FEATURES OF SUNFLOWER YIELD FORMATION

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Introduction. Yield and yield components are specific to sunflower varieties and hybrids, but they are influenced by various growing factors, both environmental and technological. Typically, the genetic potential of sunflower hybrids or varieties is reduced by the stress factors of cultivation [40].

Plant productivity depends on the ability to effectively use the variability of environmental factors at different stages of vegetation. When developing new agricultural technologies, due attention should be paid to the peculiarities of the phenological stages of plants [1, 3].

Seed yield is a quantitative trait and can be significantly influenced by the environment. It is a so-called "supertrait" and selection for any other trait is positively or negatively correlated with seed yield. Seed yield and individual yield components are specific to each sunflower hybrid, but are influenced by various growing factors (ecological and technological), including soil and climatic conditions. High-yielding varieties require an appropriate level of agricultural technology to produce yield [3, 19].

In sunflower, seed yield is determined by indirect traits, such as optimal plant density, growth period, plant height, and direct traits, such as head diameter, number of seeds per head/or per plant/unit area, seed weight, weight of 1000 seeds, number of seeds per head, etc. [7, 9, 12, 18, 24].

Sunflower productivity is determined by the complex interaction of the biological characteristics of the crop, environmental conditions and elements of growing technology. When assessing the efficiency of sowing, special attention is paid to the crop structure, which reflects the contribution of individual elements to the formation of the final yield.

The main elements of the sunflower yield structure are:

- plant density;
- head diameter;
- number of seeds per head;
- weight of 1000 seeds;
- oil content in the seeds

Plant density is a key regulator of productivity. For sunflower, the optimal density is usually 45–65 thousand plants/ha (depending on the moisture zone and hybrid). Excessive density reduces the diameter of the head and the weight of the seeds, while thinned crops form large baskets, but do not provide the maximum yield per area [35, 37].

The diameter of the basket is directly related to the potential number of seeds. It is formed in the early stages of organogenesis and largely depends on the provision of plants with moisture and nutrients, especially nitrogen and boron. Stress during this period leads to a decrease in the size of the head and, accordingly, the number of flowers. The seed number in the head is one of the most important components of the yield. This indicator is determined by the conditions during flowering and pollination. Lack of moisture, high temperatures or a deficiency of microelements (in particular boron) can cause incomplete and reduced seed setting [17, 31, 38].

One of the important characteristics that determine yield is 1000 seeds weight. It is characterized the level of filling and accumulation of reserve substances. This factor varies in plant varieties and hybrids within the same species and depends on growing conditions. The weight of 1000 seeds reflects the size of the seeds and their fullness. This parameter becomes important as a factor in achieving an accurate seeding rate, which, due to the density of sowing, affects the yield of plants per unit area. This indicator depends on the photosynthetic activity of plants during the filling period, the supply of potassium and moisture. Drought or premature aging of the leaf apparatus lead to the formation of thin seeds [15, 23, 31].

The weight of 1000 seeds is a variable parameter. It is influenced by genetic factors and the environment.

The variability of this trait size is characteristic both for different genotypes in the same area and for the same genotype in different areas. This parameter may be due to the matric origin of the seeds (the location of the rows of seeds in the head).

In the experiments of Radic et al. it was also recorded that the weight of 1000 seeds depended on the year of observation and genotype. Sterile lines had seeds of greater weight compared to seeds of restorer lines, which is explained by the active branching of the latter [31].

When studying different genotypes (CMS-based lines and restorer lines) under different growing conditions, it was found that the weight of 1000 seeds was higher in CMS-based lines than in restorer lines, which was expected, taking into account the branching of restorer lines. It was also found that the weight of 1000 sunflower seeds depended on the characteristics of the year of observation and the genotype under study.

Studies have shown that such traits as germination, 1000-seed weight, huskiness, protein content, and seed yield per hectare were most influenced by genotype. All of the factors studied separately caused significant differences in husk content and protein content in seeds

The fullness of the head reflects the efficiency of pollination and fertilization processes. It largely depends on the activity of pollinating insects, in particular bees, as well as on weather conditions during the flowering period.

The number of seeds per basket, seed weight and oil content as individual components of the crop structure and its quality are closely related to genetic factors and sensitive to environmental factors. In particular, late sowing dates are a powerful factor that reduces the oil content and yield of sunflower seeds. Late sowing dates are associated with higher temperatures during the growing season, which leads to excessive stem growth and a reduction in the time required for flowering [25, 27].

When determining the reactions of sunflower varieties to different sowing dates, it was found that they significantly affect the duration of ripening, plant height, head diameter, total number of seeds per head, seed setting efficiency, 1000-seed weight, seed yield, husking coefficient and oil content in sunflower varieties.

Early sowing dates provide the largest head diameter, total number of seeds per head, higher seed setting efficiency, 1000-seed weight and yield. While late sowing dates led to the highest oil content [26,27, 32].

The oil content in seeds is an important qualitative indicator of the yield. It is formed under the influence of the genetic characteristics of the hybrid, temperature conditions and the provision of plants with nutrients. Excess nitrogen can reduce oil content, while potassium and sulfur contribute to its increase [8, 11].

Among the environmental factors, water and temperature regimes are of decisive importance for sunflower. The critical periods are the budding phase - flowering and seed filling. It is at this time that the lack of moisture has the most negative impact on all elements of the crop structure.

The influence of higher temperatures and solar radiation negatively affects the seed filling phase. The seed filling phase varies greatly depending on the year, place and date of sowing due to fluctuations in temperature and solar radiation [4, 6,10,11].

Mineral nutrition is no less important. Sunflower is characterized by a high need for potassium, which regulates water balance and promotes seed filling. Phosphorus ensures the development of the root system, and boron plays a key role in the processes of flowering and fertilization. The need for sunflower fertilizers depends not only on the soil, but also on climatic conditions, the yield of a particular variety, agrotechnical and organizational factors [8,14,17].

Nutrient management is one of the main factors affecting sunflower yield, seed oil content and fatty acid ratios. Sunflower removes many nutrients from the soil as a crop. Compared to other crops, sunflower is a significant nitrogen and phosphorus uptaker, and has no equivalent in potassium uptake.

Even with proper cultivation techniques, high or optimal yield levels are often not achieved due to insufficient soil fertility. Balanced fertilization plays a crucial role in providing sunflower with the nutrients necessary for maximum growth and development. Inorganic fertilizer components such as N, P and K are essential nutrients for plant growth and yield formation [14, 17, 21].

The fertilizer requirements of sunflower varieties vary depending on environmental conditions, rainfall, irrigation regimes, etc. During the growing season, sunflowers use nutrients unevenly.

A large amount of nitrogen and phosphorus is consumed by plants before flowering, when leaves, stems and root systems are formed. After this, phosphorus use decreases sharply. Potassium is absorbed by sunflowers throughout the growing season, but especially intensively before the flowering phase [8].

Although sunflowers respond less well to mineral fertilizers than grain crops, sufficient amounts of nitrogen, phosphorus, and potassium fertilizers must be provided in production.

Nitrogen (N) is the most important nutrient for increasing the yield and quality of sunflower seeds. This element stimulates plant growth and development, affects yield and quality. Nitrogen enhances vegetative growth and the rate of photosynthesis, gives plants their green color, and is a component of chlorophyll [24].

Nitrogen deficiency causes modification of many morphological and physiological parameters: growth restriction, leaf number and leaf area have been reported. Higher doses of nitrogen improve the photosynthesis process, increase the leaf surface area.

Sunflower yield is the result of the formation and interaction of elements of the crop structure. Management of seeding density, nutrition, water regime and plant protection allows to optimize these elements and ensure maximum realization of the hybrid's potential. An integrated approach to regulating environmental factors is the basis for stable and high-yielding sunflower cultivation.

Sunflower yield is the product of 3 components:

a) number of head per hectare;
b) number of seeds per head;
c) average seed weight.

Since most varieties form one inflorescence/head per plant, component (a) is determined by the number of plant populations. The other two components are influenced by the first component, variety characteristics, abiotic (weather conditions), edaphic and biotic (pests, diseases) factors.

Certain morphological characteristics of the plant are varietal characteristics, but under the influence of environmental factors and growing technology they can change. In particular, nitrogen fertilizers increase the yield of sunflower hybrids, increase the diameter of the basket [21, 28]. Characteristics such as grain yield and oil content in sunflower are complex and are determined by genetic, ecological and genotypic interactions of the environment.

It is difficult to develop criteria for characterizing and assessing productivity under the strategic interaction of genotype with the environment. Sunflower seeds are characterized by almost 100 different traits. Only 20 of them have production significance, the functions of 10-15 are still being studied, and all the others are beyond the attention of scientists [1, 3].

In the process of selection work to obtain varieties and hybrids for the northern regions, such characteristics as seed yield per plant, weight of 1000 seeds, solar radiation intensity, stem diameter and basket diameter should be taken into account. Given the results of the experiment, it can be concluded that the northern latitudes have good potential for sunflower production.

A wide range of originators and the availability of seed material provide the opportunity to select the optimal list of hybrids for different conditions and growing technologies. Along with this, against the background of the tendency to increase the contrast between weather conditions in individual years, there is an increase in demand for unified genotypes with an increased level of adaptability to the complex of agroecological environmental conditions. The presence of several different vectors of sunflower crop development necessitates the improvement of genotype identification methods, approaches to the selection of the analyzing background and evaluation indicators.

Conditions, materials and research methods.

Soil conditions. The soil of the experimental site is typical of the northeastern Forest-Steppe of Ukraine, classified as a powerful heavy loamy medium humus chernozem on loess-like loam. According to the agrochemical analysis, the soil was characterized by the following indicators: the humus content in the arable layer was 3.6%, the reaction of the soil solution was close to neutral (pH 6.3), the content of easily hydrolyzed nitrogen was 8.3 mg, mobile phosphorus and exchangeable potassium were 12 mg and 7.2 mg per 100 soil, respectively. During the research period, the predecessor was spring barley. The main soil tillage was improved cold plowing in the second decade of October to a depth of 22–24 cm. Mineral fertilizers were applied in the spring for pre-sowing cultivation in the form of nitroammophos fertilizers ($N_{15}P_{15}K_{15}$) according to the experimental scheme.

Weather conditions. The dynamics of soil and air temperatures in the northeastern Forest-Steppe zone of Ukraine are provided by optimal conditions for sunflower vegetation from May to September. Vegetation at earlier times is limited by low spring soil temperatures. The shift of vegetation to the autumn months is blocked by a decrease in daily temperatures (less than +14 °C), starting from the second decade of September.

Under these conditions, the most favorable date for sowing is the third decade of April, while September is considered exclusively as a period of technological maturation. Therefore, the weather conditions of the period "May-August" have a decisive influence on the development of vegetative organs of plants, the flowering phase, the formation and filling of seeds, (table 1).

Table 1. Main indicators of weather conditions during the sunflower growing season (May-August).

Indicator	Years		
	2019	2020	2021
Sum of temperatures, C	2614	2447	2592
Precipitation, mm	120	219	230
Hydrothermal coefficient (GTC)	0,46	0,89	0,89

In general, the weather conditions of the 2019–2021 growing seasons contributed to the identification of genotypes capable of intensive growth in conditions of reduced temperatures and sufficient water supply in the juvenile phases of development, as well as the combination of these traits with the ability to accumulate photosynthesis products in arid conditions of the second half of the growing season.

The research material was nine sunflower hybrids selected based on the results of environmental tests, namely the onset of the technological maturation phase by September 20. The duration of the vegetation period of these hybrids declared by the originators ranged from 110 to 115 days, (Table 2).

Table 2. General characteristics of sunflower hybrids (open data from originator institutions)

Hybryd		Height of stem, cm	Diameter of inflorescens, cm	1000 seed weight, g	Yield potential, t/ha	Seed oil content, %
1	Phenomen	170–180	19–20	55-56	4,3	50–51
2	Nabir	150–160	18–20	50	4,0	50–55
3	Yason	175–185	22-24	62	4,3	49–50
4	Teo	185–195	17-19	58	4,2	48,0
5	Oscar	160–170	18-20	60-62	4,0	49–51
6	Agent	170–180	19–22	62	4,8	50
7	Zlanson	160–165	21–23	till 60	4,7	48,4
8	LG 53.77	155–165	16-18	70	5,0	49–50
9	Dobrodiy	175–185	20–22	52	5,0	48,3

Research methods. Experimental studies were conducted according to the scheme of a 3-factor field experiment on the experimental field of Sumy National Agrarian University, (Table 3). The plots were 2-row, 9 m long, with an area of 12.6 m^2. Repetition was 3 times.

The placement of plots by factor A was randomized, by factors B and C was systematic. Depending on the tasks, calculations were carried out according to the scheme of a one-, two- or three-factor experiment. In some cases, weather conditions were considered as a separate factor.

Table 3. Scheme of field research with the development of characteristics and the formation of productivity of dormouse hybrids (2019–2021)

Factor A – hybrid	Factor B – fertilizer rate	Factor C – final seeding density
• Phenomen • Nabir • Yason • Teo • Oscar • Agent • Zlanson • LG 53.77 • Dobrodiy	• Without fertilizers (control); • $N_{45}P_{45}K_{45;}$ • $N_{90}P_{90}K_{90}$	• 45 thousand plants/ha; • 55 thousand plants/ha; • 65 thousand plants/ha

Results.

Development and structure of the leaf surface of sunflower hybrids. At the current stage of breeding, the model of development of the leaf apparatus of plants is increasingly considered as the main element of the adaptability of genotypes to specific growing conditions, geographical zoning zones, etc.

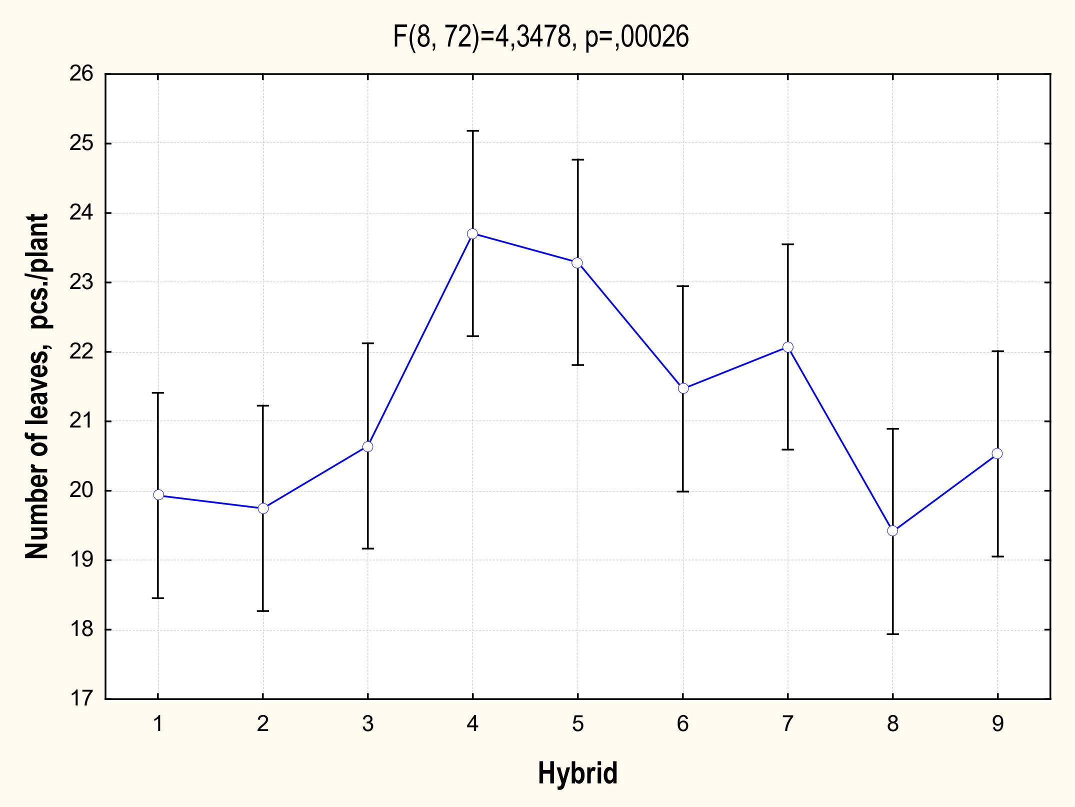
The basis of this approach is the primacy in plant ontogenesis of programs for the implementation of vegetative potential, while the object of breeding programs (the entire period of domestication of the crop) are the parameters of generative development, the programs of which are implemented in the second half of the plant vegetation [39].

Under these conditions, the potential of the hybrid, the range of its adaptability to environmental conditions is determined by the level of interaction between the development of the assimilation apparatus and generative organs. Thus, in each specific case, its own, original scheme of donor-acceptor relationships is formed, which regulate the formation of photosynthesis products, growth processes, life support and accumulation of reserve nutrients.

Number of leaves. The apical type of inflorescence formation in single-inflorescens forms of sunflower determines a high level of genetic control of the trait of leaf number. Since inflorescence formation in sunflower plants occurs in the juvenile phases of development, environmental conditions only partially determine the number of leaves that the plant forms during the growing season.

Currently, in breeding practice, it is accepted to estimate the potential duration of this period based on the calculation that the formation of one leaf occurs in 2.5–3.0 days. The average data on the number of leaves in each of the sunflower hybrids in the experimental plots are shown in Fig. 1.

The total level of variation of this trait varied from 18.5 to 26.7 pieces per plant. Such a significant range can be explained by the peculiarities of the formation and life span of individual leaves. Thus, in areas with the maximum level of thickening, even in the middle of the flowering phase (taking into account the main morphological parameters of plants), the dying off of the lower tier of leaves was observed. However, in some years, especially in thinned crops, the last pair of leaves (mostly underdeveloped) formed full-fledged leaf blades.



1 – Phenomenon; **2** – Nabir; **3** – Yason; **4** – Teo; **5** – Oscar; **6** – Agent; **7** – Zlatson; **8** – LG 53.77; **9** – Dobrodiy

Figure 1. Dynamics of the average number of leaves of sunflower hybrids, pieces/plant.

Analysis of the figure shows that the overall level of variation of this trait varied from 18.5 to 26.7 pieces per plant.

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However, in some years, especially in thinned crops, the last pair of leaves (mostly underdeveloped) formed full-fledged leaf blades.

According to the average value of the indicator, it is advisable to distinguish three groups, namely:

- hybrids Phenomen, Nabir, LG 53.77, which formed less than 20 leaves (19.4–19.9);
- hybrids Yason, Agent, Zlatson, Dobrodiy formed 20.5–22 leaves;
- hybrids Teo and Oscar formed more than 23 leaves (23.3–23.7).

The presence of a statistically significant difference between the indicators of groups 1 and 3 indicates potential differences in the duration of the vegetation period, which in turn implies different algorithms for implementing generative functions.

Dynamics of indicators of the single leaf area. In the theoretical aspect, the presence of differences in the algorithms for the formation of the yield of sunflower hybrids is based on the primacy of the development of vegetative organs of plants and the realization of their generative potential on this basis.

Due to the gradual nature of growth processes, the parameters of generative development are less dependent on environmental factors.

At the same time, the primacy of the realization of the vegetative potential itself can block the development of generative parameters in stressful environmental conditions.

An additional factor limiting the size of the crop yield is the difference in the population and economic optima of the realization of the generative potential. In the first case, the determining factor is the indicator of the number of seeds formed per unit area.

In the case of the economic optimum, we are talking about the mass of fruits, which is determined by two indicators - the number and weight of 1000 seeds. The value of the latter (within one genotype, or a group of genotypes with similar parameters of plant development) is closely correlated with the duration of post-embryonic development of fruits.

The conditions for the postembryonic period of fruit development (seed filling phase) are determined by the level of provision of the formed embryo with water and photosynthesis products. The root system, size and structure of the plant's leaf apparatus play a decisive role in this.

The next stage in the study of the features of the formation and functioning of the leaf apparatus in early-ripening sunflower hybrids was the determination of the average leaf size and structure of the crop leaf layer. The area of an individual leaf directly affects the intensity of photosynthesis: the larger the leaf surface, the more solar energy is absorbed to form organic substances. Too large leaves can overlap each other, reducing the efficiency of light absorption, while a small surface area limits growth even with high activity of an individual leaf. Leaves should form an optimal area that will ensure maximum photosynthesis efficiency and productivity.

The graph of the average values and the range of variability of the average leaf blade area of sunflower hybrids is shown on the Fig. 2.

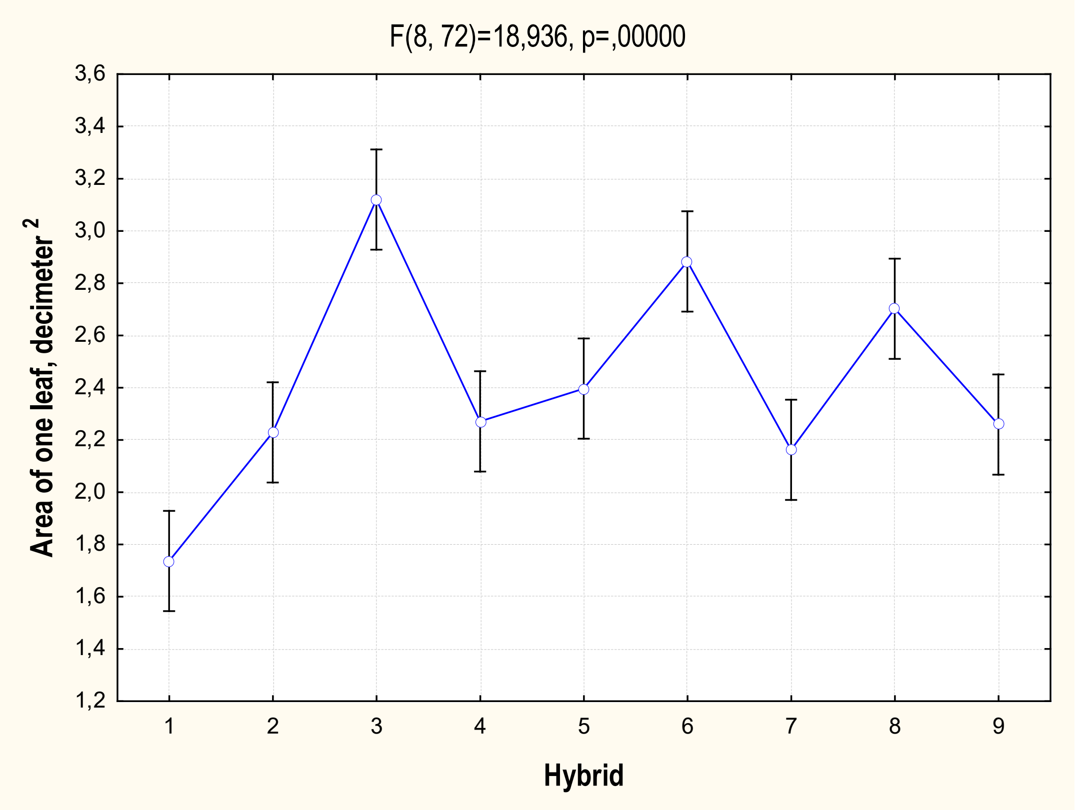

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Figure 2. Dynamics of the average leaf blade area of sunflower hybrids, dm^2.

Analysis of the values indicates a significant difference between the average leaf blade size indicators of the hybrids. In ascending order of the indicator, from 1.74 to 3.14 dm^2, the hybrids were ranked in the following sequence: Phenomenon, Zlatson, Nabir, Teo, Dobrodiy, Oscar, LG 53.77, Agent, Yason.

The range of variation of the average values provided the possibility of distinguishing three groups that statistically significantly differed in the values of the indicator, namely:

- with minimum values– hybrid Phenomenon;
- with transitional values– Nabir, Teo, Oscar, Zlatson, Dobrodiy;
- with maximum values– Yason, Agent, LG 53.77.

Generalized information on the dynamics of the leaf blade area indicator in terms of fertilizer and density factors is presented in Table 4.

Data analysis shows a gradual increase in the leaf blade area, on average by 8–9% with a multiple increase in the rate of mineral fertilizers. In terms of the density factor, a reverse reaction was observed. The difference between the leaf area in plots with a minimum density and 55 and 65 thousand/ha was 7.7 and 11.2%, respectively.

Table 4. Average values of the leaf blade area index of sunflower hybrids depending on the fertilizer rate and sowing density

Factor		**X**	**± to control for the factor**		**Average for factor**	
B – fertilizer rate, active ingredient. kg/ha	**C** – sowing density, thousands of units/ha		B	C	B	C
No fertilizers (control)	45 (к)	2,41			2,22	2,58
	55	2,17		-0,24		2,38
	65	2,08		-0,33		2,29
$N_{45}P_{45}K_{45}$	45 (к)	2,52	0,11		2,41	
	55	2,39	0,22	-0,13		
	65	2,31	0,23	-0,21		
$N_{90}P_{90}K_{90}$	45 (к)	2,81	0,4		2,62	
	55	2,56	0,39	-0,25		
	65	2,49	0,41	-0,32		

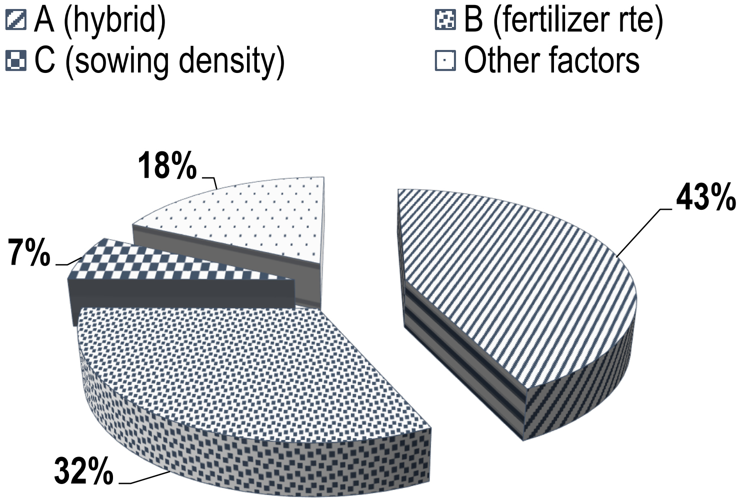

Figure 3. Structure of the influence of factors on the dynamics of the leaf area index of sunflower hybrids.

The results of the variance analysis show that the genotype had a decisive influence on the dynamics of the area of one leaf. The strength of the influence of this factor was 67.8%, the influence of the fertilizer and density factors was 11.8 and 6.4%, respectively.

Leaf surface area coefficient. One of the main indicators of potential sowing efficiency is the ability to intensively form and maintain sufficiently high leaf surface area indicators for a long time. The leaf surface area coefficient is a determinant of abiotic factors such as radiation interception, water exchange, and it is important variable for crop growth. This indicator measurement is essential for understanding the interactions between crop growth, cultivation ways, and environment conditions. Moreover it is important biological variable, because it represents the area exposed to solar radiation and measures the surface area responsible for gas exchange. According to literature data, the value of this coefficient in certain periods of development (beginning of the flowering phase) can reach 5.0–6.0. However, for the most part, the range of values of the indicator in the Forest-Steppe zone varies from 1.5 to 3.5. The higher the indicator value, the more solar energy the crop captures, but at very high values (above 6–7), the lower leaves are shaded, die, and productivity drops. The value of it significantly depends on the sowing density, sowing dates, varietal characteristics, and nutrition (in particular nitrogen).

In the study, on average, the coefficient value for the experiment was 2.81. Depending on the conditions of the years, the indicator changed from 2.62 in the hot and dry year of 2019 to 2.93 in the hot and moderately humid year of 2021 (2.62; 2.88; 2.93).

In general, the experiment clearly showed a trend towards an increase in leaf surface area in proportion to the increase in seeding density and the rate of mineral fertilizer application.

Thus, the application of fertilizers at the rate of $N_{45}P_{45}K_{45}$ was accompanied by an increase in the coefficient values from 2.3 to 2.77 or by 20.4%.

In areas with the maximum rate, the coefficient value was 3.34, which is 45.2% more compared to the control. A similar situation occurred in the density variants. A gradual increase in the sowing density from 45 to 55 and 65 thousand ha was accompanied by an increase in the indicator from 2.56 to 2.82 and 3.04, which was 10.1 and 18.7%.

Comparison of the growth rates of the coefficient values under the influence of the fertilizer and density factors indicates differences in the response in the variants with the maximum manifestation of the factor.

Thus, a multiple increase in the fertilizer rate from $N_{45}P_{45}K_{45}$ to $N_{90}P_{90}K_{90}$ was accompanied by a 25% increase in the coefficient, while the difference between the $N_{45}P_{45}K_{45}$ variant and the control was only 20.4%.

The opposite relationship was observed in the variants with an increase in density. As a result, such dynamics of the influence of factors provided a close to a linear type of response to changes in the coefficient in the experimental variants. The difference between the extreme values of the average indicators (1.99 and 3.61 m^2/m^2) was 70.2%.

Depending on the genotype nature, the average coefficient values varied from 1.87 in the Phenomenon hybrid to 3.57 in the Yason hybrid. However, the most clearly visible difference between the genotypes was in the reaction to the factors of changing the fertilizer rate and sowing density.

In the variants with the maximum values of the factors ($N_{90}P_{90}K_{90}$ and 60.0 thousand/ha), the difference between the control variant was 100 and more percent for the Yason, LG 53.77 and Agent hybrids; more than 60% for the Oscar and Zlatson hybrids. The minimum reaction to the influence of factors was noted in the hybrids of Dobrodiy (+44.2%), Teo (+43.1%), Nabir (+42.3%), and Phenomen (+32.1%).

As expected, the largest difference between the indicators of leaf surface area, namely 3.23 times, was noted for Phenomenon hybrid with a density of 45 thousand/ha without fertilizers and for Yason hybrid with a density of 65 thousand/ha and the fertilizer rate of $N_{90}P_{90}K_{90}$, - 1.62 and 5.24 m^2/m^2 respectively.

Generalization of data on the dynamics of the leaf apparatus of sunflower plants under the influence of technological factors allowed us to make the following findings.

The change in the development indicators of the leaf apparatus of plants was determined by the indicators of the leaves number, their area and tier distribution.

The determining factor in the dynamics of the area indicator of single leaf was the genotype. The strength of the influence of this factor was 67.8%.

The influence of fertilizer and density factors was 11.8 and 6.4%, respectively. The group with high indicators of the area of the leaf blade (> 2.8 dm^2) included the following hybrids: Jason; Agent and LG 53.77. The minimum indicators of 1.7 dm^2 were the Phenomenon hybrid.

For the group of medium-early hybrids, the average coefficient of the leaf area of crop was 2.81 m^2/m^2. In terms of the fertilizer factor, the coefficient value changed from 2.3 in the control to 2.77 (+20.4) and 3.34 m^2/m^2 (+45.2%). A similar situation occurred in the density factor variants. A gradual increase in the density of the crop from 45 to 55 and 65 thousand ha was accompanied by an increase in the indicator from 2.56 to 2.82 and 3.04, which amounted to 10.1 and 18.7%.

In terms of hybrids, the average values of the leaf area coefficient of sowing varied from 1.87 in Phenomenon hybrid to 3.57 in Jason hybrid. A statistically significant difference was noted in the reaction of hybrids to changes in fertilizer rates and sowing density.

In the variants with the maximum values of factors ($N_{90}P_{90}K_{90}$ and 60.0 thousand hectares), the difference between the control variant was 100 and more percent for the Yason, LG 53.77 and Agent hybrids; more than 60% for the Oscar and Zlatson hybrids. The minimum reaction to the influence of factors was noted in the hybrids of Dobrodiy (+44.2%), Teo (+43.1%), Nabir (+42.3%) and Phenomen (+32.1%).

For research period, the average index value of leaf surface area was 62.1%. In terms of hybrids, the highest share of shaded layers (more than 65%) was in the hybrids of Agent, Yason, Oscar. The lowest share was 46.1% in the hybrid of Phenomenon.

Table 5. Leaf area coefficient of sunflower hybrids depending on fertilizer rate and seeding density, % (2019–2021).

Factor											Average for factor		
B – fertilizer rate,, kg /ha	**C** – seeding density, thousand/ha	**A** – hybryds									X	**B**	**C**
		Phenomenon	Nabir	Yason	Teo	Oscar	Agent	Zlatson	LG 53.77	Dobrodiy			
No fertilizers	45	1,62	2,01	2,34	2,32	2,25	2,35	2,08	2,08	1,99	2,12	2,30	2,56
	55	1,70	2,13	2,37	2,69	2,58	2,44	2,15	2,22	2,34	2,29		2,82
	65	1,67	2,32	2,27	3,01	3,00	2,91	2,62	2,41	2,35	2,51		3,04
$N_{45}P_{45}K_{45}$	45	1,83	2,26	3,27	2,62	2,75	3,04	2,25	2,29	2,26	2,51	2,77	
	55	1,90	2,43	3,38	3,05	3,13	3,36	2,33	2,79	2,86	2,80		
	65	1,88	2,60	3,77	3,02	3,14	3,54	2,79	3,22	3,06	3,00		
$N_{90}P_{90}K_{90}$	45	1,98	2,39	4,63	3,05	3,23	4,08	2,75	3,11	2,36	3,06	3,34	
	55	2,14	2,55	4,85	3,31	3,59	4,26	3,07	3,72	2,71	3,36		
	65	2,14	2,86	5,24	3,32	3,79	4,64	3,46	4,17	2,87	3,61		
Average for factor **A**		1,87	2,39	3,57	2,93	3,05	3,40	2,61	2,89	2,53	2,81		

The difference between the values of the coefficient and the reaction of this indicator to changes in individual factors are more clearly illustrated by the results of the 2-factor analysis of variance (Fig. 4).

In this case, the choice of the tool of the 2-factor experiment, where the density factor was considered as separate repetitions, was determined by the scheme for calculating the leaf area coefficient of crop.

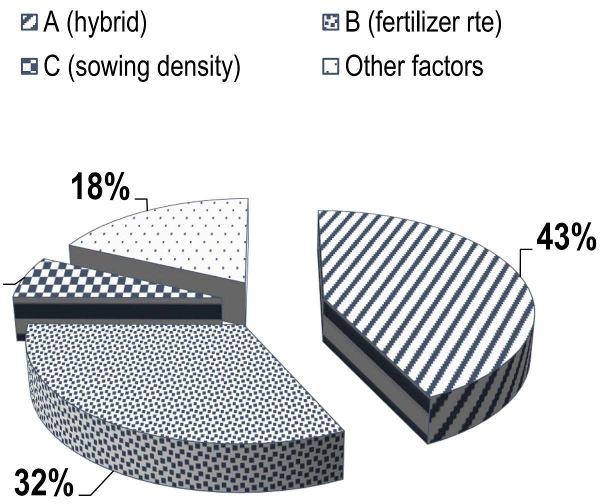

Figure 4. Structure of the factors influence on the indicator dynamics of leaf surface area of sunflower hybrids.

Dynamics of yield of sunflower hybrids depending on the rate of fertilizers and sowing density. The main indicator of the adaptability of the genotype to the growing conditions is the level of implementation of its generative functions.

In the evolutionary aspect, it was this characteristic that ensured the spread and consolidation in the genotype of individual mutations that determined deviations in the rates of passage of individual phases of development, the size and efficiency of the photosynthetic apparatus of plants, the division of photosynthesis products between individual parts of plants.

Traditionally, sunflower is considered as one that responds little to seasonal application of mineral fertilizers. This view is based on the peculiarities of the development of the plant root system, namely the dominance of the main root with the concentration of its active part at a depth of more than one meter. Under these conditions, the increase from the use of fertilizers is determined by the average rate of fertilizers applied in crop rotation.

At the same time (especially in recent years) sunflower is increasingly considered as an intensive type of crop, which provides a stable increase in yield precisely in technologies with the introduction of higher than average (in crop rotation) rates of mineral fertilizers.

Analysis of available literary sources shows that the reasons for the change in approaches to the crop are the selection and technological modernization of the crop. First of all, an increase in the number of hybrids capable of effective absorption of mineral elements from the upper (arable) layer of soil, improving the quality (primarily the level of solubility) of fertilizers, the use of complex mineral fertilizers, etc.

Data on yield by three-factor experiment variants is presented in Table 6. The average yield in the experiment over the research period was 2.91 t/ha, changing from 3.22 in the favorable year of 2019, to 2.92 and 2.59 in 2020 and 2021, respectively.

The results analysis of variance indicate the dominant role of factor A (hybrid) in the favorable year 2019 (the share of the factor's influence was 60.2%) with a gradual decrease in the influence in 2020 and especially in 2021. The opposite dynamics was observed for the mineral fertilizer factor, the influence of which was 16.5; 17.5 and 52.2% in 2019, 2020 and 2021, respectively.

A significant difference in the share of "other" factors, namely 23.0% in 2019 and only 12.5% in 2021, shows that the formation of high yields involves the presence of additional weather factors specific to 2019.

The minimal influence of the density factor on changes in yield indicators indicates its secondary role in the processes of forming crop yields.

The highest average yield in the experiment of 3.99 t/ha was noted on the LG 53.77 hybrid variant with a density of 55 thousand/ha and a fertilizer rate of $N_{90}P_{90}K_{90}$. Under the same conditions, a similar yield indicator (3.96 t/ha) was provided by the Agent hybrid.

In terms of individual years, the maximum yield indicator of 4.44 t/ha was noted in 2019 for the Agent hybrid on plots with a density of 45 thousand/ha and fertilizer application at the rate of $N_{90}P_{90}K_{90}$.

In general, on the base of increasing average yield, the hybrids were arranged in the following order: Phenomenon (2.3 t/ha), Yason (2.37 t/ha), Dobrodiy (2.98 t/ha), Nabir (2.58 t/ha), Teo (2.9 t/ha), Oscar (3.02 t/ha), Zlatson (3.12 t/ha), LG 53.77 (3.4 t/ha), Agent (3.49 t/ha).

Depending on the characteristics of the growing season, changes in the rating of hybrids primarily concerned the rating of the Dobrodiy, which, more than other hybrids, reduced yield in less favorable years. The reverse dynamics, namely, an improvement in the rating in less favorable years for vegetation, was observed for the Nabir, Yason, and Zlatson hybrids.

In the technological aspect of sunflower cultivation, it is important to determine the reaction of hybrids to the application of medium and high doses of mineral fertilizers. The results of the experiment show that a stepwise increase in the rate of fertilizer application to the level of $N_{45}P_{45}K_{45}$ and $N_{90}P_{90}K_{90}$ was accompanied by an increase in yield from 2.56 to 2.93 and 3.22 t/ha or by 0.37 and 0.66 t/ha compared to the initial value (without fertilizers).

Under the conditions of using the average rate of fertilizers, the highest level of yield increase of 0.5 t/ha was noted in the Agent hybrid, the minimum increase, namely 0.3 t/ha, was provided by the Phenomenon, Nabir, and Jason hybrids. The most numerous was the proportion of hybrids in which the level of increase was 0.4 t/ha - Teo, Oscar, Zlatson, Dobrodiy and LG 53.77.

Table 6. Average yield of sunflower hybrids depending on fertilizer rate and sowing density, t/ha

Factor											for the option	Average for factor	
B – fertilizer rate,.kg /ha	**C** – seeding density, thousand/ha	**A** – hybryds										**B**	**C**
		Phenomenon	Nabir	Yason	Teo	Oscar	Agent	Zlatson	LG 53.77	Dobrodiy			
No fertilizers	45	1,89	2,16	1,99	2,45	2,62	3,18	2,82	3,20	2,90	2,58	2,56	2,90
	55	1,95	2,36	2,14	2,78	2,81	3,06	2,62	2,96	2,53	2,58		2,94
	65	2,36	2,34	2,19	2,39	2,49	2,88	2,81	2,74	2,38	2,51		2,88
$N_{45}P_{45}K_{45}$	45	2,09	2,40	2,22	2,75	2,94	3,58	3,18	3,62	3,28	2,90	2,92	
	55	2,27	2,75	2,49	3,26	3,30	3,54	3,09	3,48	2,97	3,02		
	65	2,68	2,66	2,49	2,72	2,86	3,24	3,17	3,10	2,69	2,84		
$N_{90}P_{90}K_{90}$	45	2,60	2,88	2,65	3,20	3,33	4,05	3,46	3,73	3,25	3,24	3,26	
	55	2,35	2,68	2,47	3,04	3,26	4,19	3,52	3,99	3,60	3,23		
	65	2,49	3,00	2,72	3,55	3,58	4,01	3,37	3,78	3,21	3,30		
Average for factor **A**		2,30	2,58	2,37	2,90	3,02	3,52	3,12	3,40	2,98	2,91		

A slightly different dependence was observed in the variants with a high rate of fertilizer application. Under the conditions of a proportional increase in the amount of fertilizer applied, only four hybrids (Teo, Oscar, Dobrodiy and LG 53.77) provided a yield increase close to the previous variant.

For the hybrids Nabir, Hason, Agent and Zlatson, the yield increase was only to 0.21–0.25 t/ha. The minimum effect of an increase in the amount of fertilizer applied was on the Phenomen hybrid, for which the yield increase was only 0.13 t/ha.

The analysis of variance conducted on individual factors indicates the presence of a statistically significant difference between the yield indicators for factor A and indicates the isolation of two groups that differ significantly in the level of realization of their biological potential.

The group with the minimum yield indicators (at the level of 2.3–2.37 t/ha), formed by the hybrids Phenomen and Yason, and the group consisting of the hybrids Agent and LG 53.77. The yield indicators of these groups differed statistically significantly regardless of the years of research and experimental variants.

Despite the significant dispersion of the yield index of different sunflower hybrids, on average they demonstrated a statistically significant increase in the yield index when using medium and high rates of mineral fertilizers.

The influence of the density factor was less certain. Analysis of the experimental results indicates the absence of a clear response of the yield index to changes in the final density values, which indicates the inexpediency of its isolation as an independent (universal) factor of technology. Thus, this parameter should be considered as a derivative determined by the nature of the variety and the rate of fertilizers.

Yield structure. Plant productivity. An important feature of the hybrid's compliance with the complex of soil and agrotechnical conditions is the ability of plants to form high and stable indicators of individual seed productivity.

Modern sunflower crop, although it uses branched multi-head forms (which are the dominant type in natural populations) in the breeding process, is oriented towards the use of single-head forms with apical inflorescence formation.

Therefore, the orientation of natural selection and the modern breeding process to increase individual seed productivity have a number of differences, primarily related to the ability of plants to compete for environmental resources.

In natural populations, the process of vegetative branching and the formation of additional inflorescences is inter-connected, which provides the possibility of self-regulation of the generative load within a single plant and population.

Such a mechanism ensures the effective realization of the genetic potential of plants with simultaneous adjustment of their development (investment in reproduction) in accordance with the actual state of the environment.

Under the conditions of using single-head forms, the mechanism of self-regulation of the generative potential of plants, present in the basic (branched form), is less effective.

Under these conditions, the determining factor in the realization of the generative potential is the provision of parameters that meet the basic requirements of the genotype, especially in matters of levels of intraspecific competition. The dynamics of the productivity index of sunflower hybrids plants depending on the fertilizer rate and density are given in Table 7.

Over the years of research, the average productivity was 54.14 g. The range of variability of the average value was about 25%, varying from 59.87 g in the favorable year of 2019 to 54.49 and 48.06 g in 2020 and 2021, respectively.

Depending on the fertilizer rate, the indicator varied from 47.59 g in areas without fertilizer use to 54.32 and 60.52 g for the use of medium and high rates. In percentage terms, this was plus 14.4 and plus 11.5%.

More significant was the response of the indicator to changes in seeding density. On average, over 3 years, this indicator changed from 64.53 g in areas with a density of 45 thousand/ha to 44.38 g in areas with a density of 65 thousand/ha.

Table 7. Productivity of sunflower hybrid plants depending on fertilizer rates and sowing density, t/ha (2019–2021)

Factor											for the option	Average for factor	
B – fertilizer rate,.kg /ha	**C** – seeding density, thousand/ha	**A** – hybryds										B	C
		Phenomenon	Nabir	Phenomenon	Nabir	Phenomenon	Nabir	Phenomenon	Nabir	Phenomenon			
No fertilizers	45	41,85	48,08	44,30	54,37	58,30	70,59	62,67	71,04	64,37	57,28	47,59	64,53
	55	35,51	42,97	38,85	50,55	51,09	55,64	47,70	53,76	45,94	46,89		53,51
	65	36,36	36,05	33,69	36,82	38,25	44,26	43,18	42,10	36,56	38,59		44,38
$N_{45}P_{45}K_{45}$	45	46,52	53,26	49,26	61,04	65,41	79,48	70,67	80,45	72,96	64,34	54,32	
	55	41,27	50,00	45,21	59,27	60,00	64,30	56,18	63,28	54,06	54,84		
	65	41,28	40,97	38,36	41,79	43,95	49,85	48,72	47,64	41,34	43,77		
$N_{90}P_{90}K_{90}$	45	57,78	63,93	58,82	71,18	73,93	90,07	76,96	82,81	72,30	71,98	60,52	
	55	42,67	48,67	44,97	55,27	59,33	76,18	64,06	72,54	65,45	58,79		
	65	38,31	46,21	41,80	54,67	55,13	61,69	51,79	58,10	49,39	50,79		
Average for factor A		42,39	47,79	43,92	53,88	56,15	65,79	57,99	63,52	55,82	54,14		

Thus, the step-by-step decrease in the plant productivity indicator with an increase in seeding density was about 17% for every 10 thousand/ha. A comparison of the average values and levels of dispersion of the plant productivity indicator of individual hybrids indicates the presence of two clearly separated groups, namely, groups with minimum values at the level of 35–55 g/plant (Phenomenon, Nabir, Jason) and groups with a range of average values at the level of 60–73 g/plant (Agent, LG 53.77.). The transitional group was formed by the hybrids Teo, Oscar, Zlatson and Dobrodiy.

The difference between the average values of the indicator in the context of options B (fertilizer rate) and C (sowing density) was also statistically significant. An important addition to the characterization of the processes of crop yield formation is the analysis of the dynamics of the productivity indicator in years with different weather conditions.

Weight of 1000 seeds. In evolutionary terms, the formation of a massive inflorescence in the *Asteraceae* family ensured a deeper differentiation of seeds within one plant (due to the effect of matric heterogeneity), primarily in size and nutrient supply.

An important stage in the formation of sunflower culture was the isolation of populations of single-head forms. Single-head plant is a recessive trait with two alleles, which determines the dominance of multi-head branched forms. It was the isolation of the single-head form that gave impetus to effective selection for seed weight during the period of sunflower formation as a "garden crop".

The transition to the "field crop" of sunflower, which took place in the second half of the 19-th century, suspended selection on this basis. Due to the dominance of the "oil" ecotype and selection to reduce the huskiness of the seeds, genotypes with 1000-seed weight indicators at the level of 45–65 g gained priority. This value of the indicator was determined by "sufficiency" to ensure germination processes and technological processes of sowing. At the same time, this process is based on a close correlation between the mass of the kernel and the mass of the pericarp.

The trend towards an increase in the average weight of 1000 seeds in modern sunflower crops began to manifest itself only in the last twenty years due to the intensification of the confectionery direction of selection. This became an impetus for the creation of high-yielding genotypes with an increased contribution to the increase in yield due to an increase in the weight of 1000 seeds.

A derivative of this process was the differentiation of the varietal assortment of the crop by the predominant type of formation of plant productivity and crop yield. Currently, the highest level of differentiation is observed for groups of hybrids (and technologies) of traditional, oilseed and confectionery use of the crop. Table 8 presents data on the dynamics of the weight of 1000 seeds depending on the hybrid, mineral fertilizer rates and sowing density.

Table 8. Weight of 1000 seeds of sunflower hybrids depending on the fertilizer rate and sowing density, t/ha

Factor											for the option	Average for factor	
B – fertilizer rate, kg /ha	**C** – seeding density, thousand/ha	B - hybryds										**B**	**C**
		Phenomenon	Nabir	Yason	Teo	Oscar	Agent	Zlatson	LG 53.77	Dobrodiy			
No fertilizers	45	70,02	61,10	60,40	55,32	58,75	55,84	61,29	55,65	68,09	60,72	57,58	67,01
	55	67,63	61,07	59,74	51,68	57,18	53,27	57,12	50,34	63,30	57,93		65,24
	65	63,86	54,50	55,70	49,73	49,58	50,00	54,25	48,49	60,85	54,11		61,81
$N_{45}P_{45}K_{45}$	45	77,57	68,72	66,84	61,97	65,50	64,22	68,75	62,17	76,20	67,99	64,64	
	55	76,16	68,35	66,20	59,98	64,99	60,71	65,92	57,88	71,77	65,77		
	65	71,30	60,83	62,07	55,53	55,86	55,03	59,69	53,70	67,30	60,15		
$N_{90}P_{90}K_{90}$	45	83,77	74,15	74,51	66,67	70,27	67,31	71,86	64,99	77,31	72,31	71,83	
	55	85,67	73,58	74,57	67,12	71,44	66,11	71,06	62,95	75,59	72,01		
	65	84,13	73,84	73,35	65,95	69,65	65,49	71,30	62,29	74,61	71,18		
Average for factor **A**		75,57	66,24	65,93	59,33	62,58	59,78	64,58	57,61	70,56	64,69		

The average indicator was 64.7 g, changing from 66.5 g in the favorable year of 2019 to 63.9 and 63.6 in the less favorable for the formation of plant productivity years of 2020 and 2019. In terms of factor A, the highest indicators were observed in the hybrids: Phenomenon - 75.57 g and Dobrodiy - 70, 56 g. The minimum indicators of 57.61 and 59.33 g were characterized by hybrids LG 53.77. and Teo.

In terms of factors B and C, two opposite effects were observed, namely, an increase in the indicator in proportion to the increase in the rate of mineral fertilizers and a decrease in seed size with an increase in the sowing density indicators. The average value of 1000 seed weight in areas without fertilizer application was 57.58 g. An increase in the indicator to 64.4 g (+ 6.8 g) was noted in the variant with the application of $N_{45}P_{45}K_{45}$ and to 71.8 g (+7.4 g) in the variant with the maximum rate of fertilizers ($N_{90}P_{90}K_{90}$). Thus, the stepwise increase with a multiple increase in the rate of mineral fertilizers was +11.8 and +11.5%.

At the minimum (under experimental conditions) density of 45 thousand/ha, the value of the indicator was 67.0 g. A stepwise increase in density by 10 thousand/ha was accompanied by a decrease in values to 65.2 (-1.8 g) and 61.8 g (- 3.4 g). In percentage terms, this was minus 1.8 and minus 3.4% on plots with a density of 55 and 65 thousand/ha, respectively. The results of the analysis of variance, carried out in terms of individual factors, indicate the presence of a statistically significant difference between the options

A general analysis of the materials in the section shows that the dominant role in changing yield indicators under favorable conditions (2019) was played by the hybrid factor (the share of the factor's influence was 60.2%). In less favorable conditions (2020 and 2021), the influence of the hybrid factor decreased.

The opposite dynamics was observed for the mineral fertilizer factor, the influence of which was 16.5; 17.5 and 52.2% in 2019, 2020 and 2021, respectively. A significant difference in the share of "other" factors, namely 23.0% in favorable 2019 and less than 15% in 2020–2021, indicates that the formation of high yields requires additional (specific to 2019) weather conditions.

It was found that the use of medium and high rates of fertilizer provided an increase in the average yield from 2.56 to 2.93 and 3.22 t/ha, or by 0.37 and 0.66 t/ha, respectively.

When using medium rates of fertilizer, the highest level of increase (+ 0.5 t/ha) was provided by the Agent hybrid. In variants with high rates of fertilizer, the best indicators of yield increase were provided by the following hybrids: Teo, Oscar, Dobrodiy and LG 53.77.

In terms of the density factor, yield fluctuations were less significant and did not have a systemic nature. The absence of a statistically significant difference in the response levels of the yield indicator to changes in density indicates the inexpediency of isolating the latter as an independent factor of technology. Sowing density should be considered as a feature characterizing the nature of the variety or environmental conditions (fertilizer rate).

The use of medium and high fertilizer rates ensured an increase in the average plant productivity from 47.59 to 54.32 and 60.52 g/plant, or by 14.4 and 25.9%. The stepwise decrease in the productivity indicator (due to an increase in sowing density) was -17% for every 10 thousand plants/ha. The highest average productivity was observed for the hybrids 0f Agent 65.79 g and LG 53.77 63.52 g/plant

Changes in productivity indicators were determined by the dynamics of the parameters of the weight of 1000 seeds (and the number of seeds in the head). The highest values of the indicator were observed in the hybrids Phenomenon - 75.57 and Dobrodiy 79.56 g. In terms of the number of seeds, the ranking was led by the hybrids LG 53.77, Agent and Zlatson with indicators of 1118.5; 1089.3 and 901.6 pcs./plant.

The application of the average rate of fertilizers provided an increase in the indicator from 57.58 to 64.4 and 71.8 g, or by 11.8 and 23.3 %. The increase in plant density was accompanied by a decrease in the indicator from 67.0 (45 thousand/ha) to 65.2 and 61.8 g.

Conclusion. The experiment and the analysis of the collected digital material allowed us to draw the following general conclusions regarding the peculiarities of the formation of the yield of sunflower hybrids in the conditions of the northeastern Forest-Steppe of Ukraine.

For the group of medium-early hybrids, the average coefficient of the area leaf area surface of crop in the conditions of the research zone was 2.3 m^2/m^2 without fertilizers; 2.77 (+20.4%) and 3.34 m^2/m^2 (+45.2%) with the application of $N_{45}P_{45}K_{45}$ and $N_{90}P_{90}K_{90}$, respectively.

A gradual increase in the sowing density from 45 to 55 and 65 thousand/ha was accompanied by an increase in the indicator from 2.56 to 2.82 and 3.04 m^2/m^2, which was +10.1 and +28.7% respectively

It was established that the main parameter that determined the dynamics of changes in the indicators of the leaf apparatus of plant and crop was the area of one leaf. The determining factor in the dynamics of this indicator was the genotype (the strength of the factor's influence was 67.8%); the influence of fertilizer and density factors was 11.8 and 6.4% respectively.

The group of hybrids with high indicators of the leaf area (> 2.8 dm^2) included: Yason; Agent and LG 53.77. The minimum indicators of 1.7 dm^2 were the Phenomenon hybrid.

A statistically significant difference was noted in the response of hybrids to changes in fertilizer rates and sowing density. In variants with maximum factor values ($N_{90}P_{90}K_{90}$ and 60.0 thousand/ha), the difference between the control variant was 100% or more for the Yason, LG 53.77 and Agent hybrids; more than 60% for the Oscar and Zlatson hybrids.

The minimum response to the influence of factors was noted in the Dobrodiy (+44.2%) hybrids, Teo (+43.1%), Nabir (+42.3%) and Phenomen (+32.1%).

It was calculated that the dominant role in the change in yield indicators under favorable conditions (2019) was played by the hybrid factor (the share of the factor's influence was 60.2%). In less favorable conditions (2020 and 2021), the influence of the hybrid factor decreased. The opposite dynamics was observed for the mineral fertilizer factor, the impact of which increased in less favorable years.

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