material. The area of the

experimental plot was: total – 60 m^2, accounting – 50 m^2. Placement of variants was systematic, and replication was threefold. The technology of growing crops was the generally accepted technology for the Western Forest-Steppe zone of Ukraine. The sum of active temperatures in the years of research exceeded the biological requirements of hybrids of the early-maturing and mid-early maturing groups by 211.1-348.5°C and 111.1-248.5°C with slightly lower precipitation in 2020 – 414.8 mm, in 2021 – 432.9 mm (for 450 mm).

The study was conducted according to generally accepted author's methods: phenological observations of plants (Dudka *et al.*, 2019); phytopathological assessment of plants – accounting for diseases and pests of agricultural crops (Omelyuta *et al.*, 1986); determination of plant leaf area duration and net photosynthetic productivity of maize (Peterson *et al.*, 1993); determination of morpho-biological indicators (Fursova *et al.*, 2004); maize grain yield (Methodology..., 2003); general statistical processing of research data ($LSD_{0.05}$ – least significant difference) (Atramentova & Utevskaya, 2014).

RESULTS AND DISCUSSION

Due to the compaction of the soil under the influence of a large amount of precipitation (176% of the average long-term indicator), the duration of the sowing-seedling period in the studies conducted at the Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences of Ukraine was 16 days. In 2020, the difference between high day and low night temperatures led to an increase in the duration of this period to 18 days. Low rainfall in 2021 (68%) provided seedling in 13 days. On average, over the years of research, the sowing-seedling period lasted 15 days (Table 1).

***Table 1**. Duration of stages of plant development and grain maturation of maize hybrids (2019-2021)*

Hybrid	FAO	Number of days								Total
		Vegetating period					Grain maturing			
		BBCH 00-09 (germination)	BBCH 10-19 (leaf development)	BBCH 30-39 (stem elongation)	BBCH 51-59 (inflorescence emergence)	BBCH 61-69 (flowering)	BBCH 71-79 (milky)	BBCH 83-85 (waxy)	BBCH 87-89 (full-ripe)	
Pochaevsky 190 MV	150-199	15	44	13	5	7	17	13	11	125
DN Meotyda	150-199	15	45	13	5	7	17	13	11	125
DN Khortitsa	200-299	15	46	14	6	6	16	12	12	127
Orzhitsa 237 MV	200-299	15	47	14	6	6	16	12	12	127
Deviation		0	2	1	1	1	1	1	2	4

According to the duration of the BBCH 10-19 stage (leaf development), the difference between the early-maturing and medium-early maturing groups was 1-2 days. In the stages: BBCH 30-39 (stem elongation), BBCH 51-59 (inflorescence emergence) and BBCH 61-69 (flowering), the difference was one. The duration of milky stage in hybrids varied within 16-17 days, waxy stage – 12-13 days, full-ripe stage – 11-12 days. The total number of days from germination to flowering was 77-82, grain formation and maturation – 41 (early maturing) and 40 (medium-early), the growing season of early-maturing hybrids was 125 days, medium-maturing – 127 days.

The leaf area duration in the flowering stage of maize was formed in the close interaction of the biological characteristics of the hybrid, its maturing group and weather conditions that developed over the years of research. Depending on the weather conditions of the year and the productivity of the hybrid, the average area of the maize leaf area duration ranged from 34.1 thousand m^2/ha up to 40.1 thousand m^2/ha (Fig. 1).

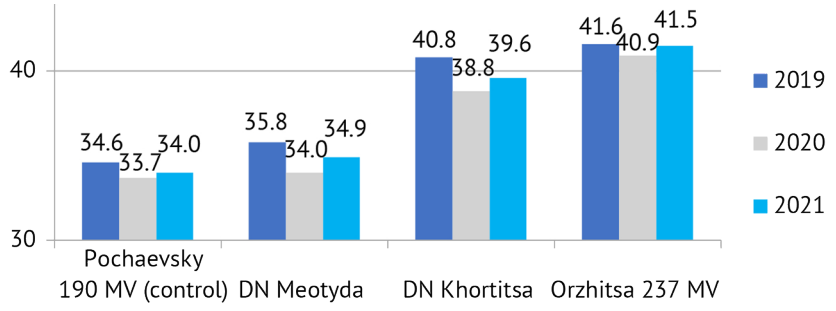

***Figure 1**. The leaf area duration of maize depending on the hybrid maturing group (2019-2021), thousand m^2/ha*

The maximum development of the leaf surface during the flowering period was recorded in 2019 with the sum of active temperatures higher than the annual average by 304°C and precipitation 9.7 mm – 34.6-41.6 thousand m²/ha. In 2020, compared to the previous year, these meteorological indicators were: 178°C, and 45.6 mm. Under such weather conditions, the leaf area duration varied from 33.7 to 40.9 thousand m²/ha, and in 2021 – from 34.0 to 41.5 thousand m²/ha. A significant difference in this indicator was recorded between the groups of hybrids maturing. Due to the longer growing season in the varieties of the medium-maturing group compared to the early-maturing one, it was larger by 5.6-7.2 thousand m²/ha. The range of variability over the years was within the margin of error of 7.0-7.5 thousand m²/ha for LSD_{05}=0.9.

The net photosynthetic productivity of maize hybrids was within 10.5-12.6 g/m² per day – in 2019, 9.8-11.6 g/m² per day – in 2020 and 9.9-12.1 g/m² per day – in 2021 (Fig. 2). The volatility of this indicator ranged from 1.8 (in 2020) to 2.2/m² per day (in 2021).

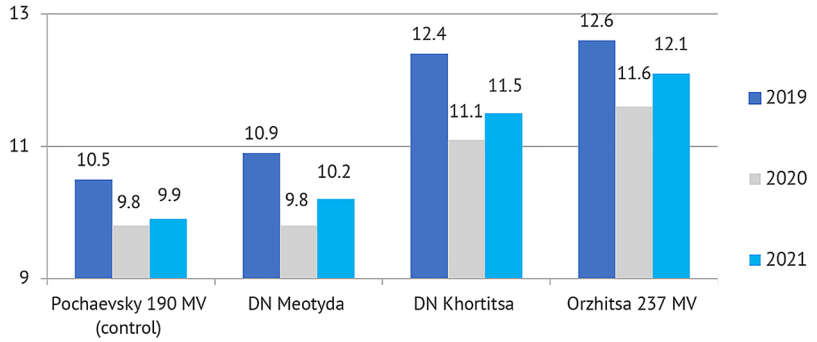

***Figure 2**. Influence of the hybrid maturing group on maize photosynthesis productivity (2019-2021), g/m² per day*

The spread of diseases was affected by hot temperature (20-25°C) and humidity during the flowering period, which contributed to the damage of generative organs (cob, panicle). Plants were evaluated on a 5-point scale, where plant damage of 0-10% corresponds to 9 resistance points. According to this definition, it was found that the maize hybrids under study were resistant to smut (Fig. 3). The percentage of plant damage in the early-maturing hybrid Pochaevsky 190 MV, which was taken as a control, was 12.1%, which corresponds to a resistance score of 7. A 1.5% lower development of the disease was found in a hybrid of DN Meotyda. In medium-early maturing hybrids (FAO 200-299), the development of this disease was significantly lower than the control by 2.6-3.3% per LSD_{05}=1.3%.

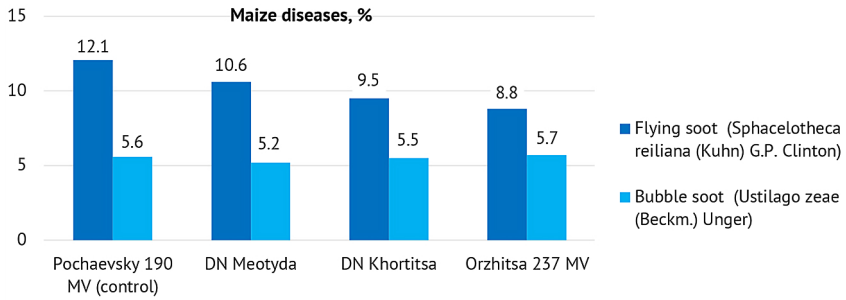

***Figure 3**. Smut development on maize plants depending on the biological characteristics of the hybrid in the BBCH 89 stage (2019-2021), %*

Since maize was sown in a crop rotation with the observed rotation of alternating crops, and the sown seeds were characterised as biologically healthy, the development of this disease was insignificant (5.2-5.7%), i.e., all hybrids were classified as resistant (7 points). There was no significant difference between the maturing groups, and the difference was within the margin of error.

Among the various types of stem rot, the most dangerous is fusarium rot, which affects the roots and lower internodes and affects the lodging of plants, especially if the soils of the soil and climate zone under study are sufficiently moist. The average percentage of disease intensity in the experiments of this study ranged from 13.9% in the early-maturing hybrid Pochaevsky 190 MV (control) to 14.7% in the mid-early maturing Orzhitsa 237 MV (Fig. 4). According to the degree of damage to the cob area, hybrids were classified as medium-resistant – 24.4-29.1%. Group resistance to major diseases of maize from early-maturing (FAO 150-199) hybrids was provided by DN Meotyda, from medium-early maturing (FAO 200-299) – Orzhitsa 237 MV.

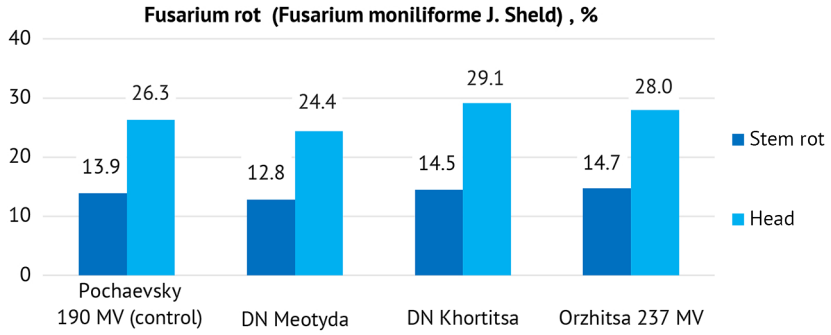

***Figure 4**. Development of fusarium rot (Fusarium moniliforme J. Sheld) on maize depending on the biological features of the hybrid in the BBCH 89 stage (2019-2021), %*

***Note:** the degree of damage: wea – up to 25%, average – 26-50%, strong – above 50%*

In the authors' experiments, the highest grain productivity was obtained in 2019 – 7.49 t/ha in hybrids of the early-maturing group and 7.62 t/ha – in mid-early maturing; the productivity was lower in 2020 – 7.07 and 7.22 t/ha, respectively (Table 2). In terms of average yield, the following hybrids were more productive: DN Meotyda (7.68 t/ha), Orzhitsa 237 MV (7.67 t/ha).

***Table 2**. Maize grain yield depending on the hybrid maturing group (2019-2021)*

Indicator	FAO					
	150-199			200-299		
	Pochaevsky 190 MV	DN Meotyda	Mean	DN Khortitsa	Orzhitsa 237 MV	Mean
2019	7.11	7.87	7.49	7.46	7.78	7.62
2020	6.59	7.55	7.07	6.88	7.56	7.22
2021	6.87	7.63	7.25	7.11	7.67	7.39
Mean	6.86	7.68	7.27	7.15	7.67	7.41
min	6.59	7.55	7.07	7.11	7.56	7.22
max	7.11	7.87	7.49	7.46	7.78	7.62
R	0.52	0.32	0.42	0.35	0.22	0.40
LSD_{05}	0.21	0.17		0.14	0.11	

The range of grain yield variability over the years ranged from 0.22 to 0.52 t/ha, which confirms the individual reaction of the hybrid to growing conditions.

Several institutions of the National Academy of Agrarian Sciences are working on solving the urgent problem of the development of grain production, namely maize, in Ukraine; at the same time, agricultural production declares an elevated practical interest in innovative developments. Since the new maize hybrids included in the Register (Methodology for the examination and state..., 2003) react differently to particular growing conditions of different zones, subzones, and soil differences, their implementation requires a scientific justification of the advantages of genetic productivity. This task is particularly relevant in the Western Forest-Steppe zone, where maize is not selected, and agricultural producers use hybrids of originator institutions located in the Central Forest-Steppe and Steppe zones.

According to the results of the authors' research, hybrids that provided grain yields at 7.07-7.62 t/ha were ecologically flexible to the growing conditions of the Western Forest-Steppe zone. The conclusions made by the authors of this study are consistent with the experimental data of researchers and scientists in various soil and climatic zones of Ukraine.

Andrienko *et al.* (2017a) confirms the effective use of soil and climatic potential by maize hybrids of early-maturing and medium-early maturing groups, which allows obtaining not only high yield and quality of grain, but also save material, technical, and monetary resources. They offer medium-early hybrids with high potential yields for the eastern part of the Forest-Steppe of Ukraine: Lyubchik (FAO 240), Vektor (FAO 270) of the grain direction, Stavr (FAO 290) – universal direction.

According to the recommendations of Shevchuk & Kyriyenko (2022), the best Ukrainian hybrids for the

conditions of the Polessia zone of Ukraine are Pochaevsky 190 SV (early-maturing), Baturinsky 278 MV and Orzhitsky 237 MV (medium-early maturing).

Researchers (Zaplitnyi *et al.*, 2010) believe that for more economical use of energy resources for drying maize grain, considering the level of energy supply in the south-western part of the Forest-Steppe, it is possible to grow hybrids: early-maturing at the sum of active temperatures of 2200°C, medium-early – 2400°C and medium-maturing – 2600°C. Introduction of immune-resistant products is the most effective means of preventing diseases and pests, and therefore agricultural producers should pay special attention to the choice of hybrids considering a complex of biological and economic characteristics.

Andrienko *et al.* (2017b) emphasise that the main step in growing maize for grain and dealing with stress should be the correct identification of the hybrid that best meets the available soil-climatic, agrotechnical conditions and technical support of a particular farm. Increasing the level of production, reducing the cost of post-harvest grain determine the timing of sowing and the choice of maize hybrids of different maturing groups, the share of which in the structure of sown areas for grain should be differentiated and vary depending on the specialisation of the farm and its practical orientation.

Tsekhmeystruk *et al.* (2014) note a 40-50% use of the genetic potential by modern hybrids with a potentially high yield of 16-18 t/ha. The authors present the data of the National Institute of Agricultural Botany of Great Britain on the increase in yield growth due to varieties and hybrids over thirty years. It is indicated that for the first decade it is 38%, the second decade – 42% and the third decade – 60%. It is noted that the maximum yield is provided by hybrids with the optimal FAO for the growing area, since the choice with less than the recommended one leads to incomplete use of solar radiation during the growing season and a shortage of crops, while greater FAO does not necessarily allow achieving full-ripe maturing of grain and unjustified costs for its drying.

Kaminsky & Asanishvili (2020) found a different reaction of hybrids to cultivation technologies. In intensive farming systems, production resources are most effectively used for growing a medium-early hybrid with a high genetic productivity potential. To expand grain production, increase gross grain volumes and land use efficiency, it is advisable to use high-intensity maize cultivation technology, which makes provision for the introduction of $N_{180-240}P_{120}K_{180-240}$ against the background of by-products of the precursor, herbicides, microfertilisers and growth stimulants. With a yield of 11.21-12.10 t/ha, the profitability is 118-128%, which allows agricultural enterprises to conduct large-scale commercial grain production. It is advisable to grow the early-ripening hybrid Trubizh SV using intensive technology with mineral fertilisers in a dose not higher than $N_{120}P_{80-90}K_{100-120}$ against the background of by-products of the predecessor, which provides a profit of 23.0-23.96 thousand UAH/ha, profitability of 121% at a yield of 8.40-8.77 t/ha and a reduction in production costs by 22.7-28.4% due to herbicide control of segetal vegetation in crops, foliar top dressing with microfertilisers, and the use of plant growth regulators in various regulations.

The selection of environmentally friendly maize hybrids of various originator institutions with high productivity and product quality and lower humidity during harvesting will contribute to an increase in gross collections in the zone of excessive moisture in the Western Forest-Steppe of Ukraine, which leads to further research.

CONCLUSIONS

Ukrainian selection has created a number of new maize hybrids that are offered to producers, but they have different morpho-biological features and characteristics, a reaction to favourable and adverse factors of production, which requires differentiated selection to achieve an increase in grain yield and quality.

During the vegetation period of maize plants, the sum of active temperatures varied from 2311°C in 2021 to 2448.5°C in 2019 with a long-term average of 2372.2°C. Moisture supply was at 414.8 mm (2020) – 432.9 mm (2021). Under the influence of weather conditions and the maturing group of the hybrid, the duration of the growing season varied within 125-127 days.

Depending on the biological characteristics, the hybrids provided a different leaf area duration during the flowering stage (BBCH 61-69) – grain formation (BBCH 71-79) (34.1-41.3 thousand m^2/ha) and net photosynthetic productivity (10.1-12.1 g/m^2) per day.

The highest percentage of disease damage was observed in 2021 with a large amount of precipitation during June-September. Group resistance to major diseases of maize from early-maturing (FAO 150-199) hybrids was provided by – DN Meotyda, from medium-early (FAO 200-299) – Orzhitsa 237 MV. Grain yield was ensured by the productivity of the hybrid to effectively use the available soil and climatic resources of the zone under study. In early-maturing hybrids, this economically valuable indicator was formed at 7.07-7.49 t/ha, in mid-early hybrids – at 7.22-7.62 t/ha.

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Продуктивність гібридів кукурудзи в умовах Західного Лісостепу України

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Анотація. Актуальним науковим обґрунтуванням для західного регіону України є комплексна оцінка та добір гібридів кукурудзи з широкою екологічною пластичністю забезпечувати високу і стабільну урожайність зерна під впливом специфічних погодних чинників. Збільшення валових зборів кукурудзи можливе за рахунок ефективного використання генетичних можливостей нових гібридів і є надзвичайно важливим для зони Західного Лісостепу де не ведеться селекція даної культури, а сільськогосподарські виробники користуються гібридами інших установ-оригінаторів. Метою дослідження було встановити зернову продуктивність гібридів ранньостиглої і середньоранньої груп в досліджуваній ґрунтово-кліматичній зоні України. У дослідженнях застосовували загальноприйняті і спеціальні методи: польовий, вимірювально-ваговий, статистичний. На основі отриманих результатів досліджень за 2019–2021 рр. підтверджено про зміну погодних умов у досліджуваній ґрунтово-кліматичній зоні. Визначено тривалість періоду вегетації кукурудзи залежно від погодних факторів та гібриду. Встановлено площу листкової поверхні в фазу цвітіння (ВВСН 61–69) – формування зерна (ВВСН 71–79) та чисту продуктивність фотосинтезу. Обґрунтовано стійкість рослин гібридів до хвороб та виявлено найвищий їх відсоток ураження в 2021 р., за великої кількості опадів впродовж червня-вересня. Доведено залежність між гібридами та їх біологічними властивостями ефективно використовувати наявні ґрунтово-кліматичні умови, що впливало на зернову продуктивність і розмах мінливості за роками. Отримані результати дозволяють зробити висновок, що зміни погодних факторів, зокрема підвищення суми активних температур та достатня кількість опадів впродовж вегетації дозволяють отримувати високі врожаї зерна гібридів кукурудзи ранньостиглої і середньоранньої груп стиглості. Господарствам різних організаційно правових форм рекомендовано впроваджувати в сільськогосподарське виробництво українські гібриди: ДН Меотида та Оржиця 237 МВ

Ключові слова: ФАО, фази розвитку ВВСН, площа листкової поверхні, чиста продуктивність фотосинтезу, хвороби, урожайність