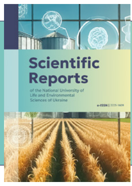
Received 20.02.2025 Revised 22.06.2025 Accepted 27.08.2025

Vol. 21, No. 4
2025



Scientific Reports of the National University of Life and Environmental Sciences of Ukraine

Journal homepage: https://scireports.com.ua/en

UDC 633.15:631.53.048:57.087.1

DOI: 10.31548/dopovidi/4.2025.81

Dynamics of biometric indicators of maize plants under the influence of sowing rates and field productivity zones

Lesia Harbar
PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0003-4249-0434

Bohdan Vaskivskyi*
Postgraduate Student
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0009-0003-6852-3844

Abstract. Biometric indicators of maize are an important indicator of the effectiveness of agricultural technologies and reflect the adaptive response of crops to spatial heterogeneity of growing conditions. The aim of the study was to determine the effect of zonal productivity and sowing rates on the height and dry matter formation of maize in the early stages of organogenesis. Field studies were conducted in 2023-2024 within three field productivity zones: high, medium and low. Five sowing rates were varied, ranging from 65 to 85 thousand seeds/ha. The results of the studies show that the productivity zone had the main influence on the biometric parameters of plants, while the sowing rate had an additional but less significant effect. At the V2-V3 stage of corn development, the maximum dry matter content (up to 23.5%) was observed in the high-yield zone at a sowing rate of 70 thousand seeds/ha. In low-productivity zones, the indicators decreased to 15.5%. Plant height in this phase ranged from 22.5 cm in the high zone to 16.6 cm in the low productivity zone. In the early flowering phase (R1), a decrease in dry matter content was observed towards less productive zones: from 31.7% (high zone, 70 thousand/ha) to 25.3% (low zone, 85 thousand/ha) in 2023. Plant height varied from 252 cm in high-yielding areas to 143 cm in low-yielding areas. The biometric parameters of maize can be used as a reliable criterion for assessing the response of crops to differentiated

Suggested Citation:
Harbar, L., & Vaskivskyi, B. (2025). Dynamics of biometric indicators of maize plants under the influence of sowing rates and field productivity zones. *Scientific Reports of the National University of Life and Environmental Sciences of Ukraine*, 21(4), 81-91. doi: 10.31548/dopovidi/4.2025.81.

**Corresponding author*

technological techniques, which is a promising direction in precision farming systems. The use of zonally differentiated sowing rates allows for more efficient use of resources and optimisation of agricultural technologies for growing maize in fields with varying productivity

Keywords: *Zea mays* L.; plant height; differentiated sowing; plant density; dry matter

Introduction

In the current conditions of climate change and increasing spatial variability in the productivity of agrocenoses, it is particularly important to improve the technologies used to grow maize, a crop that plays a key role in the global grain and feed system. The use of intensive hybrids with high genetic potential requires precise selection of sowing rates and a differentiated approach to fertilisation depending on growing conditions, which is the basic principle of precision farming technologies. Taking into account field productivity zones allows for the optimisation of resource use and increased efficiency of agrotechnical measures.

Recent studies emphasise that spatial management of sowing rates allows for the optimisation of corn photosynthetic activity by adapting the sowing structure to environmental conditions. In particular, according to research by N. Saleem *et al*. (2025), the use of differentiated sowing rates in combination with consideration of leaf orientation (phyllotaxis) improves light use efficiency in dense crops. Similarly, the results of studies by K. Djaman *et al*. (2022) in North America showed that optimal densities (approximately 80-90 thousand/ha) contribute to increased moisture efficiency and yield under conditions of limited moisture supply, which is relevant in the context of adapting corn crops to climate change. Research by G. Lacolla *et al*. (2023) in Mediterranean conditions indicates that optimising corn planting density has a positive effect not only on yield, but also on root system formation and soil water balance, which is critically important for regions with seasonal droughts. In addition, recent developments by K. Bűdi *et al*. (2025) in the field of precision farming demonstrate that the use of Variable Rate Seeding technology in combination with adaptive hybrid selection reduces seedling heterogeneity and ensures more uniform biometric indicators within a heterogeneous field.

The work of E. Sarauskis *et al*. (2022) analyses modern approaches to variable seeding rates based on the use of yield maps, remote sensing data and sensor systems. The results show that combining different sources of information for field zoning makes it possible to increase the accuracy of determining the optimal plant density and reduce spatial variability in yield. According to the results of Z. Du *et al*. (2022), the use of spatial gradient analysis for decision-making on VRS allows for a 5-10% increase in maize yield while reducing seed costs. The researchers emphasise that this approach is effective in fields with heterogeneous soil and climatic conditions, where traditional fixed sowing rates do not ensure optimal productivity.

The study by K. Bakó *et al*. (2025) summarises current approaches to modelling the leaf area index (LAI) of maize using remote sensing and models such as CERES-Maize, AquaCrop, WOFOST, APSIM and RZWQM2. The authors point out that a decrease in LAI under conditions of insufficient moisture directly correlates with a decrease in CO_2 absorption and plant productivity, while accurate LAI prediction allows for the optimisation of seeding rates to improve adaptation to stressful conditions. The work of D. Li *et al*. (2022) demonstrates the potential of integrating machine learning and active sensor monitoring to predict the nitrogen status of maize crops. This allows the optimisation of plant density to be combined with nitrogen nutrition regulation, which together contributes to increased grain yield and quality.

Field experiments by M. Videgain *et al.* (2024), conducted under commercial farming conditions, showed that optimising plant density in the range of 350-450 grains/m² while taking into account microzone productivity resulted in improved yield and agrophysiological characteristics of the crop without additional resource costs. In addition, the use of VRS improved the uniformity of emergence and reduced intraspecific competition between plants. Thus, a modern corn cultivation strategy must take into account the interaction of planting density, zonal productivity, and nutritional conditions to achieve the maximum genetic potential of the crop. In this context, studying changes in maize biometric indicators depending on field spatial conditions and sowing rates is extremely relevant.

The aim of the study was to analyse the effect of seed sowing rates and zonal field productivity on changes in morphometric indicators and dry matter accumulation in maize during different phases of its growth and development.

Materials and Methods

Field studies were conducted in 2023-2024 on the territory of "Chernihiv Industrial Dairy Company" LLC, located within the Chernihiv district of the Chernihiv region, in the transition zone between Polissia and Forest-Steppe. The agricultural landscape of this territory is characterised by high spatial heterogeneity in terms of relief, granulometric composition and agrochemical condition of soils, which creates optimal conditions for studying changes in the biometric parameters of maize depending on field productivity zones.

The field experiment was two-factor. Factor A – field productivity zones (high, medium, low), determined on the basis of long-term yield, relief, agrochemical maps and cluster analysis in the QGIS environment (Havlin *et al.*, 2013). Factor B was the corn sowing rate (65, 70, 75, 80, and 85 thousand seeds/ha). The object of the study was the DKS 3939 maize hybrid of the medium-early maturity group. The experiment was set up in four replicates on three experimental plots with an area of 6.6 ha. The predecessor crop was winter wheat. Plant density at the time of harvesting was ensured by controlling sowing rates and the quality of seedling formation. The boundaries of the zones were determined using digital yield maps and spatial analysis modules, and the agrochemical status of the zones was detailed using the analysis of soil samples taken from a depth of 0-30 cm with a density of 10-20 points per zone. The samples were mixed, processed and analysed in accordance with the requirements of DSTU ISO 11260:2001 (2001). Biometric indicators of maize were determined at the initial stages of maize development (V2-V3) and flowering (R1). The following were measured: plant height (from the soil surface to the growing point), dry matter content (drying at 105°C to constant weight). Data collection was based on a sample of 10 typical plants in each variant. Mathematical statistics methods were used to analyse the impact of factors on biometric parameters. In particular, mean values and standard deviations were calculated. Correlations between sowing rates, productivity zones and dry matter accumulation were also identified. The study was conducted in accordance with the Convention on Biological Diversity (1992).

Meteorological conditions during the experiment were monitored using an automatic weather station installed directly on the experimental site, recording air temperature, precipitation, relative air humidity and wind speed at 1-hour intervals. To assess the statistical significance of the differences between the variants, a two-factor analysis of variance (ANOVA) was used, followed by a comparison of the means using the least significant difference (LSD_{05}) criterion in the R software environment, version 4.3.0. Correlation analysis was performed to establish relationships between agrochemical soil indicators (humus content, mobile forms of phosphorus and potassium, pH) and biometric parameters of plants at different sowing rates. Plant samples for determining biometric indicators were selected in the morning (7:00-9:00) to minimise the impact of daily fluctuations in turgor and photosynthetic activity on the measurement results.

Results

Despite differences in weather conditions between years, similar patterns in changes in biometric indicators were observed. The highest plant height and dry matter indicators were observed in high-yield areas with sowing rates of 70-75 thousand/ha, while in medium and low areas, the effectiveness of factors increased with increasing sowing rates. The results of the studies show that the level of biometric parameters of maize in the early stages of vegetation was determined by the influence of the zonal productivity of the field. The sowing rate in the early stages of development (V2-V3 emergence phase) had a negligible effect on plant growth intensity, which is explained by insufficient competition among plants for resources in dense crops. The dry matter content and plant height showed a clear gradation in accordance with the productive potential of the zones. The actual plant density reflected a high level of maize field emergence, but at the same time indicated the presence of plant losses at certain stages of seedling establishment (Table 1).

Table 1. *Actual plant density of maize and its deviation from planned values at the seedling stage*

Zone	Sowing rate, thousand/ha	Actual plant density, thousand/ha			Deviation from planned sowing rate, %		
		1	2	Avg.	1	2	Avg.
High	65	63.8	62.7	63.3	1.8	3.5	2.7
	70	68.4	67.6	68.0	2.2	3.4	2.9
	75	73.4	72.4	72.9	2.1	3.4	2.8
	80	78.1	77.2	77.7	2.3	3.5	2.9
	85	83.2	82.1	82.7	2.1	3.4	2.8
Average deviation for high-productivity zone, %:					2.1	3.4	2.8
Medium	65	63.1	62.1	62.6	2.9	4.4	3.7
	70	68.2	66.7	67.5	2.5	4.7	3.6
	75	73.1	71.7	72.4	2.5	4.4	3.5
	80	78	76.7	77.4	2.5	4.1	3.3
	85	82.9	81.6	82.3	2.4	4.0	3.2
Average deviation for medium-productivity zone, %:					2.6	4.3	3.5
Low	65	61.8	61.3	60.7	4.9	6.6	5.8
	70	66.5	66.0	65.4	5.0	6.5	5.8
	75	71.3	70.7	70.1	4.9	6.5	5.7
	80	76	75.4	74.8	5.0	6.5	5.7
	85	80.8	80.2	79.5	4.9	6.4	5.7
Average deviation for low-productivity zone, %:					4.9	6.5	5.7

Note: 1 – 2023; 2 – 2024

Source: developed by the authors

In the high-yield zone, with a sowing rate of 65-85 thousand plants per hectare, the actual density in 2023 was 63.8-83.2 thousand plants per hectare, and in 2024 – 62.7-82.1 thousand pcs/ha, which indicates a deviation from the planned indicators at the level of 1.8-2.4% in 2023 and 3.4-3.5% in 2024. The average deviation for this zone over two years was 2.8%, indicating relatively stable conditions for crop growth and effective seedling formation. In the medium productivity zone, there was a slightly greater deviation from the planned density: 2.5-2.9% in 2023 and 4.0-4.7% in 2024. This is explained by less favourable conditions. The average deviation in this zone was 3.5%, which is acceptable for field conditions but indicates the need to adjust agronomic measures in less favourable microzones. The largest deviations were observed in the low-productivity zone: 4.9-5.0% in 2023 and 6.4-6.6% in 2024. The average deviation from the planned density was 5.7%, which indicates a significant impact of unfavourable environmental conditions on seed germination processes.

In general, the results show a steady trend towards a decrease in actual density as we move from high-yield to low-yield zones, indicating spatial heterogeneity in the conditions for the formation of initial plant cover density. The data obtained are important for optimising maize cultivation technology, in particular for the application of precision farming and differentiated seed sowing technologies. Studies of the influence of spatial variability and variable sowing rates on plant height and dry matter content at the V2-V3 stage of maize development showed that these parameters varied significantly depending on the productivity zone of the field and, to a lesser extent, on the sowing rate (Table 2).

Table 2. *Effect of spatial variability and variable sowing rates on dry matter content and plant height of maize at the V2-V3 stage of development*

Zone	Sowing rate, thousand/ha	Dry matter content in plants, %,			Plant height, cm		
		1	2	Avg,%	1	2	Avg,%
High	65	22.3	17.6	20.0	21.7	19.9	20.8
	70	23.5	19.4	21.5	22.5	19.2	20.9
	75	22.6	18.3	20.5	21.2	18.3	19.8
	80	20.5	19.7	20.1	21	19.7	20.4
	85	21.4	18.6	20.0	22.2	19.4	20.8
Average for high zone:		22.1	18.7	20.4	21.7	19.3	20.5
Medium	65	19.8	16.2	18.0	19	17.8	18.4
	70	18.8	16.6	17.7	20.7	16.5	18.6
	75	17.2	15.1	16.2	19.4	16.5	18.0
	80	19.4	15.1	17.3	19.6	17	18.3
	85	17.5	16.3	16.9	19.9	16.6	18.3
Average for medium zone:		18.5	15.9	17.2	19.7	16.9	18.3
Low	65	15.7	10.9	13.3	17.2	13.5	15.4
	70	15.5	12	13.8	16.6	13.8	15.2
	75	14.6	10.7	12.7	16.9	14.4	15.7
	80	14.6	10.6	12.6	16.5	14	15.3
	85	15.6	11.8	13.7	17.2	13.4	15.3
Average for low zone:		15.2	11.2	13.2	16.9	13.8	15.4

Note: 1 – 2023; 2 – 2024
Source: developed by the authors

The highest dry matter content values were observed in the high-yield zone, where the average values for two years were 20.1-21.5%, and the average value for the zone was 20.4%. In the middle zone, this indicator ranged from 16.2 to 18.0%, with an average value of 17.2%, and in the low-productivity zone, it was only 12.6-13.8%, with an average level of 13.2%. This confirms the close relationship between the level of environmental productivity and the intensity of biomass accumulation in the early stages of organogenesis. Plant height in the early stages of development (at the V2-V3 stage), as one of the key morphometric indicators, differed significantly between productivity zones. In the highly productive zone, the average height was 20.5 cm, in the medium zone – 18.3 cm, and in the low-productive zone – 15.4 cm. Within each zone, the sowing rate had a less significant effect on plant height, although a slight decrease in height was observed with an increase in sowing density. This pattern can be explained by the initial competition for moisture. Thus, the results show that in the early stages of maize vegetation, the main determining factor of biometric indicators was the productivity of the zone, while the differentiation of sowing rates had only a slight effect. At the beginning of maize flowering (R1), biometric indicators showed significant variability depending on spatial productivity zones and sowing rates, reflecting the interaction of the genetic potential of plants with environmental conditions (Table 3).

Table 3. *Effect of spatial variability and variable sowing rates on dry matter content and plant height at the beginning of maize flowering (R1)*

Zone	Sowing rate, thousand/ha	Dry matter content in plants, %,			Plant height, cm		
		1	2	Avg,%	1	2	Avg,%
High	65	32.2	30.6	31.4	225	178	201.5
	70	31.7	30.1	30.9	235	185	210.0
	75	31.2	29.5	30.4	245	192	218.5
	80	30.7	29.1	29.9	252	196	224.0
	85	30.1	28.5	29.3	250	194	222.0
Average for high zone:		31.2	29.6	30.4	241.4	189.0	215.2
Medium	65	30.1	28.4	29.3	200	164	182.0
	70	29.6	27.9	28.8	210	171	190.5
	75	29.1	27.3	28.2	220	178	199.0
	80	28.6	26.8	27.7	218	176	197.0
	85	28.1	26.2	27.2	215	175	195.0
Average for medium zone:		29.1	27.3	28.2	213	173	192.7
Low	65	27.2	25.6	26.4	160	147	153.5
	70	26.8	25.1	26.0	170	154	162.0
	75	26.3	24.5	25.4	168	153	160.5
	80	25.8	24.0	24.9	165	150	157.5
	85	25.3	23.4	24.4	155	143	149.0
Average for low zone:		26.3	24.5	25.4	163.6	149.4	156.5

Note: 1 – 2023; 2 – 2024
Source: developed by the authors

The general trend showed an increase in dry matter content and plant height in more productive areas under optimal density conditions. The highly productive zone provided the highest dry matter accumulation rates, averaging 30.4%, with a variation from 29.3 to 31.4% depending on sowing rates and weather conditions during the year. In the medium zone, dry matter content decreased to 28.2%, and in the low-yield zone to 25.4%, indicating the limiting effect of less favourable soil and microclimatic conditions. The decrease in dry matter content from high-yielding to low-potential zones confirms the dependence of maize growth and development intensity on resource availability.

Plant height in the R1 phase proved to be the most sensitive indicator to growing conditions. In the high-yield zone, the average height was 215.2 cm, ranging from 201.5 to 224 cm depending on the sowing rate and year. In the medium zone, the average plant height was 192.7 cm, and in the low zone, it was 156.5 cm. The decrease in plant height from high to low productivity zones is due to a reduction in the amount of available nutrients and moisture and less favourable conditions for photosynthetic activity. Optimal height indicators were observed at a density of 80 thousand/ha in highly productive zones, indicating a balance between resource availability and the intensity of competition between plants. In less productive areas, increasing density did not result in further height growth, indicating limited environmental resources. Thus, at the flowering stage, the main factors influencing the biometric indicators of maize were the productivity zone and weather conditions of the year, while the sowing rate had an additional but less pronounced effect. The results indicate the feasibility of a spatially differentiated approach to managing sowing rates and fertiliser application to optimise maize growth and development in heterogeneous field conditions.

Discussion

The results of the study indicate a significant influence of sowing rates and productivity zones on the formation of biometric indicators of maize and dry matter accumulation during vegetation. Similar patterns are described in the work of W. Liu *et al.* (2023), where it was found that spatial differences in soil fertility and moisture supply determine the rate of dry matter accumulation in different phases of maize growth. A. Shatkovskyi *et al.* (2020) note that under favourable conditions, dry matter accumulation is linearly increasing until the beginning of the milk ripeness phase, while under moisture deficit, there is an early decrease in photosynthesis intensity and premature leaf senescence, which reduces potential yield. Compared to the results of this study, in highly productive areas, the rate of dry matter accumulation corresponded to global trends, indicating the effectiveness of adapting plant density to spatial conditions.

A study by Z. Zhu *et al.* (2022), which used the Richards model to describe the growth dynamics of maize, showed that optimising agronomic parameters, in particular plant density, affects not only the final amount of dry matter accumulated, but also the duration of the active growth phase. The authors emphasise that prolonging the period of maximum absorption of photosynthetically active radiation directly correlates with an increase in yield and energy use efficiency. In the same study, increasing the duration of active vegetation in high-yield areas also resulted in higher yields, confirming the importance of regulating sowing density to optimise plant photosynthetic activity. A.A. Anselmi *et al.* (2021) note that under conditions of high productivity, thickening is advisable, while in low-productivity areas, moderate density is more effective. The results of this study confirm this pattern: in a high-yielding area, a density of 70-75 thousand/ha proved to be optimal, while in medium and low-yielding areas, increasing the sowing rate did not result in an increase in biometric indicators. A.F. Silva *et al.* (2021) showed that spatially differentiated sowing rates increase resource efficiency and reduce stress risks for plants. This is consistent with the data from this study: the actual density and dry matter content differed significantly between productivity zones, confirming the need to adapt density to local field conditions.

A study by M. Zhang *et al.* (2025) showed that optimising corn seeding density significantly affects both yield and resource use efficiency. Based on a meta-analysis of 1951 data sets, it was found that increasing seeding density increases leaf area by 23.4%, plant height by 1.8%, dry biomass accumulation by 15.9%, water use efficiency by 3.8%, nitrogen use efficiency by 34.2% and yield by 10-11%. At the same time, a decrease in the weight of 1,000 grains by 7.2% and the collection coefficient by 2.4% was found, indicating a compromise between the structural components of yield. The authors emphasise that the optimal plant density should take into account hybrid characteristics and moisture levels in order to avoid the negative effects of excessive crop compaction.

Field trials by J. Cui *et al.* (2022) of modern maize hybrids at three density levels, where stem strength indicators were measured: stem breaking strength (SBS), dry weight per unit length, stem cross-section, lignin and cellulose content showed that at high densities, modern hybrids exhibited lower SBS, lower stem weight and reduced structural biomass content, which correlated with an increased likelihood of lodging. These findings are consistent with the observations in this study: the highest resistance to lodging was achieved at a density adapted to the resource potential of the productivity zone. The interaction between sowing rate and nitrogen nutrition level, according to the results of a study by P. Tian *et al*. (2022), indicates a significant increase in photosynthetically active radiation (PAR) absorption, yield and nitrogen use efficiency in maize. Thus, an increase in density, together with optimal N application, stimulated better light absorption due to a change in the structure of the crop.

The results of the study showed that the correct allocation of productivity zones significantly enhances the effect of sowing rate differentiation: in highly productive zones, the potential of density is better realised, while in low-productive zones, the risk of seed overspending and increased intraspecific competition is reduced. A similar pattern is demonstrated by the study by M.A. Munnaf *et al*. (2022). The authors formed productivity zones by merging data from proximal soil probing and plant indicators and showed that map-based site-specific seeding (SSS) allows the seeding rate to be aligned with the spatial fertility of the field; at the same time, excessive rates in areas with lower potential worsen economic results, indicating the need for initially high-quality zoning and then VRS.

In the context of the accuracy of productivity zones and the predictability of management effects, it is important to combine field, proximal and satellite data. B.B. Bantchina *et al*. (2024) showed that the combination of visible/near-infrared soil spectra (Vis-NIRS), satellite plant indices and ML algorithms not only allows for the correct identification of productivity zones, but also enables the prediction of yield at the zone level, which directly reinforces the rationale for VRS and VR fertilisation in production conditions. Observations of persistent differences in dry matter accumulation curves between zones are consistent with their conclusion.

The role of classification/clustering algorithms and geostatistics in the practical formation of MZ maps should be noted separately. D.J. Gallardo-Romero *et al*. (2023) demonstrated a multi-layer scheme: cleaning and interpolation of yield data, followed by classification and morphological post-processing to obtain machine-readable field productivity maps suitable for loading into equipment. This approach explains why, in this work, the use of yield stability maps and vegetation indices resulted in better alignment with the actual boundaries of productive microzones, and the VRS parameters were acceptable for agricultural machinery.

Conclusions

Studies revealed that a spatially heterogeneous productive environment significantly affects the biometric indicators of maize in the early stages of development and at the beginning of flowering. It has been determined that the productivity zone is the main factor in the formation of dry matter content and plant height, while the influence of sowing rates is additional and less pronounced. The highest dry matter content (20.4% in the early stages and 30.4% in the flowering phase) and plant height (up to 215 cm) were recorded in highly productive areas with sowing rates of 70-75 thousand seeds per hectare. In less productive areas, these indicators decreased, indicating the limiting effect of soil and microclimatic conditions. Increasing sowing rates in the early stages of development did not have a significant effect on biometric indicators, but during the flowering phase, a moderate decrease in plant height was observed in variants with increased sowing density. This indicates the emergence of competition for resources (nitrogen, light, moisture) during the active growth phase. Spatial variability in field productivity necessitates a differentiated approach to managing sowing rates. The highest sowing density efficiency was observed in highly productive areas with moderately high rates (70-75 thousand/ha), where an optimal balance between density and resource potential of the environment is ensured.

The results indicate the stable nature of the influence of productivity zones: regardless of the weather conditions in 2023-2024, spatial patterns remained unchanged, indicating the dominant role of soil potential and relief-hydrological characteristics of zones over the inter-seasonal variability of climatic conditions. Prospects for further research lie in studying the interaction of differentiated sowing with other elements of corn cultivation technology, in particular, variable fertilisation and irrigation rates, as well as in developing yield prediction models based on a combination of remote sensing data, sensor monitoring and machine learning. This will allow the creation of comprehensive recommendations for managing crop productivity in space and time.

Acknowledgements

None.

Funding

None.

Conflict of Interest

None.

References

[1] Anselmi, A.A., Molin, J.P., Bazame, H.C., & Corrêdo, L.P. (2021). Definition of optimal maize seeding rates based on the potential yield of management zones. *Agriculture*, 11(10), article number 911. doi: 10.3390/agriculture11100911.

[2] Bakó, K., Rácz, C., Dövényi-Nagy, T., Molnár, K., & Dobos, A. (2025). Advancements in leaf area index estimation for maize using modeling and remote sensing techniques: A review. *Agronomy*, 15(3), article number 519. doi: 10.3390/agronomy15030519.

[3] Bantchina, B.B., Qaswar, M., Arslan, S., Ulusoy, Y., Gündoğdu, K.S., Tekin, Y., & Mouazen, A.M. (2024). Corn yield prediction in site-specific management zones using proximal soil sensing, remote sensing, and machine learning approach. *Computers and Electronics in Agriculture*, 225, article number 109329. doi: 10.1016/j.compag.2024.109329.

[4] Bűdi, K., Bűdi, A., Tarcsi, Á., & Milics, G. (2025). Variable rate seeding and accuracy of withinfield hybrid switching in maize (*Zea mays* L.). *Agronomy*, 15(3), article number 718. doi: 10.3390/agronomy15030718.

[5] Convention on Biological Diversity. (1992, June). Retrieved from https://www.cbd.int/doc/legal/cbd-en.pdf.

[6] Cui, J., Cui, Z., Lu, Y., Lv, X., Cao, Q., Hou, Y., Yang, X., & Gu, Y. (2022). Maize grain yield enhancement in modern hybrids associated with greater stalk lodging resistance at a high planting density: A case study in northeast China. *Scientific Reports*, 12, article number 14647. doi: 10.1038/s41598-022-18908-z.

[7] Djaman, K., Allen, S., Djaman, D.S., Koudahe, K., Irmak, S., Puppala, N., Darapuneni, M.K., & Angadi, S.V. (2022). Planting date and plant density effects on maize growth, yield and water use efficiency. *Environmental Challenges*, 6, article number 100417. doi: 10.1016/j.envc.2021.100417.

[8] DSTU ISO 11260:2001. (2001). *Soil quality – determination of cation exchange capacity and base saturation using barium chloride solution (ISO 11260:1994, IDT)*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=57138.

[9] Du, Z., Yang, L., Zhang, D., Cui, T., He, X., Xiao, T., Xie, C., & Li, H. (2022). Corn variable-rate seeding decision based on gradient boosting decision tree model. *Computers and Electronics in Agriculture*, 198, article number 107025. doi: 10.1016/j.compag.2022.107025.

[10] Gallardo-Romero, D.J., Apolo-Apolo, O.E., Martínez-Guanter, J., & Pérez-Ruiz, M. (2023). Multilayer data and artificial intelligence for the delineation of homogeneous management zones in maize cultivation. *Remote Sensing*, 15(12), article number 3131. doi: 10.3390/rs15123131.

[11] Havlin, J.L., Tisdale, S.L., Nelson, W.L., & Beaton, J.D. (2013). *Soil fertility and fertilizers* (8th ed.). Upper Saddle River, NJ: Pearson Education.

[12] Lacolla, G., Caranfa, D., De Corato, U., Cucci, G., Mastro, M.A., & Stellacci, A.M. (2023). Maize yield response, root distribution and soil desiccation crack features as affected by row spacing. *Plants*, 12(6), article number 1380. doi: 10.3390/plants12061380.

[13] Li, D., *et al.* (2022). Corn nitrogen nutrition index prediction improved by integrating genetic, environmental, and management factors with active canopy sensing using machine learning. *Remote Sensing*, 14(2), article number 394. doi: 10.3390/rs14020394.

[14] Liu, W., *et al.* (2020). Contribution of total dry matter and harvest index to maize grain yield – a multisource data analysis. *Food and Energy Security*, 9(4), article number e256. doi: 10.1002/fes3.256.

[15] Munnaf, M.A., Haesaert, G., & Mouazen, A.M. (2022). Site-specific seeding for maize production using management zone maps delineated with multi-sensors data fusion scheme. *Soil and Tillage Research*, 220, article number 105377. doi: 10.1016/j.still.2022.105377.

[16] Saleem, N., Jubery, Z.T., Balu, A., Zhou, Y., Li, Y., Schnable, P.S., Krishnamurthy, A., & Ganapathysubramanian B. (2025). Accessing the effect of phyllotaxy and planting density on light use efficiency in field-grown maize using 3D reconstruction. *ARXIV*. doi: 10.48550/arXiv.2503.06887.

[17] Șarauskis, E., Kazlauskas, M., Naujokienė, V., Bručienė, I., Steponavičius, D., Romaneckas, K., & Jasinskas, A. (2022). Variable rate seeding in precision agriculture: Recent advances and future perspectives. *Agriculture*, 12(2), article number 305. doi: 10.3390/agriculture12020305.

[18] Shatkovskyi, A., Zhuravlov, O., Melnychuk, F., Ovchatov, I., & Yarosh, A. (2020). Influence of irrigation methods on corn's productivity. *Plant and Soil Science*, 11(4), 34-42. doi: 10.31548/agr2020.04.034.

[19] Silva, E.E., Baio, F.H.R., Kolling, D.F., Schneider Júnior, R., Zanin, A.R.A., Neves, D.C., Fontoura, J.V.P.F., & Teodoro, P.E. (2021). Variable-rate in corn sowing for maximizing grain yield. *Scientific Reports*, 11, article number 12711. doi: 10.1038/s41598-021-92238-4.

[20] Tian, P., Liu, J., Zhao, Y., Huang, Y., Lian, Y., Wang, Y., & Ye, Y. (2022). Nitrogen rates and plant density interactions enhance radiation interception, yield, and nitrogen use efficiencies of maize. *Frontiers in Plant Science*, 13, article number 974714. doi: 10.3389/fpls.2022.974714.

[21] Videgain, M., Martínez-Casasnovas, J.A., Vigo, A., Vidal, M., & García Ramos, F.J. (2024). On-farm experimentation of precision agriculture for differential seed and fertilizer management in semi-arid rainfed zones. *Precision Agriculture*, 25(6), 3048-3069. doi: 10.1007/s11119-024-10189-y.

[22] Zhang, M., Zhao, X., Han, X., Chen, Y., Dang, P., Xue, J., Qin, X., & Siddique, K.H.M. (2025). Optimizing planting density for enhanced maize yield and resource use efficiency in China. A meta-analysis. *Agronomy for Sustainable Development*, 45(3), article number 29. doi: 10.1007/s13593-025-01027-0.

[23] Zhu, Z., Friedman, S.P., Chen, Z., Zheng, J., & Sun, S. (2022). Dry matter accumulation in maize in response to film mulching and plant density in northeast China. *Plants*, 11(11), article number 1411. doi: 10.3390/plants11111411.

Динаміка біометричних показників рослин кукурудзи за впливу норм висіву та зон продуктивності поля

Леся Гарбар
Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0003-4249-0434
Богдан Васьківський
Аспірант
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0009-0003-6852-3844

Анотація. Біометричні показники кукурудзи є важливим індикатором ефективності агротехнологій та відображають адаптивну реакцію культури на просторову неоднорідність умов вирощування. Метою дослідження було встановити вплив зональної продуктивності та норм висіву на висоту та формування сухої речовини кукурудзи на ранніх етапах органогенезу. Польові дослідження проведено у 2023-2024 рр. у межах трьох зон продуктивності поля: високої, середньої та низької. Варіювали п'ять норм висіву – від 65 до 85 тис. насінин/га. Результати досліджень свідчать, що зона продуктивності чинила основний вплив на біометричні параметри рослин, тоді як норма висіву мала додатковий, але менш суттєвий ефект. На стадії розвитку кукурудзи V2-V3 максимальні показники сухої речовини (до 23,5 %) спостерігалися у високопродуктивній зоні за норми висіву 70 тис. насінин/га. У низькопродуктивних зонах показники знижувались до 15,5 %. Висота рослин у цій фазі варіювала від 22,5 см у високій зоні до 16,6 см у низькій зоні продуктивності. У фазі початку цвітіння (R1) відзначено зменшення вмісту сухої речовини у напрямку до менш продуктивних зон: від 31,7 % (висока зона, 70 тис./га) до 25,3 % (низька зона, 85 тис./га) у 2023 р. Висота рослин варіювала від 252 см у високопродуктивних зонах до 143 см у низьких. Біометричні параметри кукурудзи можна використовувати як надійний критерій для оцінки реакції культури на диференційовані технологічні прийоми, що є перспективним напрямом у системах точного землеробства. Застосування зонально диференційованих норм висіву дозволяє підвищити ефективність використання ресурсів та оптимізувати агротехнології вирощування кукурудзи на неоднорідних за продуктивністю полях

Ключові слова: *Zea mays* L.; висота рослин; диференційована сівба; густота стояння; суха речовина