Agraarteadus
2 • XXXI • 2020 219–243

Journal of Agricultural Science
2 • XXXI • 2020 219–243

MODULAR-VITALITY AND IDEOTYPICAL APPROACH IN EVALUATING THE EFFICIENCY OF CONSTRUCTION OF OILSEED RADISH AGROPHYTOCENOSISES (*RAPHANUS SATIVUS* VAR. *OLEIFERA* PERS.)

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Saabunud: Received: 11.09.2020
Aktsepteeritud: Accepted: 18.12.2020

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Keywords*:* oilseed radish, vitality, variability, capacity, vitality tactics, plant ideotype, agrophytocenosis layering.

DOI: 10.15159/jas.20.27

ABSTRACT. The paper provides the results of a multi-year study of the peculiarities of phytocoenology of oilseed radish agrophytocenosises using various methods of its condition assessment and studying the tactics of plant vitality strategy. A comprehensive assessment was made of the impact of changes in inter-row spacing width, sowing rates and fertilizer on the formation of different plant ideotypes, the variability of their morphological features and general indicators of viability.

Three ideotypes of oilseed radish plants in the vertical study of agrophytocenosises were identified, based on which a detailed analysis of the variability of each group and a statistical assessment of the reliability of its existence was made. The peculiarities of morphological integration of each tier were analyzed and its influence on the formation of the overall field capacity was assessed. Based on the modular and vitality grouping, the efficiency and feasibility of combining different stand density and fertilizer options in the range of 30–90 kg of primary material per 1 hectare were evaluated.

Due to the application of regression analysis, the impact of climatic conditions on the formation of different morphological types of plants and the nature of relationships between oilseed radish plants in cenosises of different stand densities with different fertilizer options was assessed. The main perspective directions of further research on the peculiarities of the creation of highly productive and highly adaptive agrophytocenosises of oilseed radish are outlined.

Introduction

The agrophytocenosis assessment of any crop species has two typologically different approaches. The first one is based on using the average cenosis value for a certain indicator, for example, the height of plants, the individual mass of the plant, *etc*. This approach implies the use of a certain selection from which the average value of the indicator is statistically determined. The second one is based on the phytocoenological approach to the structure of agrophytocenosises in various forms – vertical and horizontal architecture of the spatial orientation of the cenosis plants, assessment of the level of coenotic tension, considering the density of cenosis, the level of fertilization, hydrothermal factors of vegetation. According to many researchers, in modern agrotechnological scientific practice, the second approach is more rational and essential, as it answers the urgent questions of the optimal construction of the cenosis already conducted at the sowing technological stage. Further, it is decisive in plants' growth and physiological processes, being determinative in implementing their genotypic potential. (Zlobin, 1989, 1993, 2009; Isaacs *et al*., 2016; Burstin *et al*., 2018).

The aspects of the idiotic structure of sowing, the formation of its high-altitude layering and the plant stand differentiation into the corresponding plant ideotypes are also based on the same approach (Zeven, 1975; Martre *et al*., 2015; Barot *et al*., 2017). Ensuring a certain ratio between plants idiotypes defined for each agricultural crop is crucial in ensuring optimal plant growth formats, since ensuring uniformity of agrophytocenosises, even considering modern selection practice and genetic uniformity of plants is a very problematic issue (Zhang, 1999; Anten, Vermeulen, 2016).

It should also not be forgotten that modern approachhes to mineral nutrition of major crops should be adaptive and correspond to both hydrothermal conditions of the territory and specific biological features of the crop itself, considering the plant variety architecttonics. In recent years, the format for evaluating fertilizer performance has been moving in the phytocoenological direction. Phytocoenological approaches are technologically introduced into the strategy of precision farming, as they transform the concept from general to the individual, allowing treating the agrophytocenosis of a certain crop from the standpoint of individual development considering the stress factors that arise when certain technological regulations of cultivation are observed (Shanda, 2017). Mineral fertilizers in the phytocoenological assessment approach are considered as a stress-regulating factor and are evaluated in the format of a stimulant for ensuring the receipt of plants of different vitality class, different idiotype (Debaeke, Quilot-Turion, 2014).

Although the issue of the vitality strategy of agrophytocenosises is relatively well researched, aspects of their application in the development of technologies for growing certain crops, including such basic elements as sowing rate, plant nutrition area and fertilizer, which should effectively combine and intensify the previous two factors. This approach is especially important and appropriate for crops that have high rates of modifiable variability at the level of reproductive effort and individual parameters of seed productivity, and are sensitive to changes in sowing parameters at technological setting and formation of agrophytocenosises. Given the fact that oilseed radish can be classified as such crop varieties (Tsytsiura, 2018, 2019), the application of a system of phytocoenological fertilizer assessment will be relevant and reasonable.

TA number of researchers in their studies covers the issue of vitality strategy of formation of agrophytocenosises in crops of the different development cycle. Thus, it is noted (Jeuffroy *et al*., 2014; Van der Meulen, Chauhan, 2017) that it is necessary to consider the aspects of inter- and intraspecies competition in the technologies of main crops growing. On their basis, the approaches to the productive efficiency of agrophytocenosises are formed, and a possible conclusion about the expediency of the corresponding basic elements of the technology is drawn. It is pointed out (Hamblin, 1993) the necessity of the phytocoenological approach to the construction of productive crop cenosises with the evaluation of their structure and general coexistence of components.

It is mentioned (Heslot *et al*., 2014) the complex biological aspect of growth processes of plants in artificially separated cenosises which are certain fields with single-species sowing of crops. The dynamics of this growth has a complex combinatorial nature and cannot be effectively described using only a group or average approach. It is important to highlight the individual characteristics of plants, which should be combined into a system of corresponding dependencies. We've developed the approach (Mangin *et al*., 2017) using a correlation-block system of corresponding technological measures efficiency estimation by forming certain plants' morphotype in sowing, the existence of corresponding correlation dependences between morphological features vegetative and generative parts. In their turn, they provide reception of the corresponding level of biological productivity of a plant organism at a combination of corresponding nutrition area, fertilizer and other measures on a background of corresponding reaction norm. At the same time, the existence of certain morphotypes of plants as a part of single-species cenosis was specified in the '70s of last century in the concept of the plant idiotype and its importance in heterogeneous selection (Donald, 1968; Mock *et al*., 1975). Further, the concept of the plant idiotype started to include features of plant morphometry by key parameters of the ratio of separate organs and their general development. The concept also considered the average indicator typical for the cenosis at the given technological parameters of its pre-sowing formation and the corresponding additional mineral nutrition. (Haverkort, Kooman, 1997; Semenov, Stratonovitch, 2013; Martre *et al*., 2015; Vincourt, Carolo, 2018). Ideotypical approach to plant morphometry assessment allows to conduct appropriate levels of modelling of physiological and growth processes and determine the efficiency of use of hydrothermal and physiological and genetic factors of plant growth and development by plants (Ishbirdin *et al*., 2005; Qia *et al*., 2010; Van Tassel *et al*., 2017; Tonin *et al*., 2018). It's also noted that the said different plant morphotypes have different reproductive tactics and corresponding indicators of reproductive effort (Samson, Werk, 1986; Dickmann *et al*., 1994; Ly *et al*., 2018). Moreover, the plant idiotype (morphotype) can be attributed to the respective modelled level of plant development with an assessment of their suitability for the respective level of technology (Ellisséche *et al*., 2002; Cilas *et al*., 2006), can be used in the options of pest and disease resistance assessment (Le May *et al*., 2009; Calonnec *et al*., 2013; Andrivon *et al*., 2013), as well as in the assessment of the stress tolerance and adaptability level of varietal agrotechnologies (Loison *et al*., 2017; Gauffreteau, 2018) and the assessment of allelopathic resistance (Grodzinskiy, 1973; Rais, 1978). It is further noted (Zhilyayev, 2005) that the format of the relevant technological components will be effective as a whole if it is based on the viability properties of the population or agrophytocenosis. This indicator should be interpreted as a general plant architectonics in single-species coenopopulations, which include field-planting crops. The very implementation of the vital strategy of the cultivated plants will be determined by the level of competitiveness of the plants, primarily with each other and to the vegetation of other species groups. Under these conditions, an effective option for the plant cenosis construction will be one that guarantees a weaker variant of intra-species competition against the background of optimization of the growth processes of plants.

The consistency of studying the issue of the vitality strategy of cenosises, considering their construction and application of respective regulators, which may include mineral fertilizers, is reflected in numerous scientific papers by Zlobin (1989, 2009). Based on the generalization of various scientific hypotheses and numerous research carried out by various scientists, the author has formulated the basic regularities of coenopopulation relations of different levels, and peculiarities of formation of plant morphotypes. He has also described the basic components of plant vitality strategy and has outlined the main tactics of the general methodology of assessment of the viability of plants coenopopulations and agrophytocenosises. Despite the multiplicity of covered and discussed problematic issues, the role of plant stands density and its corresponding individual nutrition area in interaction with additional mineral nutrition is a determining factor model in the regulation and expression of intra-species variability, weakening or strengthening of single-species competition and ensuring the desired vitality strategy in the formation of signs of productive morphology, both in terms of leaf mass and seed yield indicators. It is a matter that requires further scientific study and generalization with the development of recommendations for optimizing the mineral nutrition of crops (using the example of oilseed radish) based on the phytocoenological approach.

Materials and methods

The research was conducted on the experimental field of the Vinnytsia National Agrarian University on dark grey forest soils (Luvic Greyic Phaeozem soils (IUSS Working Group, 2015)). The agrochemical field potential according to the main agrochemical indicators defined by the National Standard of Ukraine 4362:2004: Soil quality. Indicators of soil fertility. (2006) meets the general characteristics of this soil type and is as follows: humus content: 2.02–3.2%, lightly hydrolyzed nitrogen 67–92, mobile phosphorus 149–220, exchangeable potassium 92–126 mg kg^{-1} of soil at pH$_{\text{кcl}}$ 5.5–6.0. Technological parameters for the formation of oilseed radish agrophytocenosises were carried out in the interval of recommended variants in terms of common row (row spacing of 15 cm) and wide-row (row spacing of 30 cm) sowing methods. The variants are selected considering the uniformity of seed placement along the length of the row from 15 to 60 similar seeds per linear meter in a row (Table 1).

The climate of the region is moderately continental (Dfb according to the Köppen-Geiger climate classification (Pivoshenko, 1997)). The hydrothermal parameters of the oilseed radish vegetation period differed, forming certain typological features of the years of study.

The 2013–2014 conditions (Fig. 1) can be classified as the most optimal for growth processes of oilseed radish due to the combination of slow growth rates of average daily temperatures and uniform precipitation at the end of May-mid-June. In the study area, it's phenologically corresponds to active vegetation of oilseed radish and coincides with the interphase phenological period of stooling-flowering (BBCH 30-65) (Test Guidelines…, 2017).

Table 1. Scheme of the experiment under wide-spread variants of oilseed radish agrophytocenosis formation

Factors of the trial (A – conditions of the year)		
B – planting method	C – seeding rates (mln germinable seeds ha^{-1})	D – fertilization
B$_1$ – row method (15 cm)	B$_1$ – 1.0 (15 seeds m^{-1} per row*)	C$_1$ – without fertilizers C$_2$ – N$_{30}$P$_{30}$K$_{30}$ C$_3$ – N$_{60}$P$_{60}$K$_{60}$ C$_4$ – N$_{90}$P$_{90}$K$_{90}$
	B$_2$ – 2.0 (30 seeds m^{-1} per row)	
	B$_3$ – 3.0 (45 seeds m^{-1} per row)	
	B$_4$ – 4.0 (60 seeds m^{-1} per row)	
B$_2$ – wide-row method (30 cm)	B$_5$ – 0.5 (15 seeds m^{-1} per row)	
	B$_6$ – 1.0 (30 seeds m^{-1} per row)	
	B$_7$ – 1.5 (45 seeds m^{-1} per row)	
	B$_8$ – 2.0 (60 seeds m^{-1} per row)	

The conditions of 2015 and 2018 for the research period based on the of precipitation uniformity and the nature of the average daily temperature rise curve ratio should be considered as stressful for the physiological and growth processes of oilseed radish plants.

Thus, in 2015, the precipitation distribution was uneven, with no precipitation during the second decade of May to the second decade of June, with an intensive and rapid rise in average daily temperatures during the same period and a high amplitude of values. As a result, there was a double effect of general stress of the environmental factor during the interphase period of the beginning of budding-flowering (BBCH 38-64) concerning oilseed radish plants and it allowed to effectively evaluate the studied indicators in the system of environment-forming features.

For the conditions in 2018, there was a prolonged atmospheric and soil drought with slight moistening by the second decade of June against the background of low average daily temperatures, in contrast to the conditions in 2015, which affected the value of the architectonics of the oilseed radish plants starting from the rosette formation phase and its subsequent stooling (BBCH 19-38). These are the reasons why the 2018 vegetation year is the most indicative of stress assessment.

The 2016 and 2017 research years on hydrothermal regime parameters should be classified as intermediate in a six-year study cycle with a similar dynamic regime of average daily temperatures and irregular atmospheric moistening. Meanwhile, the 2016 conditions are close to the 2013–2014 period, and the 2017 conditions are similar to the 2015 conditions. Thus, an increase in the overall favorable hydrothermal vegetation regime for the oilseed radish towards reducing weather risks in terms of optimality for the growth and development of the oilseed radish should be placed in the following order: 2018–2015–2017–2016–2013–2014.

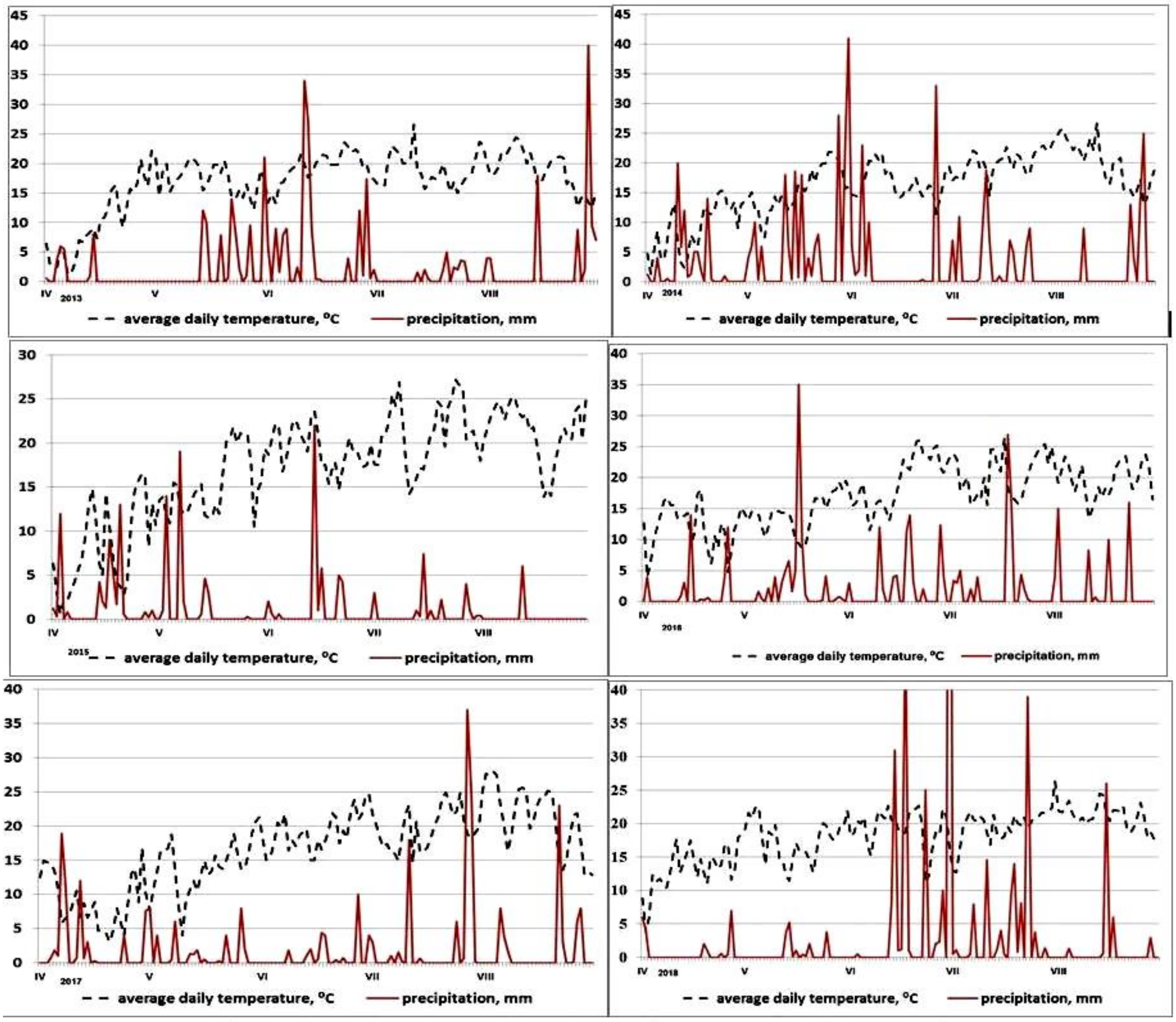


Figure 1. Hydrothermal conditions for April–August (2013–2018 period) (sequentially left-right and top-down: 2013–2014–2015–2016–2017–2018)

At the same time, the impact of environmental parameters on the studied indicators was analyzed in the paper using the hydrothermal coefficient (HTC) developed by Selyaninov (Mukhortov, Ryabchikova, 2012), which was calculated using the Formula 1:

$$HTC = \frac{\sum R}{0.1 \times \sum t_{>10}}, \qquad (1)$$

where the amount of precipitation (ΣR) in mm for the period with temperatures, above 10 °C, the sum of active temperatures (Σt>10 °C) for the same period reduced by 10 times.

The assessment of the oilseed radish vitality strategies against the background of the technological regulations for the pre-sowing construction of its agrophytocenosises was carried out using modular-distinctive and vitality approaches, considering the fertilizer options as stress-regulating and corrective factors in the light of changes in oilseed radish cenosis density combined with sowing rates and row spacing. The study was conducted on basic area-specific oilseed radish genotypes, namely 'Zhuravka', 'Lybid' and 'Raiduha'.

Given the similarity of the identified regularities and peculiarities, the materials presented in this paper relate to the 'Zhuravka' variety with relevant practical conclusions regarding the general species of oilseed radish (*Raphanus sativus* var. *oleifera* Pers.).

The following indicators were used to systematically evaluate the formation of vital strategies of oilseed plants.

Vitality coefficient (calculated according to defined methods (Zlobin, 1989; Ishbirdin *et al.*, 2004), using the Formula 2:

$$IVC = \frac{1}{N} \times \sum_{i=1}^{N} \frac{x_i}{X_i}, \qquad (2)$$

where IVC – agrophytocenosis vitality index; N – total number of features that are determined in agrophytocenosis; x_i – the value of the i-th feature in agrophytocenosis with certain cultivation technology parameters; X_i – the average of the i-th feature for all agrophytocenosises in the interval of cultivation technology parameters under study.

Morphological variability module according to recommendations (Glukhov, Prokhorov, 2008) using Formula 3:

$$Mod_x = \frac{CV}{CV_{St}} \tag{3}$$

where Mod_x – morphological variability module of the respective plant parameter, CV – coefficient of variation of a feature from the variant under the study, CV_{st} – coefficient of variation in the variant of maximum morphological development.

Modified morphological integration index (I_{mmi}) was determined by the recommendations (Zlobin, 2009; Sherstyuk, 2017) using Formula 4:

$$I_{mmi} = \frac{1B \le 0{,}5 + 2B > 0.5... < 0{,}8 + 3B \ge 0{,}8}{(n^2 - n)/2} \tag{4}$$

where I_{mmi} – modified morphological integration index; $B \le 0.5$ – the number of statistically reliable (at the probability level of 0.95) correlation coefficients in the matrix, the values of which by the module are in the range from 0 to 0.5 inclusive; $B > 0.5 \ldots < 0.8$ – the number of statistically reliable (at the probability level of 0.95) correlation coefficients in the matrix, the values of which by the module are higher than 0.5 and lower than 0.8; $B \ge 0.8$ – the number of statistically reliable (at the probability level of 0.95) correlation coefficients in the matrix, the values of which by the module are equal to or greater than 0.8; n – total number of morphometric parameters that have been assessed.

The degree of integrated connection of plant morphological features was assessed using the weight correlation graph method in two interpretations using Formula 5 and 6:

$$G = \sum_{|r_{ij}| \ge \alpha} |r_{ij}| \tag{5}$$

where r_{ij} – correlation coefficient between *i*-th and *j*-th indicator. Reliable correlation coefficients are considered.

$$G' = \Big(\sum_{|r_{ij}| \ge \alpha} |r_{ij}|\Big) / n \tag{6}$$

n – number of statistically significant correlation coefficients.

To assess the vitality of oilseed radish agrophytocenosises, a quality index (Q) was used for the various study options by the recommendations (Rasevich, 2008) using Formula 7:

$$Q = \frac{(A + B)}{2} \tag{7}$$

The vitality classes have been interpreted in terms of the idiotype of oilseed radish plants, which were mentioned earlier in our publications on the specifics of the layering formation of the crop's agrophytocenosis. Given these conditions, in the formula, A and B, respectively, represent the number of species of the first and second ideotype, *i.e.* the upper and middle dominating tier. The resulting average between the first and second plant ideotype was compared to the third plant ideotype (lower-tier) (C). The principle of comparison provided for the use of equation in the following format: Q>C, cenosis has growth and development-friendly structure for species, Q<C – regressive, Q = C – equilibrium-dynamic.

The agrophytocenosis flourishing index (I_Q) was determined by the recommendations (Ishbirdin *et al.*, 2005) using Formula 8:

$$I_Q = \frac{(A + B)}{2C} \tag{8}$$

Phytocoenotic plasticity index I_p was determined by the recommendations (Zlobin, 1989) using Formula 9:

$$I_p = \frac{(A \cdot B)}{A} \tag{9}$$

where A and B – respectively the maximum and minimum average value of the feature by year of observation.

The ecological amplitude of the technological variant of oil radish cultivation was assessed based on the size plasticity index, which was calculated using Formula 10 (Ishbirdin *et al.*, 2004):

$$ISP = \frac{IVC_{\max}}{IVC_{\min}} \tag{10}$$

where IVC_{max} – vitality index for plants with signs of the most distinct morphotype; IVC_{min} – vitality index for plants with signs of the least distinct morphotype.

Morphological features were assessed by sampling typical plants at five locations along the length of a row in a stochastic manner along the width of the area, with row horizontal displacement in non-contiguous repetitions at four single repetitions. The morphological features were registered in the following phenological phases: flowering (BBCH 65), green pod (BBCH 75-78), and yellow pod (BBCH 79-83). To register the features, the plants were marked and numbered for the non-destructive recording of the relevant indicators. Those indicators, which required the selection of a part of the plants (area of leaves, the weight of separate parts, the weight of fruits, *etc.*), were recorded on parallel plants which were the closest to the main (numbered) plants in the records. Such a system of conditional comparison of the integrity of typical plants applied in the evaluation of the system of matrix correlations of plant features in dynamics (Rostova, 2002) has allowed us to compile a matrix of correlations that connects the full range of morphological vegetative features of plants and individual basic indicators of their seed productivity. The system of morphological features used in the assessment results was divided into blocks (Table 2).

Table 2. Modular blocks for morphological and productive analysis of oilseed radish plants (grouping)

Modular and morphological block	Feature and dimension of its evaluation	Trivial designation
Stem and root block	Stem height, cm	H
	Stem diameter at the base, mm	D
	Stem height to the first branching, cm	H_1
	Stem morphology index, cm mm^{-1}	HDR
	Weight of the stem part of the plant, g	w_1
	Root weight, g	WR
Block of the leaf part	Number of leaves on the stem, pcs.	n
	Leaf length, cm	l
	Leaf width, cm	a
	Area of plant leaves, cm^2	S
	Average leaf area, cm^2	$S\ n^{-1}$
	Thickness of 10 leaves, mm	h
	Weight of leaves from the plant, g	w_2
	Elongation of the leaf blade	$l\ a^{-1}$
	Leaf area per unit of leaf phytomass, cm^2 g^{-1}	SLA
Block of the generative part	Number of flowers on the plant, pcs.	N_1
	Total weight of the inflorescence, g	w_3
	Number of reproductive branching of the stems, pcs.	R
	Number of pods on the plant, pcs.	N_2
	Number of seeds in the pod, pcs.	g
	Total weight of pods from a plant at green pod phase, g	w_4
Productive block	Total weight of the plant, g	$W\ (WR + w_1 + w_2 + w_3 + w_4)$
	Photosynthetic effort (leaf weight per unit of phytomass)	LWR
	Reproductive effort RE (flower),%	$w_3\ w_1^{-1}$
	Reproductive effort RE (fruit),%	$w_4\ w_2^{-1}$
	Reproductive effort RE assimilation,%	$w_3\ (w_4)\ S^{-1}$
	Ratio of leaf surface area to plant weight, cm^2 g^{-1}	LAR
	Ratio of leaf surface area to stem diameter, cm^2 cm^{-1}	ADR
	Relative increase in height, cm g^{-1} $(H\ (w_1+w_2+w_3+w_4)^{-1})$	HWR
	Weight of 1000 seeds, g	m
	Seed projection surface area, mm^2	s
	Seed yield from the plant, g	Y

Tier structure of agrophytocenosises along with the determination of plant ideotypes was registered and analyzed at selected parts of the experimental plots in each repetition. The main morphological features were registered using standardized and widely accepted methods for a group of cruciferous crops (Sayko, 2011). Also, we used methodological descriptive recommendations of classification rank tables of species expertise (Test Guidelines…, 2017) with experimental statistical approaches (Zaytsev, 1984; Rumsey, 2016) in the format of four-factor dispersion analysis (Multivariate Analysis of Variance (MANOVA) and a pack of statistical programs Statistica 10 and MS Excel 2013. The correlation coefficient values $r < 0.5$ were considered as weak, $0.7 > r \geq 0.5$ – as moderate, $0.9 > r \geq 0.7$ – as strong (Rumsey, 2016). The level of variability of morphological features and grouped indicators was based on the Zaytsev H.N. scale (Zaytsev, 1984): very low (CV < 7%); low (CV = 8–12%); medium (CV = 13–20%); elevated (CV = 21–30%); high (CV = 31–40%); very high (CV > 40%).

Results and discussion

Modern practical approaches to the formation of agrophytocenosises of agricultural plants are aimed at the maximum realization of their genetic potential and are expressed in the formation of a specific, desirable ideological structure of sowing. Today, the "ideotype" term is defined as a "biological model", which results in programmed plant productivity under specific cultivation conditions due to a combination of the respective habitus project and the biological properties of the genotype, which should, in the resulting variant, ensure maximum yield of the plants with the corresponding high indicators of its quality (Donald, 1968; Zeven, 1975; Foltyn, 1977; Ma *et al.*, 2014; Zhang, 1999; Rötter *et al.*, 2015; Skliar *et al.*, 2016; Gauffreteau, 2018, Mangin *et al.*, 2017). The modern interpretation of the term is a search for appropriate plant microbiotypes that form the agrophytocenosis of any agricultural plant to make the most efficient use of growth resources under the respective physiological needs of the plant and agro-climatic resources of the territory (Tandon *et al.*, 2004, Andrivon *et al.*, 2013; Bassu *et al.*, 2014). On the other hand, it is noted that when assessing such microbiotypes in general cenosis, it is necessary to determine the correlation between morphometric parameters and individual plant productivity indicators, considering the respective soil and climate resources of the territory against the background of their abiotic adaptation (Zhuchenko, 2001, Rostova, 2002; Tandon *et al.*, 2004; Araus, Cairns, 2014). The integrity of these microbiotypes and the predominant expression of some of them determine, by their very nature, the life strategy of cenosis and its corresponding ideotype structure, the analysis of which is an indicator of performance at both the individual and general levels (Rasmusson, 1991; Abuelgasim, 1991; Thurling, 1991; Notov, 1999; Dolotovsky, 2003; Rostova, 2002; Desclaux, 2008; Rötter, 2015; Van Oijen, 2016; Van Tassel *et al.*, 2017; Anderson, 2019).

In our system of assessments, the integrity of the morphological features of oilseed plants was assessed by three criteria mentioned above: modified morphological integration index (I_{mmi}), weight correlation graph method (G) and morphological variability module (Mod_x). The first of the two indicators are based on a system of pairwise correlations by the methodology used to determine them. Correlation analysis on basic morphological features, by the conclusions on the influence of abiotic factors and technological aspects of the cultivation of crops on the materiality of dependencies (Labana *et al.*, 1976; Rostova, 2002) was carried out in the format of the annual correlation matrix in the context of the studied options of oilseed radish cultivation (Table 1). The paper presents pairwise correlation coefficients for two types of vegetation years concerning hydrothermal supply (2014 and 2018, respectively (Table 3)) and for two radically different technological variants of sowing rates (4.0 and 0.5 million pcs ha^{-1} of germinable seed respectively, against the background of the two fertilizer limit systems – fertilizer-free and $N_{90}P_{90}K_{90}$ application (Tables 4, 5)). A general stress assessment of the correlation matrix for radically different vegetation years showed several features. Firstly, oilseed radish can be classified as plant species with a sufficiently high level of morphological integration, taking into account the average level of cohesion, according to an average value of $G^{'}$ 0.533 for the year with the lowest (2014), and $G^{'}$ 0.639 for the year with the highest stress (2018). Secondly, under conditions of 2018, the average correlation coefficient in the sum of morphological features was 19.8% higher than in 2014, which according to the hydrothermal regime was considered to be the most favourable year for physiological growth processes of oilseed radish plants. This means that abiotic pressure, by limiting the intensity of growth processes, both radial and linear, ensures the formation of distinct pleiades in the basic characteristic plant blocks that characterize their morphological integrity. In the case of the moistening limit against the background of intensively rising temperatures (conditions of 2018), an overall miniaturization effect is observed for oilseed radish plants – a significant reduction in species by linear size, size of the assimilation surface and mass of the generative part. Under the same conditions, the tendency described in several studies is typical (Grime, 1979, 1988; Usmanov, 1990; de Kroon *et al.*, 2005; Murren, 2002; Sultan, 2004; Zlobin, 1993, 2009), namely the specific reaction to the complex stress of allometric parameters: the photosynthetic effort (LWR) of plants naturally increases and the reproductive effort (RE) significantly decreases. In other words, the overall ontogenetic tactics are maintained, and plant survival becomes an important factor in their reproductive tactics. Given these conditions, the narrowness of the variability of the morphological features in terms of the variation coefficient increases the contingency in their combinatorial variation in the ratio of pairs of features. For the oilseed radish, such features can be seen between the following pairs of features: stem diameter (D) – the weight of the plant (W), stem diameter (D) – the area of plant leaves (S), area of plant leaves (S)-leaf morphological parameters (length (l) and width (a)) and others. In the optimal combination of abiotic growth and development parameters, there is an opposite situation to stress conditions, which ensures the growth of the interval of values of plant morphological parameters of both allometric and reproductive nature and reduces the overall integration of plant morphological development. However, there is general preservation of the nature of pleiad pairs in terms of reducing the materiality of the correlation link of the features that form them, by the values of the correlation graph correlated by the number of significant correlation coefficients ($G^{'}$). Due to certain facts, the morphological and weight integrity of oilseed radish plants in a single system of comparison of technological variants, under conditions of significant abiotic stress, is substantially higher than under an optimal combination of environmental factors.

At the same time, in terms of the value of the correlation graph (G), the formation of correlation dependencies for various features has its peculiarities when comparing stressful and optimal conditions. Thus, the highest degree of integration of the connection for indicator G, significant stress conditions of vegetation, was noted for such features as the area of plant leaves (S) and weight of the plant stem (w_1) – 12.57 and 12.53 respectively. Substantially higher morphological and weight integration values were also recorded for leaf length (l) 11.99, the weight of the inflorescence (w_3) 11.84, the weight of leaves from the plant (w_2) 11.79 and stem diameter (D) 11.53. These are the features that form the middle and high-level pleiade correlation structures by the bond materiality. Low integration values were noted for the features of stem height to the first branching (H_1) and seed projection surface area (s) – 7.64 and 8.14, respectively. The weight 1000 seeds (m) should also be attributed to the group of indicators with a low level of integration, both because of the intermediate effects of interaction in the formation of the indicator and because of the corresponding level of its genetic determinacy. Under the conditions of 2014, with a decrease in abiotic pressure, the overall integration in terms of the value of the correlation graph of features (G) decreased by 16.4% for the group as a whole, with a maximum decrease for features of leaf width (a) 28.4%, plant height (H) 28.1%, number of pods on the plant (N_2) 25.0%, number of leaves on the plant (n) 23.0%, root weight (WR) 22.4%. The minimal decrease in the value of the correlation graph was observed with a decrease in abiotic pressure for the features of the weight of leaves from the plant (w_2) 5.1%, number of seeds in the pod (g) 6.7%, the total weight of pods from a plant at green pod phase (w_4) 7.9%, weight of 1000 seeds (m) 11.5%. This nature of change indicates a change in the correlation structure between the oilseed radish organs due to more intense linear and radial growth, the overall increase in the linear size of the assimilation apparatus. At the same time, the ratio between the above-ground system and the root system is disproportionate, and the total number of reproductive elements of flowers and pods has less reproductive effort than in stressful conditions. In this case, the conditions of assimilation feeding require an appropriate area of leaf apparatus to support growth processes. This is the reason for the minimal decrease in the correlation graph by the feature of the weight of leaves from the plant and the intensive decrease in the graph by the features of the number of leaves on the plant and leaf width. Again, the intensive growth of above-ground plant biomass with a decrease in abiotic pressure contributes to the associated changes in the reproductive effort (with a certain proportional formation of plant weight and pod weight) and to an increase in the correlative determinacy of the indicator. The nature of changes in the number of seeds in the pod and weight of 1000 seeds is determined by the same genetic determination in cruciferous crops highlighted in several publications (Zhuchenko, 2001). It should be noted that the expression of the pleiade structure of the bonds in 2014 for indicator D' shifts towards such features as stem diameter (D), area of plant leaves (S) and its weight (w_2), the weight of the stem plant (w_1) and weight of pods from a plant (w_4).

Preliminary conclusions are also confirmed in the evaluation of the correlation matrix for features of oilseed radish plants in different technological variants of oilseed radish cultivation (Tables 4, 5). Given that the plant stand density per unit of feeding area should be considered as an option for the agrophytocenosis regulation (Rabotnov, 1998; Rostova, 2002; Shanda, 2017), and the additional use of mineral fertilizers as a factor to increase or decrease plant stress, especially at cenosises of different density (Sinyagin, 1975; Chapin, 1980; Poluektov, 2006) analysis of the obtained data allows us to assess the degree of morphological integration of plants at different fertilization and stand density. It should be noted that the results we have obtained indicate certain stability in the system of correlation bonds at different cenosis densities of the oilseed radish. This is evidenced by the results of assessing the weight of the average correlation graph G on comparable technology variants. Thus, with a sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds on a nonfertilized ground this indicator was 8.20, on the ground with the application of $N_{90}P_{90}K_{90}$ kg ha^{-1} – 6.97. The same indicators for the same types of fertilizer with a sowing rate of 0.5 million pcs. ha^{-1} were 8.47 and 7.05, respectively, for the survey period. The similarity was also determined for the examined system of plant features and the indicator of the corrected correlation graph on the materiality of the bond: for both density and fertilizer comparisons, they were 0.513 and 0.482 and 0.507 and 0.459, respectively. Thus, with lower stand density on a nonfertilized ground, there is a greater weight of the graph than in the variant with significantly higher stand density. On the contrary, mineral fertilizers, within the studied options, contributed to a 17.3% reduction in morphological integration with a sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds and a 20.3% reduction with a sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds. Thus, for the oilseed radish, we have established the stability of integration of the general morphogenesis, where the reduction of the bond density in one pair of features with changes in the agrophytocenosis construction technology is balanced by an increase in its materiality in another system of features. At the same time, with the relative stability of the bonding tendencies and the existence of relatively stable correlation pleiades in the system, they are being reformatted. Thus, the constancy of the bonds between such features as stem diameter (D), root weight (WR), area of plant leaves (S), leaf length (l) for both dual variants of comparison with the relatively constant range of the pairwise correlation coefficients in the range of 0.397–0.968 (Tables 4, 5) is heterogeneously compensated or, conversely, weakened by the specificity of the interaction of the total reduction of the oilseed radish plant's habitus. It's accompanied by the increase in cenosis density (Tsytsiura, 2018, 2019) and an increase in the overall variability of morphological features and associated weight characteristics of oilseed radish plants with different fertilizer variants. Thus, for the variant of 4.0 million pcs. ha^{-1} of germinable seeds, on a nonfertilized ground, significant correlation bonds were noted in the system of integration of such features as plant height, stem diameter, root weight, stem weight, number of leaves, morphological features of the leaf itself, individual features of the seeds. For the technological variant of assessment of 0.5 million pcs. ha^{-1} of germinable seeds, the bond intensity of the above-mentioned features is reduced, especially concerning the height of the plants, but due to the growth of the total branching of plants in the variants of oilseed radish sowing rate of 0.5–1.0 million pcs. ha^{-1} of germinable seeds in the variant of wide-row sowing (Tsytsiura, 2018) the role of the height of plants to the first branching (H_1) in the morphological integration of the plants is increased.

Table 3. Correlation matrix for morphological and productive analysis of oilseed radish plants of "Zhuravka" variety in the system of technological variants for the construction of its agrophytocenosises, in the consolidated system of technological variants – years of cultivation, 2013–2018 (for N in total annual group 480)

Year	Graph of feature (G)	Graph of feature (G')	Features	H	D	H_1	w_1	WR	n	l	a	S	w_2	N_1	w_3	N_2	g	w_4	m	s	Y	Features	Graph of feature (G)	Graph of feature (G')	Year
2018	10.05	0.591	H	1.000	0.762	0.380	0.373	0.482	0.152	0.355	0.256	0.29	0.463	0.592	0.578	0.417	0.509	0.579	0.415	0.317	0.312	H	7.23	0.425	2014
	11.53	0.678	D	0.724	1.000	–0.621	0.805	0.709	0.529	0.572	0.474	0.785	0.597	0.694	0.639	0.531	0.319	0.609	0.459	0.207	0.402	D	9.71	0.571	
	7.64	0.449	H_1	0.314	–0.714	1.000	–0.622	–0.412	–0.561	–0.358	–0.249	–0.215	–0.329	–0.259	–0.39	–0.369	–0.308	–0.292	–0.356	–0.254	–0.517	H_1	6.49	0.382	
	12.53	0.737	w_1	0.855	0.935	–0.801	1.000	0.637	0.711	0.728	0.659	0.741	0.827	0.629	0.714	0.727	0.407	0.707	0.629	0.358	0.525	w_1	10.80	0.635	
	10.72	0.630	WR	0.615	0.852	–0.693	0.852	1.000	0.501	0.517	0.505	0.491	0.609	0.396	0.488	0.515	0.392	0.535	0.336	0.318	0.423	WR	8.27	0.486	
	11.49	0.676	n	0.489	0.804	–0.562	0.805	0.653	1.000	0.309	0.367	0.859	0.902	0.571	0.505	0.609	0.517	0.529	0.367	0.319	0.544	n	8.85	0.521	
	11.99	0.705	l	0.819	0.755	–0.615	0.858	0.761	0.712	1.000	0.892	0.875	0.745	0.621	0.711	0.505	0.519	0.693	0.459	0.412	0.51	l	9.78	0.575	
	10.44	0.614	a	0.703	0.681	–0.522	0.751	0.602	0.651	0.928	1.000	0.838	0.410	0.504	0.413	0.351	0.219	0.305	0.218	0.329	0.322	a	7.31	0.430	
	12.73	0.749	S	0.715	0.892	–0.675	0.853	0.774	0.719	0.922	0.901	1.000	0.890	0.814	0.809	0.743	0.706	0.633	0.458	0.391	0.692	S	11.23	0.661	
	11.79	0.693	w_2	0.674	0.631	–0.506	0.909	0.609	0.951	0.808	0.712	0.928	1.000	0.712	0.751	0.701	0.56	0.854	0.614	0.601	0.623	w_2	11.19	0.658	
	11.11	0.654	N_1	0.307	0.814	–0.503	0.708	0.412	0.703	0.691	0.528	0.805	0.631	1.000	0.909	0.597	0.507	0.628	0.562	0.439	0.505	N_1	9.94	0.585	
	11.84	0.696	w_3	0.652	0.855	–0.568	0.801	0.669	0.735	0.752	0.654	0.827	0.677	0.851	1.000	0.394	0.389	0.639	0.502	0.456	0.378	w_3	9.67	0.569	
	10.96	0.645	N_2	0.584	0.809	–0.455	0.655	0.555	0.714	0.587	0.509	0.611	0.755	0.714	0.705	1.000	0.569	0.817	0.511	0.467	0.596	N_2	8.22	0.483	
	10.82	0.636	g	0.825	0.684	–0.494	0.515	0.618	0.622	0.693	0.569	0.752	0.582	0.613	0.557	0.628	1.000	0.526	0.463	0.491	0.815	g	10.09	0.593	
	10.95	0.644	w_4	0.488	0.886	–0.505	0.610	0.701	0.691	0.571	0.412	0.602	0.781	0.762	0.789	0.701	0.608	1.000	0.612	0.42	0.711	w_4	10.09	0.593	
	9.38	0.552	m	0.396	0.624	–0.623	0.607	0.354	0.551	0.603	0.501	0.557	0.551	0.589	0.554	0.565	0.612	0.509	1.000	0.709	0.625	m	8.30	0.488	
	8.14	0.509	s	0.202	0.509	–0.089	0.459	0.406	0.502	0.505	0.407	0.5	0.51	0.556	0.536	0.512	0.715	0.55	0.618	1.000	0.522	s	7.01	0.412	
	11.27	0.663	Y	0.687	0.791	–0.514	0.554	0.589	0.629	0.607	0.411	0.693	0.571	0.927	0.658	0.903	0.733	0.786	0.563	0.653	1.000	Y	9.02	0.531	

Levels of significance: $p \le 0.05$: $0.09 \le r \le 0.116$; $p \le 0.01$: $0.117 \le r \le 0.148$; $p \le 0.001$: $r \ge 0.148$.

Table 4. Correlation matrix for morphological and productive analysis of oilseed radish plants of ‘Zhuravka’ variety at a sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds with different fertilizer options for the 2013–2018 period (for N in technological variant 60)

Vari-ant	Graph $(G')_{minm}$	Graph $(G')_{max}$	Graph (G)	Features	H	D	H_1	w_1	WR	n	l	a	S	w_2	N_1	w_3	N_2	g	w_4	m	s	Y	Features	Graph $(G')_{minm}$	Graph $(G')_{max}$	Graph (G)	Vari-ant
4.0 million pcs. ha^{-1} of germinable seeds against the $N_{90}P_{90}K_{90}$ ground	0.444	0.548	7.10	H	1.000	0.411*	0.525	0.114	0.405	0.156	0.562	0.442	0.521	0.507	0.365	0.411	0.511	0.402	0.409	0.283	0.401	0.612	H	0.451	0.711	6.77	4.0 million pcs. ha^{-1} of germinable seeds fertilizer-free
			9.31			0.793**	0.521	0.684	0.683	0.883	0.824	0.672	0.765	0.708	0.814	0.771	0.837	0.632	0.761	0.411	0.603	0.727				12.09	
	0.489	0.599	6.85	D	0.287	1.000	–0.089	0.612	0.542	0.519	0.456	0.473	0.618	0.634	0.526	0.511	0.452	0.265	0.414	0.225	0.311	0.315	D	0.471	0.646	7.06	
			8.99		0.592		–0.432	0.785	0.756	0.654	0.726	0.528	0.819	0.909	0.637	0.654	0.705	0.302	0.639	0.429	0.609	0.605				10.98	
	0.366	0.436	3.66	H_1	0.464	–0.257	1.000	–0.165	–0.112	–0.169	–0.108	–0.087	–0.205	–0.315	–0.167	–0.257	–0.236	–0.107	–0.152	–0.237	–0.151	–0.251	H_1	0.366	0.438	1.10	
			4.80		0.586	–0.305		–0.326	–0.507	–0.412	0.473	–0.485	–0.569	–0.507	–0.374	–0.492	–0.452	–0.308	–0.354	–0.412	–0.391	–0.429				7.44	
	0.437	0.540	6.56	w_1	0.326	0.623	0.096	1.000	0.564	0.267	0.404	0.361	0.518	0.414	0.39	0.495	0.453	0.301	0.419	0.417	0.239	0.311	w_1	0.395	0.631	5.93	
			8.64		0.404	0.817	0.157		0.801	0.651	0.723	0.625	0.719	0.709	0.617	0.631	0.682	0.524	0.659	0.612	0.429	0.543				10.72	
	0.503	0.525	5.03	WR	0.512	0.603	–0.236	0.624	1.000	0.312	0.409	0.328	0.412	0.392	0.304	0.417	0.515	0.251	0.408	0.319	0.303	0.322	WR	0.396	0.649	5.95	
			7.87		0.633	0.704	–0.192	0.813		0.719	0.761	0.634	0.725	0.709	0.652	0.639	0.624	0.469	0.669	0.529	0.602	0.551				11.03	
	0.428	0.507	6.00	n	0.296	0.527	–0.411	0.425	0.409	1.000	0.105	0.091	0.529	0.614	0.294	0.368	0.455	0.482	0.426	0.456	0.198	0.400	n	0.380	0.669	5.32	
			8.11		0.451	0.609	–0.558	0.569	0.507		0.709	0.589	0.845	0.854	0.669	0.629	0.809	0.669	0.811	0.505	0.357	0.612				11.38	
	0.416	0.585	6.71	l	0.633	0.512	–0.523	0.428	0.394	0.211	1.000	0.822	0.751	0.702	0.369	0.41	0.318	0.353	0.31	0.327	0.205	0.387	l	0.446	0.664	6.69	
			8.78		0.708	0.617	–0.456	0.583	0.552	0.316		0.908	0.901	0.814	0.652	0.658	0.501	0.508	0.604	0.602	0.395	0.525				11.28	
	0.458	0.511	5.03	a	0.402	0.352	–0.239	0.335	0.421	0.302	0.732	1.000	0.812	0.364	0.257	0.307	0.242	0.214	0.362	0.287	0.203	0.289	a	0.400	0.562	5.20	
			7.15		0.509	0.496	–0.320	0.452	0.519	0.369	0.893		0.907	0.626	0.498	0.469	0.503	0.419	0.507	0.415	0.354	0.411				9.55	
	0.549	0.620	8.24	S	0.509	0.523	–0.294	0.529	0.507	0.622	0.828	0.802	1.000	0.625	0.574	0.521	0.504	0.369	0.542	0.257	0.303	0.459	S	0.501	0.699	8.02	
			10.54		0.631	0.781	–0.369	0.635	0.587	0.701	0.968	0.889		0.893	0.734	0.718	0.668	0.599	0.712	0.429	0.451	0.627				11.89	
	0.528	0.635	8.44	w_2	0.632	0.805	–0.322	0.524	0.451	0.702	0.751	0.529	0.816	1.000	0.407	0.521	0.521	0.269	0.587	0.421	0.25	0.459	w_2	0.485	0.662	7.75	
			10.16		0.702	0.921	–0.478	0.603	0.551	0.809	0.908	0.612	0.968		0.647	0.627	0.619	0.428	0.713	0.509	0.356	0.622				11.25	
	0.419	0.510	6.71	N_1	0.414	0.631	–0.329	0.429	0.319	0.362	0.528	0.419	0.469	0.362	1.000	0.587	0.429	0.298	0.557	0.369	0.305	0.452	N_1	0.405	0.585	6.48	
			8.66		0.529	0.745	–0.450	0.56	0.451	0.451	0.612	0.54	0.594	0.427		0.733	0.592	0.387	0.613	0.405	0.352	0.569				9.95	
	0.460	0.531	6.90	w_3	0.369	0.527	–0.269	0.429	0.456	0.502	0.524	0.327	0.563	0.527	0.638	1.000	0.452	0.303	0.51	0.289	0.326	0.412	w_3	0.417	0.585	7.10	
			9.03		0.473	0.704	–0.308	0.581	0.561	0.592	0.608	0.451	0.691	0.638	0.702		0.611	0.383	0.601	0.397	0.417	0.522				9.95	
	0.489	0.579	8.14	N_2	0.52	0.527	–0.367	0.524	0.511	0.409	0.492	0.412	0.527	0.554	0.503	0.529	1.000	0.516	0.741	0.369	0.321	0.562	N_2	0.385	0.505	5.38	
			9.85		0.592	0.63	–0.457	0.611	0.602	0.567	0.569	0.517	0.637	0.701	0.616	0.624		0.554	0.811	0.417	0.439	0.691				8.58	
	0.387	0.421	3.10	g	0.425	0.132	–0.102	0.236	0.152	0.328	0.169	0.169	0.306	0.155	0.219	0.165	0.364	1.000	0.402	0.512	0.362	0.551	g	0.457	0.615	7.31	
			5.47		0.587	0.254	–0.189	0.354	0.211	0.403	0.287	0.291	0.412	0.219	0.357	0.301	0.472		0.504	0.605	0.469	0.818				10.45	
	0.395	0.469	5.13	w_4	0.361	0.284	–0.056	0.326	0.217	0.269	0.147	0.103	0.41	0.427	0.389	0.452	0.616	0.374	1.000	0.41	0.325	0.489	w_4	0.457	0.615	7.31	
			6.57		0.471	0.351	–0.102	0.411	0.327	0.39	0.196	0.151	0.502	0.512	0.487	0.55	0.719	0.401		0.502	0.419	0.569				10.45	
	0.346	0.389	3.46	m	0.214	0.051	–0.163	0.325	0.196	0.234	0.259	0.136	0.202	0.344	0.287	0.263	0.451	0.332	0.357	1.000	0.523	0.627	m	0.391	0.510	5.87	
			5.45		0.302	0.104	–0.211	0.418	0.269	0.312	0.401	0.213	0.269	0.413	0.321	0.32	0.52	0.442	0.415		0.653	0.841				8.67	
	0.340	0.384	3.06	s	0.429	0.145	–0.103	0.269	0.208	0.169	0.11	0.129	0.209	0.269	0.301	0.214	0.32	0.359	0.329	0.417	1.000	0.628	s	0.373	0.471	4.11	
			4.99		0.505	0.289	–0.198	0.3	0.294	0.214	0.19	0.201	0.297	0.354	0.369	0.319	0.408	0.455	0.418	0.521		0.715				8.01	
	0.454	0.527	7.26	Y	0.524	0.387	–0.422	0.439	0.451	0.433	0.329	0.174	0.537	0.427	0.327	0.529	0.518	0.607	0.537	0.429	0.365	1.000	Y	0.455	0.610	7.28	
			8.96		0.633	0.425	–0.511	0.529	0.502	0.508	0.403	0.296	0.612	0.562	0.451	0.605	0.607	0.709	0.62	0.531	0.459					10.38	

*Levels of significance: $p \le 0.05$: $0.255 \le r \le 0.330$; $p \le 0.01$: $0.331 \le r \le 0.418$; $p \le 0.001$: $r \ge 0.418$; * – minimum and ** maximum correlation value for years of assessments.*

Table 5. Correlation matrix for morphological and productive analysis of oilseed radish plants of ‘Zhuravka’ variety at a sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds with different fertilizer options for the 2013–2018 period (for N technological variant 60)

Variant	Graph $(G')_{minm}$	Graph $(G')_{max}$	Graph (G)	Features	H	D	H_1	w_1	WR	n	l	a	S	w_2	N_1	w_3	N_2	g	w_4	m	s	Y	Features	Graph $(G')_{minm}$	Graph $(G')_{max}$	Graph (G)	Variant
0.5 million pcs, ha^{-1} of germinable seeds against the $N_{90}P_{90}K_{90}$ ground	0.278	0.355	0.83	H	1.000	0.318*	0.092	0.214	0.268	0.186	0.278	0.275	0.290	0.365	0.284	0.274	0.327	0.351	0.315	0.161	0.139	0.301	H	0.288	0.416	3.74	0,,5 million pcs, ha^{-1} of germinable seeds fertilizer-free
			5.33			0.471**	0.252	0.367	0.442	0.306	0.379	0.409	0.403	0.487	0.419	0.419	0.495	0.476	0.475	0.279	0.333	0.489				6.65	
	0.475	0.580	7.12	D	0.228	1.000	–0.708	0.531	0.469	0.336	0.469	0.409	0.531	0.604	0.463	0.490	0.528	0.351	0.611	0.530	0.333	0.424	D	0.477	0.645	8.11	
			9.87		0.402		–0.760	0.673	0.640	0.539	0.712	0.589	0.679	0.806	0.640	0.644	0.701	0.513	0.854	0.668	0.517	0.559				10.97	
	0.453	0.490	7.25	H_1	0.055	–0.732	1.000	–0.530	–0.589	–0.497	–0.527	–0.314	–0.428	–0.608	–0.501	–0.331	–0.555	–0.429	–0.478	–0.529	–0.612	–0.527	H_1	0.486	0.554	8.26	
			8.33		0.276	0.803		–0.562	–0.678	–0.565	–0.628	–0.382	–0.501	–0.653	–0.597	–0.408	–0.740	–0.633	–0.507	–0.561	–0.657	–0.579				9.41	
	0.452	0.579	7.23	w_1	0.203	0.462	–0.602	1.000	0.502	0.515	0.680	0.587	0.602	0.612	0.523	0.550	0.469	0.402	0.644	0.412	0.269	0.305	w_1	0.478	0.655	8.13	
			9.84		0.342	0.605	–0.698		0.674	0.582	0.775	0.664	0.759	0.857	0.751	0.701	0.653	0.567	0.878	0.663	0.539	0.471				11.14	
	0.390	0.523	6.23	WR	0.262	0.351	–0.525	0.352	1.000	0.523	0.517	0.419	0.455	0.447	0.312	0.420	0.512	0.314	0.602	0.441	0.317	0.402	WR	0.442	0.600	7.51	
			8.90		0.409	0.512	–0.566	0.521		0.659	0.666	0.609	0.597	0.604	0.537	0.562	0.655	0.489	0.801	0.565	0.471	0.551				10.20	
	0.432	0.529	5.61	n	0.226	0.429	–0.403	0.512	0.352	1.000	0.307	0.352	0.551	0.533	0.529	0.519	0.469	0.504	0.528	0.220	0.118	0.307	n	0.462	0.575	6.47	
			8.47		0.401	0.608	–0.439	0.654	0.541		0.509	0.511	0.801	0.765	0.704	0.701	0.641	0.655	0.677	0.351	0.319	0.492				9.78	
	0.397	0.516	5.17	l	0.115	0.421	–0.420	0.513	0.418	0.309	1.000	0.759	0.732	0.528	0.447	0.531	0.520	0.317	0.502	0.320	0.302	0.338	l	0.475	0.626	8.07	
			8.77		0.319	0.587	–0.501	0.655	0.567	0.453		0.856	0.835	0.734	0.572	0.734	0.694	0.521	0.561	0.483	0.497	0.478				10.63	
	0.360	0.488	5.40	a	0.208	0.463	–0.310	0.420	0.402	0.202	0.769	1.000	0.718	0.401	0.512	0.454	0.335	0.321	0.417	0.262	0.202	0.317	a	0.403	0.555	6.85	
			8.29		0.361	0.604	–0.319	0.551	0.557	0.364	0.802		0.844	0.550	0.657	0.573	0.469	0.524	0.552	0.378	0.341	0.524				9.43	
	0.490	0.580	6.86	S	0.226	0.559	–0.496	0.513	0.420	0.531	0.704	0.698	1.000	0.705	0.515	0.515	0.533	0.441	0.442	0.269	0.297	0.414	S	0.470	0.625	7.98	
			9.87		0.410	0.695	–0.502	0.708	0.546	0.704	0.816	0.781		0.858	0.654	0.668	0.731	0.569	0.578	0.451	0.376	0.559				10.63	
	0.430	0.526	5.59	w_2	0.206	0.511	–0.502	0.424	0.531	0.405	0.412	0.302	0.521	1.000	0.393	0.513	0.532	0.357	0.590	0.321	0.202	0.315	w_2	0.472	0.632	8.03	
			8.94		0.347	0.702	–0.574	0.553	0.662	0.570	0.565	0.455	0.755		0.511	0.700	0.690	0.459	0.779	0.491	0.348	0.454				10.75	
	0.414	0.540	5.80	N_1	0.302	0.269	–0.469	0.539	0.351	0.415	0.332	0.420	0.392	0.205	1.000	0.532	0.644	0.221	0.654	0.321	0.330	0.530	N_1	0.468	0.621	7.49	
			9.18		0.465	0.517	–0.474	0.702	0.454	0.583	0.537	0.559	0.543	0.351		0.663	0.876	0.408	0.874	0.519	0.469	0.709				10.56	
	0.405	0.507	5.67	w_3	0.135	0.424	–0.307	0.447	0.456	0.487	0.432	0.335	0.312	0.432	0.411	1.000	0.502	0.332	0.538	0.321	0.220	0.405	w_3	0.452	0.599	7.23	
			8.62		0.270	0.552	–0.419	0.589	0.552	0.561	0.579	0.547	0.498	0.559	0.574		0.701	0.509	0.806	0.459	0.389	0.553				10.19	
	0.446	0.571	7.13	N_2	0.269	0.469	–0.552	0.460	0.392	0.432	0.415	0.447	0.524	0.418	0.574	0.462	1.000	0.614	0.602	0.388	0.311	0.539	N_2	0.327	0.545	5.57	
			9.70		0.351	0.588	–0.598	0.570	0.558	0.553	0.605	0.552	0.655	0.631	0.789	0.564		0.800	0.842	0.504	0.456	0.777				9.26	
	0.391	0.499	5.86	g	0.212	0.344	–0.469	0.421	0.332	0.458	0.224	0.328	0.532	0.412	0.347	0.351	0.469	1.000	0.304	0.212	0.220	0.529	g	0.588	0.655	8.24	
			8.48		0.319	0.452	–0.468	0.528	0.455	0.581	0.424	0.468	0.652	0.564	0.476	0.497	0.659		0.526	0.441	0.395	0.774				11.14	
	0.410	0.560	6.55	w_4	0.136	0.532	–0.452	0.574	0.428	0.409	0.331	0.229	0.317	0.432	0.525	0.501	0.487	0.269	1.000	0.456	0.296	0.257	w_4	0.484	0.654	8.24	
			8.96		0.252	0.756	–0.269	0.750	0.589	0.584	0.510	0.442	0.497	0.585	0.755	0.673	0.691	0.405		0.575	0.406	0.447				11.14	
	0.353	0.435	3.53	m	0.027	0.455	–0.452	0.387	0.332	0.139	0.221	0.256	0.211	0.224	0.203	0.169	0.259	0.344	0.385	1.000	0.525	0.429	m	0.325	0.508	5.52	
			6.97		0.219	0.555	–0.459	0.558	0.504	0.312	0.357	0.359	0.371	0.404	0.421	0.356	0.365	0.458	0.513		0.663	0.578				8.63	
	0.351	0.384	2.47	s	0.118	0.352	–0.411	0.325	0.221	0.101	0.167	0.169	0.204	0.169	0.225	0.111	0.106	0.301	0.352	0.404	1.000	0.430	s	0.248	0.455	4.22	
			6.14		0.319	0.467	–0.417	0.455	0.402	0.246	0.301	0.256	0.271	0.258	0.401	0.311	0.271	0.408	0.479	0.572		0.559				7.74	
	0.360	0.498	5.76	Y	0.245	0.351	–0.451	0.281	0.329	0.471	0.269	0.309	0.342	0.291	0.451	0.312	0.503	0.487	0.329	0.256	0.324	1.000	Y	0.398	0.652	6.77	
			8.46		0.335	0.462	-0.543	0.402	0.501	0.559	0.446	0.453	0.464	0.406	0.583	0.521	0.701	0.669	0.459	0.403	0.551					9.55	

*Levels of significance: $p \le 0.05$: $0.255 \le r \le 0.330$; $p \le 0.01$: $0.331 \le r \le 0.418$; $p \le 0.001$: $r \ge 0.418$; * – minimum and ** maximum correlation value for years of assessments.*

Thus, in our opinion, the specificity of the variability of morphological features of a plant in a certain technological variant and the specificity of pairwise correlations in each pleiade combination will determine a reliable situation of morphological integration of plants, which is confirmed by the summary data in Table 6. A comparison of the morphological variability module (Mod_x) with sowing rate, row width and fertilizer variants (as compared to the basic variant of 0.5 million pcs. ha^{-1} of germinable seeds) confirmed our conclusions on reducing overall plant variability by comparing the fertilizer rate of the control variant with the application of $N_{90}P_{90}K_{90}$ kg ha^{-1} of the primary material against the background of row sowing with a gradual reduction in coenotic tension towards a reduction in sowing density from 4 to 1 million pcs. ha^{-1} of germinable seeds.

For wide-row sowing, an increasing role in the morphological variability of plants in cenosis at a fertilizer rate of 90 kg ha^{-1} of the primary material is noted in the range of 1.5 million pcs. ha^{-1} of germinable seeds (in years favourable by hydrothermal coefficient – HTC) – 1.0 million pcs. ha^{-1} of germinable seeds. As a result, the maximum variability of morphological features of plants was noted in the variant of 0.5 million pcs. ha^{-1} of germinable seeds with a peak value for the same variant when fertilizing $N_{90}P_{90}K_{90}$ kg ha^{-1}, which in the evaluation system became a reference for comparable variability of morphological features. The gradual growth of fertilizer rates from 0 to 60 kg ha^{-1} provides an overall average variability growth of 3.0–13.0%. At the same time, this growth rate is characterized by a gradual decrease with an overall decrease in cenosis density in the range of fertilizer application from 30 to 60 kg ha^{-1} of the primary material. A further increase in the fertilizer rate to 90 kg ha^{-1} of the primary material has a specific manifestation for various variants of cenosis density: a 2.0% increase of the morphological variability module has only been observed on variants of 1.0 and 0.5 million pcs. ha^{-1} of germinable seeds for wide-row sowing, and a constant decrease of 1.0–14.0% in other variants. Given that, the maximum level of reduction has been noted on variants of 2.0–4.0 million pcs. ha^{-1} of germinable seeds, the fertilizer rate of 60 kg ha^{-1} of the primary material is a threshold value for ensuring the morphological integrity of plants and ensuring a biologically permissible level of coenotic pressure. Crossing this threshold results in both an overall reduction in plant architecttonics and a reduction in the overall morphological and weight integration of plants according to the I_{mmi} indicator. The application of a modified morphological integration index (I_{mmi}), in our assessments, enabled us to assess the integrity of oilseed radish plants in a more differentiated way at various technologies of construction of its agrophytocenosises. Thus, its constant interval decrease from a variant with a density of 4.0 million pcs. ha^{-1} of germinable seeds to a variant of 1.0 million pcs. ha^{-1} of germinable seeds for row sowing and from a variant of 2.0 million pcs. ha^{-1} of germinable seeds to a variant of 0.5 million pcs. ha^{-1} of germinable seeds indicates that the specific manifestation of morphological integrity of oilseed radish plants and statistical significance of the correlation connection of features increases with the overall growth of coenotic tension. At the same time, mineral fertilizers provide an overall increase in the variation of morphological features, especially those related to the stem and leaf morphology block (Table 2), which becomes essential when the density is below 2.0 million pcs. ha^{-1} of germinable seeds in the variant of row sowing and 1.5 million and less pcs. ha^{-1} of germinable seeds in the variant of wide-row sowing. On the other hand, the range of values of the I_{mmi} indicator is higher in the technological variants of row sowing than in the variants of wide-row sowing, and the lower limit of this interval has a higher threshold value exactly in the case of wide-row sowing. In our opinion, this points to the greater specificity of developing the potential for morphological and weight integration of plants due to the reduced level of coenotic tension. This statement is also confirmed by two-interval levels in the value of the I_{mmi} interval at a rate of 4.0 million pcs. ha^{-1} of germinable seeds of the row sowing and 2.0 million pcs. ha^{-1} of germinable seeds of the wide-row sowing.

It should be noted that an overall analysis of the morphological integrity of plants is not complete if it does not cover an important aspect of the formation of the ideotype structure of the agrophytocenosises of a particular crop (Donald, 1968). Any agrophytocenosis as an artificially created and supporting the population of cultivated plants is characterized by the formation of differentiation with the appearance of different categories of plants both in terms of phenological and ontogenetic features and morphological development. The first of these is based on the different phenorhythms of the development of individual plants against the background of the different quality of the seed material itself and subsequent differences in the phenological stages of the plants. The other is based on the nature of plant development, the intensity of biomass growth and the overall development of morphometric.

In the system of these regularities, the most typical features of the distribution of agrophytocenosis into individual groups of plants are the size of the plants with their derivative characteristics, their calendar age and the difference in the vitality state of the plants as a certain morphological and structural state of the representation of ontogenetic strategies (Zlobin, 1989; Usmanov, Martynova, 1990).

Table 6. Modular and morphological and ideotypical assessment of oilseed radish plants of 'Zhuravka' variety considering final morphological features of plants during the yellow pod phase (BBCH 79-83) in the context of individual study variants taking into account ideotypes (classes of vitality) of plants (average for 2013–2018) (for N attribute groups = 22 at n = 15…n (linear meter)$^{-1}$ *(for 2 non-contiguous repetitions))

Sowing rate and method (B, C factors)	Fertilizer (D factor) (A factor–year conditions)	Range of average values by years (R)		Q	Average fraction of life class plants (ideotype), %			I_Q	IVC	ISP
		Mod_x	I_{mmi}		A (upper-tier)	B (middle-tier)	C (lower-tier)			
4.0 million, row	Fertilizer-free	0.41–0.64	0.525–1.179	31.3	9.2	53.4	37.4	0.84	0.536	1.235
	$N_{30}P_{30}K_{30}$	0.49–0.61	0.519–1.103	30.9	13.6	48.2	38.2	0.81	0.568	1.284
	$N_{60}P_{60}K_{60}$	0.55–0.74	0.517–0.997	32.0	13.2	50.8	36.0	0.89	0.576	1.269
	$N_{90}P_{90}K_{90}$	0.46–0.60	0.512–0.827	32.6	10.4	54.7	34.9	0.93	0.477	1.218
3.0 million, row	Fertilizer-free	0.48–0.69	0.512–1.117	32.1	10.9	53.2	35.9	0.89	0.631	1.352
	$N_{30}P_{30}K_{30}$	0.44–0.72	0.505–1.078	33.3	11.8	54.8	33.4	1.00	0.735	1.396
	$N_{60}P_{60}K_{60}$	0.42–0.75	0.493–0.974	33.9	12.5	55.2	32.3	1.05	0.815	1.440
	$N_{90}P_{90}K_{90}$	0.51–0.67	0.478–0.806	32.2	11.8	52.6	35.6	0.90	0.779	1.531
2.0 million, row	Fertilizer-free	0.56–0.68	0.509–1.102	32.0	12.4	51.5	36.1	0.89	0.672	1.225
	$N_{30}P_{30}K_{30}$	0.53–0.82	0.497–1.024	32.7	13.2	52.1	34.7	0.94	0.788	1.192
	$N_{60}P_{60}K_{60}$	0.54–0.85	0.454–0.952	33.6	13.8	53.4	32.8	1.02	0.888	1.162
	$N_{90}P_{90}K_{90}$	0.53–0.76	0.426–0.801	33.4	14.2	52.5	33.3	1.00	0.867	1.179
1.0 million, row	Fertilizer-free	0.59–0.75	0.492–1.082	35.9	13.9	57.8	28.3	1.27	0.739	1.236
	$N_{30}P_{30}K_{30}$	0.61–0.79	0.436–0.984	36.6	14.5	58.6	26.9	1.36	0.921	1.241
	$N_{60}P_{60}K_{60}$	0.63–0.86	0.425–0.918	37.4	14.9	59.8	25.3	1.48	1.033	1.256
	$N_{90}P_{90}K_{90}$	0.62–0.83	0.422–0.873	38.4	15.1	61.6	23.3	1.65	1.082	1.250
2.0 million, wide-row	Fertilizer-free	0.59–0.78	0.710–1.114	34.8	14.2	55.4	30.4	1.14	0.712	1.241
	$N_{30}P_{30}K_{30}$	0.62–0.84	0.684–1.096	36.0	14.8	57.1	28.1	1.28	0.854	1.154
	$N_{60}P_{60}K_{60}$	0.66–0.85	0.641–1.019	37.0	15.2	58.7	26.1	1.42	0.902	1.131
	$N_{90}P_{90}K_{90}$	0.61–0.70	0.639–1.004	35.4	15.0	55.7	29.3	1.21	0.917	1.117
1.5 million, wide-row	Fertilizer-free	0.69–0.84	0.674–1.092	37.6	15.8	59.4	24.8	1.52	0.850	1.180
	$N_{30}P_{30}K_{30}$	0.75–0.87	0.640–1.042	38.9	16.5	61.2	22.3	1.74	1.028	1.166
	$N_{60}P_{60}K_{60}$	0.72–0.94	0.608–1.002	40.4	17.2	63.6	19.2	2.10	1.201	1.101
	$N_{90}P_{90}K_{90}$	0.69–0.91	0.567–0.904	40.9	17.6	64.2	18.2	2.25	1.226	1.057
1.0 million, wide-row	Fertilizer-free	0.65–0.86	0.665–1.061	39.6	15.1	64.0	20.9	1.89	0.888	1.244
	$N_{30}P_{30}K_{30}$	0.74–0.91	0.618–1.008	40.6	15.6	65.5	18.9	2.15	1.049	1.188
	$N_{60}P_{60}K_{60}$	0.81–0.94	0.571–0.924	41.8	16.2	67.4	16.4	2.55	1.186	1.167
	$N_{90}P_{90}K_{90}$	0.75–0.96	0.520–0.879	41.0	15.8	66.2	18.0	2.28	1.223	1.170
0.5 million, wide-row	Fertilizer-free	0.86–0.93	0.643–1.023	40.2	13.5	66.8	19.7	2.04	1.072	1.204
	$N_{30}P_{30}K_{30}$	0.84–0.96	0.596–0.971	40.6	13.9	67.3	18.8	2.16	1.269	1.257
	$N_{60}P_{60}K_{60}$	0.81–0.98	0.502–0.907	42.0	14.7	69.3	16.0	2.63	1.480	1.302
	$N_{90}P_{90}K_{90}$	1.00^{+}	0.440–0.835	42.8	15.0	70.6	14.4	2.97	1.516	1.320
LSD_{05} (factors in the dispersion system)		*For morphological features in the group Fisher's criterion (F)F_{ϕ} = 92.1–487.9; F_m = 1.78–6.90*			*LSD_{05}* (factors in the dispersion system)				*F value Pr(>F) (655.6 <2e-16 C p 0.001)*	
A value/share of influence in the formation of the indicator, %					*0.0009* (45.00)	*0.0023* (26.73)	*0.0014* (19.16)		*0.025* *(20.19)*	
B					*0.0005* (23.34)	*0.0013* (12.68)	*0.0008* (48.44)		*0.015* *(31.70)*	
C					*0.0008* (6.25)	*0.0019* (3.23)	*0.0012* (20.91)		*0.0021* *(29.35)*	
D					*0.0008* (7.81)	*0.0019* (1.08)	*0.0012* (1.96)		*0.0021* *(12.16)*	
AB					*0.0013* (0.46)	*0.0033* (15.47)	*0.0020* (1.24)		*0.0036* *(0.37)*	
AC					*0.0019* (0.68)	*0.0047* (15.74)	*0.0028* (0.89)		*0.0050* *(0.56)*	
AD					*0.0019* (0.25)	*0.0047* (0.74)	*0.0028* (0.20)		*0.0050* *(0.23)*	
BC					*0.0011* (10.90)	*0.0027* (2.13)	*0.0016* (4.69)		*0.0029* *(0.47)*	
BD					*0.0011* (0.84)	*0.0027* (0.22)	*0.0016* (0.05)		*0.0029* *(1.40)*	
BC					*0.0015* (1.68)	*0.0038* (0.26)	*0.0023* (0.45)		*0.0041* *(2.29)*	
ABC					*0.0026* (0.47)	*0.0066* (15.73)	*0.0040* (0.27)		*0.0071* *(0.61)*	
ABD					*0.0026* (0.16)	*0.0066* (0.71)	*0.0040* (0.16)		*0.0071* *(0.08)*	
ACD					*0.0037* (0.34)	*0.0093* (2.17)	*0.0056* (0.22)		*0.0101* *(0.26)*	
BCD					*0.0022* (1.57)	*0.0054* (0.95)	*0.0033* (1.15)		*0.0058* *(0.19)*	
ABCD					*0.0053* (0.26)	*0.0132* (2.17)	*0.0080* (0.19)		*0.0142* *(0.13)*	

*Notes 1. * – for the number of plants corresponding to actual plant density per 1 linear metre in the experiment variant; 2.+– variant of maximum morphological development of plants (Mod_x ~ 1.00).*

In this perspective, the ideal state of construction of any sowing in the long term provides for such a density of plants that ensures a minimum part of different plant morphotypes and would ensure the same growth process rates of the species per area unit based on a single stage and harmony. This goal is one of the modern strategies for the successful cultivation of a particular crop, as it not only guarantees the agro-technological consistency of sowing but also reduces intra-species competition and guarantees an overall increase in the efficiency of application by correcting resources such as mineral fertilizers, stimulants, protective means, *etc*. (Zlobin, 2009).

Unfortunately, it is not possible to achieve the maximum desired effect of avoiding the appearance of different plant ideotypes in sowing, even with the best possible ideal placement of plants both in the row zone and in the inter-row zone, which results in appropriate differentiation of sowing of a certain crop into tiers (Vijaya Kumar *et al*., 1996; Zhilyaev, 2005; Zlobin *et al*., 2013; Skliar, Sherstuk, 2016).

On the other hand, it is noted that each agrophytocenosis has its specific limit on the density of species, which depends on both varietal characteristics and edaphic conditions of growth and development, as well as on many climatic, biological, and physiological factors. In most cases, self-regulation of intra-species alignment of effective productivity of species within the same area occurs in the cenosises due to the two accompanying directions – the extinction of the species and its self-liquefaction and miniaturization because of a significant reduction in all sizes of plant parts. Under these conditions, plant sizes can be reduced from hundreds to thousands of times while maintaining minimal levels of generative development with minimal ability to produce fully productive seedlings (Rabotnov, 1998; Zhilyaev, 2005; Zlobin, 2009, 2013; Temesgen *et al*., 2015; Skliar, Sherstuk, 2016). It should not be forgotten about the well-known indicator of agrophytocenosis differentiation – the Sukachev effect (Sukachev, 1956): in single-species and single-stage agrophytocenosises, there is the differentiation of individuals into small and large ones when the density increases, which is especially noticeable in fertile soil variants and when the sowing density increases to a certain limit - until the plants die off completely. It is further stated that the evaluation of the efficiency of the arrangement of species in cenosis should be carried out using a systematic approach, forming a certain model of its density given the altitude gradient of plants, which the author defines as volume density (Laman *et al*., 1999). In general, cruciferous crops are distinguished by the formation of plants of different ideotype by the value of morphological parameters (Yadav, 1978; Thurling, 1991; Vijaya Kumar *et al*., 1996; Khan, 2006; Ana *et al*., 2008; Mamun *et al*., 2014). In our studies, we have identified certain regularities in the formation of oilseed radish agrophytocenosis layering. Given this formation of different tiers of plants and their corresponding morphotypes, we considered their morphological integration as a continuation of a certain protective ontogenetic strategy of the plant body under the influence of changing stress factor. We considered the enhancement of morphological integration as a protective ontogenetic strategy and its reduction as a level of stress adaptability of the technology variant and fertilization. In our research variant, the stress factors were divided into three groups: general additive nervousness of climate factors, changes in the number of individuals due to changes in sowing rates and row width, and changes in fertilizer rates in conjunction with other factors of research. For the period 2013–2018, we have identified morphological development groups of plants that belong to three tiers in the vertical projection. These plants were grouped into three main ideotypes (vitality classes), the main statistical assessment of which is presented in Table 7 and Fig. 2. It should be noted that oil radish agrophytocoenosis is considered to be sensitive from the point of view of the reaction to changes in both the density of plants per area unit and from the point of view of optimization of mineral nutrition conditions. An important aspect of assessing the ideotype sowing structure is the differing level of variability of features. Given the coefficient of variation of morphological features, we've established that it's significantly higher for plants of the upper-tier (class of plant vitality A – with the average CV 38.2% – a high level against CV 24.8% – an increased level – for the class of vitality B (middle-tier)). Thus, we believe it's due to the dominant nature of such plants' growth processes and a gradual reduction of phenotypic tension for them due to more intensive growth rates in the early stages of vegetation. By analogy with these conclusions for oilseed radish plants of lower-tier (vitality class C), due to phenotypic pressure from more competitive species and the general slowdown in growth processes, the result is a minimization of plant architectonics and the emergence of atypical morphotypes in terms of their development. The same conclusions are confirmed by the index of phytocoenotic plasticity (I_p) in terms of morphological parameters within the selected oilseed radish plant ideotypes. The value of this indicator differed for different morphological features.

At higher maximum stability with lower I_p for middle vitality class plants (middle-tier of agrophytocenosis) and minimum stability with higher I_p for lower-tier plants, the minimum value of ecological scope of values is noted in the system of all selected ideotypes for such feature as the height of plants (at I_p 0.47), and the maximum value for the individual weight of plants (at I_p 0.80). Thus, the magnitude of changes in plant morphotypes within their defined ideotypes behind the vertical gradation tiers of agrophytocenosis is distributed in the following order: C>A>B. The system of morphological indicators that we have chosen to distribute the vertical of agrophytocenosis is indicative in the morphological plant development. Actually, ideotypical types of plants of corresponding tiers had distinctive features, which allowed to effectively determine the percentage of each tier in the cenosis of the corresponding technological variant of its construction, which is confirmed in Fig. 2–5. The degree of differentiation of the agrophytocenosis by the indicators determining the grouping had both significant differences in the comparison of the technological variants and within the technological variant itself. So, we provide, for example, data concerning interval distribution of 60 plants, which were used in our estimations on such indicator as stem diameter for one year of research on a nonfertilized ground according to the criterion of less variable component (2016, Fig. 7). Histograms for all technological variants under study have revealed a complete variability of the indicator from the smallest value, which is significantly distant from the dominant indicator for the general population to, respectively, the largest value. It should be noted that the specified number of interval groups of the indicator is the minimal one in the variants of the maximum density of oilseed radish agrophytocenosis both for row sowing (4.0 million pcs. ha^{-1} of germinable seeds – 5 interval groups) and for wide-row sowing (2.0 million pcs. ha^{-1} of germinable seeds – 6 interval groups).

Figure 2. Ideotypes of oilseed radish plants of the 'Zhuravka' variety against the ground of $N_{90}P_{90}K_{90}$ (successively positions 1, 9 – 4.0 million pcs. ha^{-1} of germinable seeds, 2, 8 – 2.0 million pcs. ha^{-1} of germinable seeds (row sowing); 3, 7 – 1.5 million pcs. ha^{-1} of germinable seeds (wide-row sowing); 4 – 1.0 million pcs. ha^{-1} of germinable seeds (wide-row sowing); 5, 6, 11 – 0.5 million pcs. ha^{-1} of germinable seeds (wide-row sowing); 10 – 4 million pcs. ha^{-1} of germinable seeds (row sowing), 2017

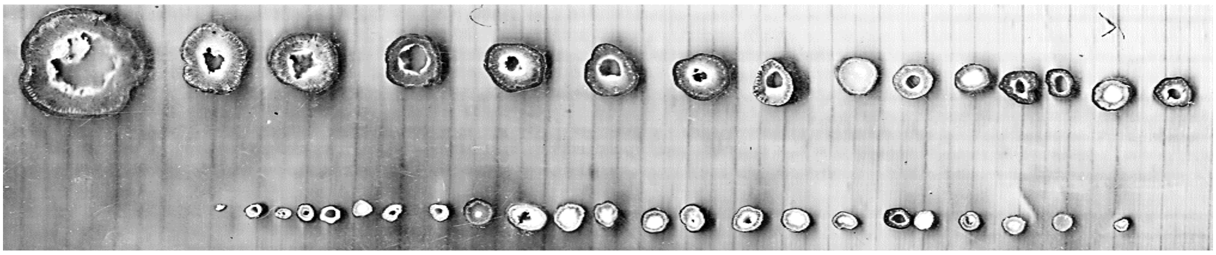


Figure 3. Dynamic stem diameter range (upper position for plants of the upper-tier, lower position for plants of the lower-tier), 2016

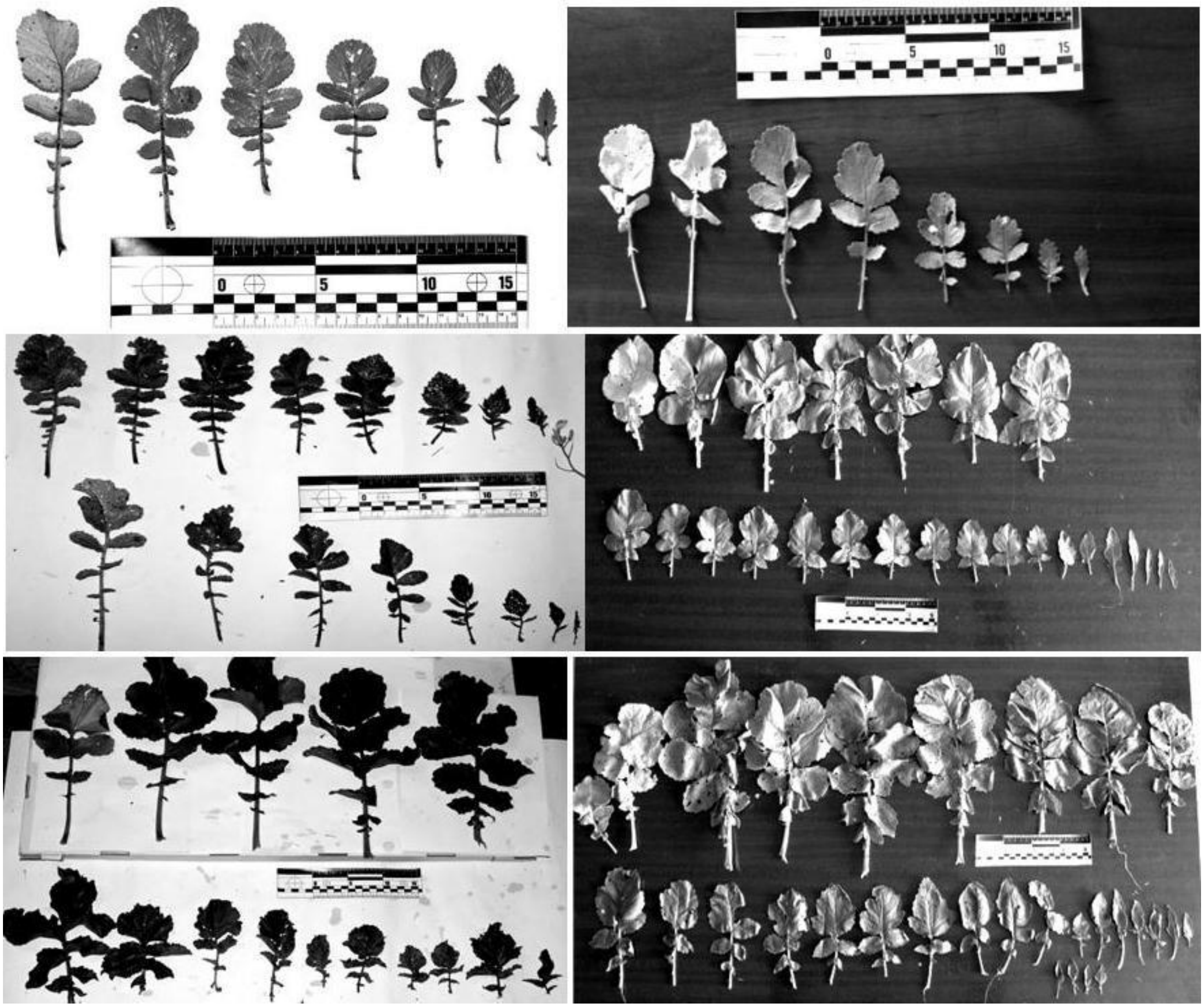


Figure 4. Morphological features and area of leaf area of plants of different ideotypes upper position 1: for plants of variant 4.0 million pcs. ha^{-1} of germinable seeds against the ground of $N_{90}P_{90}K_{90}$ (on the left – lower-tier plants, on the right – upper-tier plants); middle position 2: for plants of variant 1.0 million pcs. ha^{-1} of germinable seeds (row sowing) against the ground of $N_{90}P_{90}K_{90}$ (on the left – lower-tier plants, on the right – upper-tier plants); lower position 3: for plants of variant 0.5 million pcs. ha^{-1} of germinable seeds (row sowing) against the ground of $N_{90}P_{90}K_{90}$ (on the left – lower-tier plants, on the right – upper-tier plants), 2017

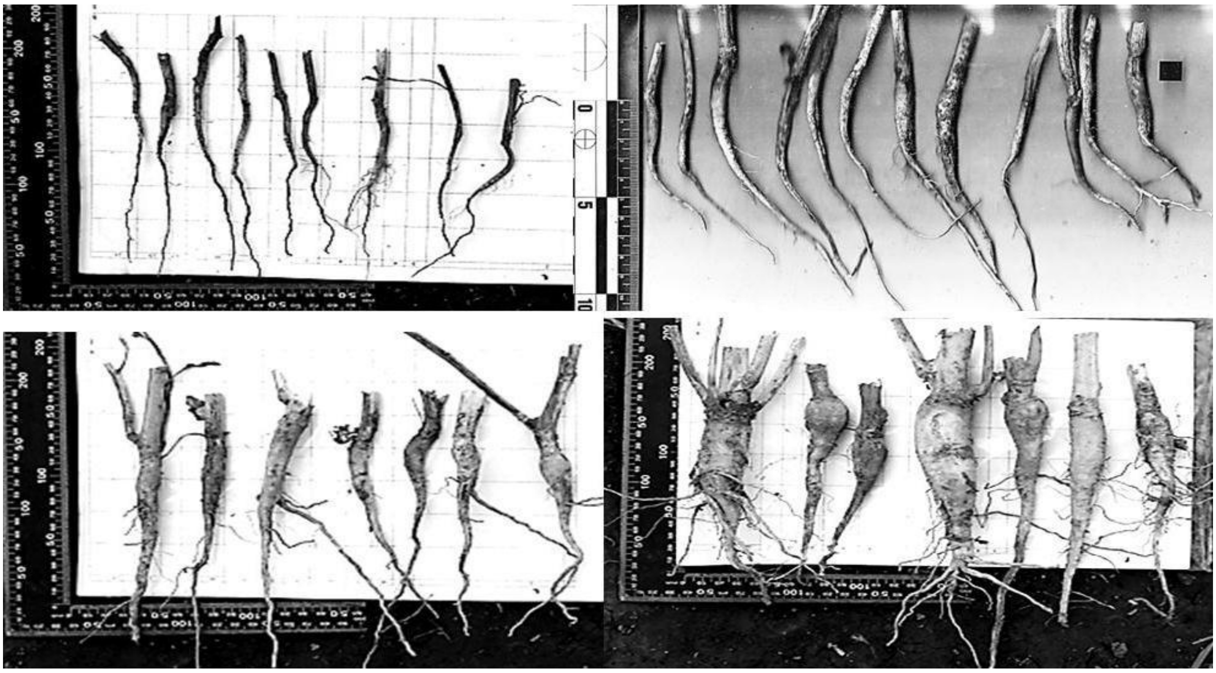


Figure 5. The root system, upper position 1: for plants of variant 4.0 million pcs. ha^{-1} of germinable seeds against the ground of $N_{90}P_{90}K_{90}$ (on the left – lower-tier plants, on the right – upper-tier plants); lower position 2: for plants of variant 0.5 million pcs. ha^{-1} of germinable seeds against the ground of $N_{90}P_{90}K_{90}$ (on the left – lower-tier plants, on the right – upper-tier plants), 2018

Table 7. Morphometry of oilseed radish plants ideotypes in the context of the general selection of variants for the 'Zhuravka' variety during the flowering phase (BBCH 65) and the yellow pod phase (BBCH 79-83) (on average for the 2013–2018 period (for N=60 plants in each variant of x years of research)

Morphological parameters of plants of the corresponding tier	Lower (vitality class C)				Middle (vitality class B)				Upper (vitality class A)			
	X_{av}	R^{+}	CV, %	I_P	X_{av}	R	CV, %	I_P	X_{av}	R	CV, %	I_P
Height of plants in the yellow pod phase, cm	60.8^{**}	29.6–102.3	32.5	0.71	100.7	72.9–111.6	28.4	0.35	114.5^{**}	90.8–143.4	35.9	0.37
Stem diameter at the base in the yellow pod phase, mm	6.1^{**}	3.2–8.9	26.4	0.64	9.1	6.5–12.9	23.5	0.50	12.3^{**}	8.7–21.5	40.2	0.60
Leaf area on the plant during the flowering phase, cm^2	169.4^{**}	82.9–211.7	20.6	0.61	292.3	108.7–313.9	22.3	0.66	425.7^{***}	256.9–1024.3	43.5	0.75
Individual weight of plants during the yellow pod phase, g	11.6^{**}	2.3–15.7	28.2	0.85	15.8	5.7–21.3	25.8	0.73	19.4^{**}	11.3–61.7	42.9	0.82
Number of side branches in the inflorescence during the yellow pod phase, pcs	3.7^{**}	2.5–6.2	19.9	0.60	6.2	3.3–8.6	20.9	0.62	8.5^{***}	5.4–11.4	28.7	0.53

*Notes. 1. $^{+}$ The range of values (R) is shown in the context of the years of study, as well as the format of the ratio of morphological features of plants of different tiers according to the methodology of one-type vegetative comparison. 2. Lower and upper-tier parameter values in relation to the middle-tier *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.*

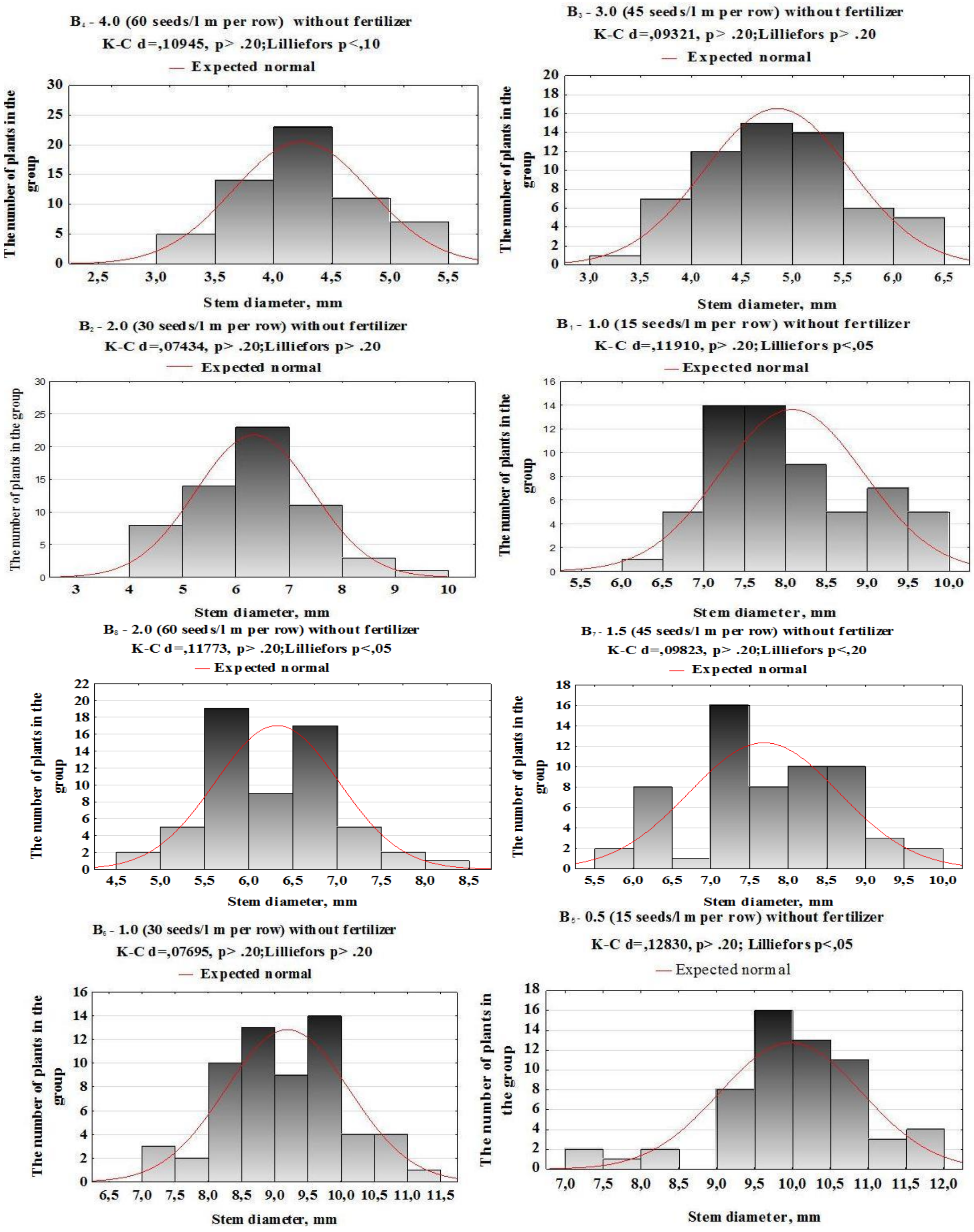


Figure 6. Histogram of the distribution of the stem diameter value of oilseed radish plants in the context of the studied technological variants consistently from left to right and from top to bottom variants: B_4, B_3. B_2, B_1, B_8, B_7, B_6, B_5 (Table 1), 2016

The maximum number of variants is noted in the variants of the lowest density for both sowing methods, respectively (1.0 and 0.5 million pcs. ha^{-1} of germinable seeds – 9 and 10 interval groups, respectively). This confirms our conclusions regarding morphological integration and morphological variability module depending on the variants under study. Thus, the intensive coenotic tension in the variant of 4.0 million pcs. ha^{-1} of germinable seeds leads to an overall decrease in the range of variation, which leads to a decrease in the area of the interval distribution curve with the simultaneous growth of the chart height. On the contrary, at the sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds, there is an expansion of interval differentiation of agrophytocenosis, the growth of the total number of intervals, which leads to a decrease in the height of the extremum of the distribution curve chart.

Using approaches to schematization of the representation of ideotypical types of plants, applied to mustard (Vijaya Kumar *et al*., 1996) and spring rapeseed (Khmelyanchyshyn, 2005), we also proposed schemes of oilseed radish plants ideotypes of different tiers presented as an example for two cardinally distant technological variants of construction of oilseed radish agrophytocenosis (Figure 7).

The features of morphogenesis, which we discovered, naturally determined the distribution of oilseed radish agrophytocenosis into corresponding classes of vitality (ideotypes). According to the conditions of the identity of the quality index comparison (Zhilyaev, 2005; Zlobin, 1989, 2009; Mirkin *et al*., 1985, 1999) (Q) in the format: Q > C, cenosis has a favourable structure for growth and development of species, Q < C – regressive, Q = C – balanced-dynamic – favorability of oilseed radish cenosis to growth and development (Table 6) is regressive in the interval to the variant of 2.0 million pcs. ha^{-1} of germinable seeds against the ground of $N_{30}P_{30}K_{30}$, and balanced-dynamic for the variant of 2.0 million pcs. ha^{-1} of germinable seeds when fertilizing in the interval of $N_{60-90}P_{60-90}K_{60-90}$ kg of the primary material ha^{-1}. All other variants should be referred to as favourable for growth and development of oilseed radish plants. The mentioned gradation of technological variants is also confirmed by the I_Q index (agrophytocenosis flourishing index) whereby the value of the indicator more than 1.5 (Zlobin, 1989), the variant with the sowing rate of 1.0 million pcs. ha^{-1} of germinable seeds with the row sowing and variants in the interval of 1.5–0.5 million pcs. ha^{-1} of germinable seeds are classified as "flourishing" (highly favourable) for the development of individual species of agrophytocenosis.

It is also important to note that the already mentioned general additive stress of climatic factors is defined as a component of the dispersion analysis of the studied variants (factor A – conditions of the year) that indicates different determinacy of abiotic conditions in the formation of the tier structure of oilseed radish agrophytocenosis by the selected ideotypes. Thus, the part of plants of the upper-tier by 45% is determined by abiotic factors of the year, and the part of plants of the middle and lower-tier by 26.73% and 19.16% respectively. A significant factor in the formation of the part of different plant ideotypes was also determined as the agrophytocenosis density – the percentage of the influence of this indicator consistently from the upper to lower-tier plants was 23.34%, 12.68% and 48.44% respectively. The sowing method factor had the greatest influence in the formation of lower-tier plants ideotypes (20.91%), and the influence of fertilizer had the maximum effect in the formation of upper-tier plants ideotypes (7.81%).

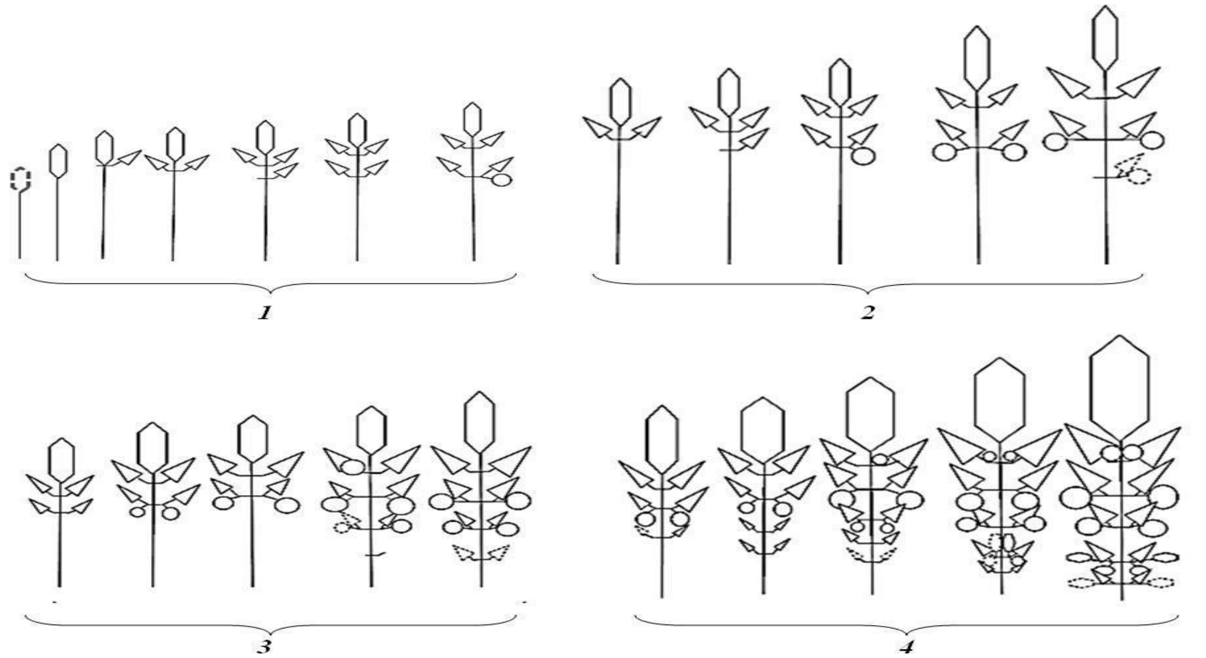


Figure 7. Ideotypical rows of oilseed radish plants of the 'Zhuravka' variety of different tiers of agrophytocenosis at different variants of its technological construction (1 – at the sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds on a nonfertilized ground; 2 – at the sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds against the ground of $N_{90}P_{90}K_{90}$; 3 – at the sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds on a nonfertilized ground; 4 – at the sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds against the ground of $N_{90}P_{90}K_{90}$ based on the results of multi-year assessments for the 2013–2018 period (conventional symbols: ⬡ – main stem inflorescence; ▷ – inflorescences of lateral branches of the first tier; ⬡ – inflorescences of branches of the second tier; ○ – inflorescences of branches of the second tier; the striation of structures determines the presence of a structural element in individual plants, the size of structures – relative morphological development

At the same time, the maximum impact of the interaction of the conditions of the year and technological parameters of the formation of agrophytocenosis is noted in the variant of the middle-tier plants ideotypes. The statistical significance of the interaction between individual environmental parameters (by a hydrothermal coefficient (HTC)), agrophytocenosis and fertilizer density expressed in index terms (0 – fertilizer-free; 1 – $N_{30}P_{30}K_{30}$; 2 – $N_{60}P_{60}K_{60}$; 3 – $N_{90}P_{90}K_{90}$)) is shown in the Figures 8, 9.

The analysis of the above graphic dependencies shows that at both low and high HTC values, mineral fertilizers have a significant stress-regulating effect (in the index format of rates) on plant morphogenesis. Thus, with an increased density of agrophytocenosis – 4.0 million pcs. ha^{-1} of germinable seeds – the growth of the part of plants in the lower-tier was observed both with a decrease in HTC in the variants of simultaneous growth of fertilizer rates and against the background of significantly high HTC (> 1.2) again in the variants of increasing the rates of mineral nutrition. Optimal technological niche to reduce the part of the lower-tier plant's ideotype, as the least productive in the structure of agrophytocenosis, at this level of plant stand density is set by HTC in the range of 0.8–1.1 at 30–60 kg ha^{-1} of the primary material. At a sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds, the minimum part of plants in the lower-tier of oilseed radish agrophytocenosis is set in the HTC range of 1.2–1.4 and fertilizer in the range of 60–90 kg ha^{-1} of the primary material.

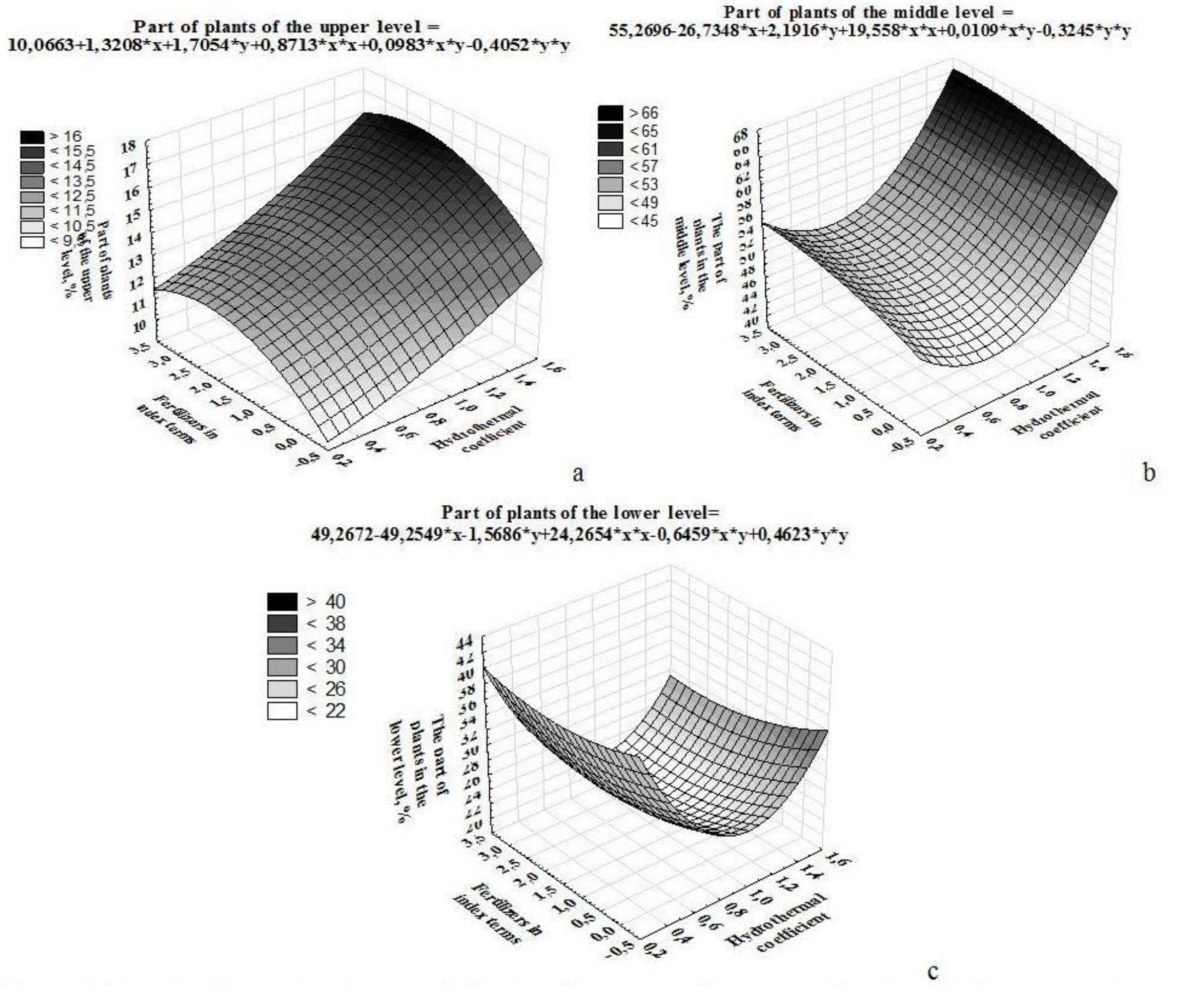
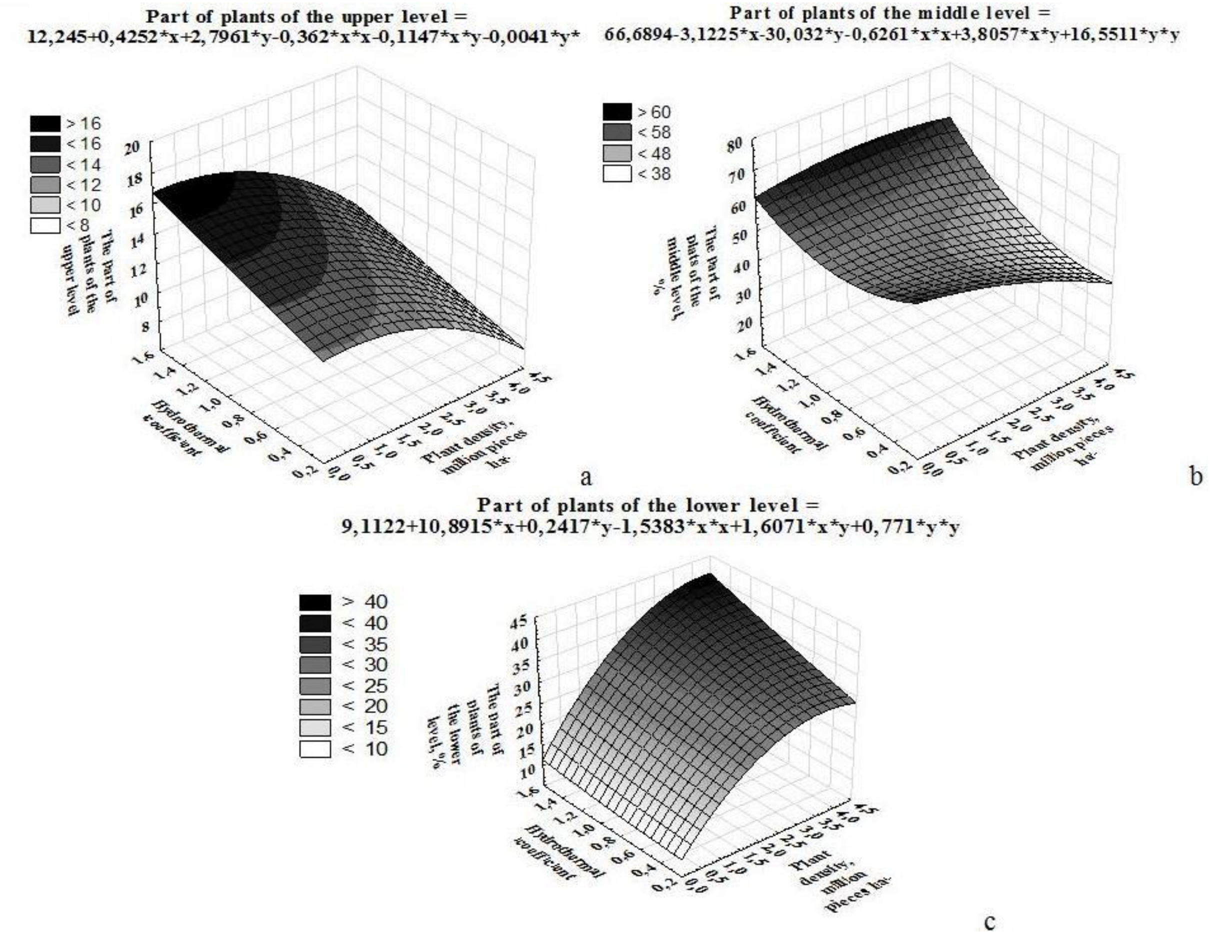


Figure 8. Dependencies graphs of a part of the plant ideotypes of the corresponding tier (Z-axis: a – upper, b – middle, c – lower) depending on the hydrothermal coefficient (HTC, X-axis) and fertilizer doses expressed in index terms (Y-axis), 2013–2018

It should also be noted that the impact of mineral fertilizers is weakening concerning intra-species competition, but according to our estimates to a certain level of the interaction system of nutrition and fertilizer area. It is demonstrated by the character of reaction curves on the Figs. 8 and 9, in particular for ideotypes of plants of upper and lower-tiers. Based on the data obtained over the years, we found that the rate of fertilizer more than 60 kg ha^{-1} of the primary material is justified with the stand density in the interval of 1.0–2.0 million pcs. ha^{-1} at row sowing and 0.5–1.0 million pcs. ha^{-1} at wide-row sowing. At technological stand densities of plants over established intervals, additional mineral nutrition is a factor of intensification of intra-species competition (which in turn, as shown by the analysis performed previously, increases at low values of HTC), which leads both to the appearance of plants with ultra-low vitality, and to the emergence of morphotypes, which significantly exceed typical plants by the average value of morphological parameters in the agrophytocenosis of oilseed radish. The latter factor is due to the general positive stimulating effect on all components of the cenosis and immobilization of growth processes in plants with supra-competitive vitality strategy.

Thus, from the perspective of plant ideotype formation, mineral fertilizers are active components of the system for regulating the degree of plant stand differentiation into morphotypes of plants of different tiers. In high-density oilseed radish cenosis, it is reasonable to increase the fertilizer rate only at a certain density, and in low-density and liquefied cenosis, only if the increased rates of fertilization are combined with the optimum moisture content. So, with the overall growth of sowing density, additional mineral nutrition only enhances the process of interspecific antagonism and provides a clear differentiation of the vertical projection of sowing to significantly different ideotypes of oilseed radish plants.



Part of plants of the upper level = 12,245+0,4252*x+2,7961*y-0,362*x*x-0,1147*x*y-0,0041*y*

Part of plants of the middle level = 66,6894-3,1225*x-30,032*y-0,6261*x*x+3,8057*x*y+16,5511*y*y

Part of plants of the lower level = 9,1122+10,8915*x+0,2417*y-1,5383*x*x+1,6071*x*y+0,771*y*y

Figure 9. Dependencies graphs of a part of the plant ideotypes of the corresponding tier (Z-axis, positions: a– upper, b – middle, c – lower) depending on the hydrothermal coefficient (HTC, X-axis) and stand density (Y-axis, million pcs. ha^{-1} of germinable seeds), 2013–2018

On the other hand, the comparison of morphological integration index, vitality index (IVC) and size plasticity index (ISP) (Table 6) testifies to the complex ontogenetic tactics of oilseed radish plants in the context of the studied variants, as the dynamic growth of variability of features with the increase of inter-row spacing, reduction of sowing rate and fertilizer growth provides the general growth of vitality index and size plasticity index, allows to state the differentiated divergent ontogenetic tactics of plants. In turn, strengthening the formation of over-dominant plant morphotypes on liquefied agrophytocenosises in the fertilization variants of 90 kg ha^{-1} of the primary material gives us reason to recommend the optimal variant of oilseed radish fertilizer for the research area with a fertilization rate of $N_{60\text{-}90}P_{60\text{-}90}K_{60\text{-}90}$ kg of the primary material ha^{-1} with a sowing rate of up to 1.7–2.0 million pcs. ha^{-1} of the germinable seeds at the row sowing and 1.5 million pcs. ha^{-1} of the germinable seeds at the wide-row sowing. The choice of optimum sowing rates and fertilizer options is also based on the value of size plasticity index (ISP): stable growth of its value with the growth of fertilizer rates is noted in the grading of options 1.0–2.0 of the row sowing and 0.5–1.5 of the wide-row sowing.

It should also be noted that, given the established features of the formation of layering of the oilseed radish agrophytocenosis in case of changes in HTC – at its value of more than 1.1, it is necessary to limit the dose of nitrogen fertilizers to 60 kg ha^{-1} of the primary material on oilseed radish sowing constructed at a rate of more than 2.0 million pcs. ha^{-1} of germinable seeds to avoid lodging by increasing competition and reducing the vitality index.

Conclusion

In the prognostic assessment approach, the vitality and coenotic tactics of oilseed radish plants in terms of variability of morphological features of all three basic blocks defined by us, both in the vertical and horizontal directions, will be enhanced with the growth of plant stand density and a decrease in the width of the row spacing with an interval factor of difference between the minimum value of morphological development of plants of the lower and upper-tiers. In an ideal combination we must ensure the growth of part of the plants of the middle-tier (the most productive component of the cenosis, which together with the part of plants of the upper-tier determines the level of productivity of sowing), should grow at a decrease in atypical plant morphotypes, especially with an extremely low vitality level.

The results of our multi-year studies have confirmed the complex vertical-spatial structure of oilseed radish agrophytocenosises. The approach we applied in our research, which is based on the basic principles of phytocoenology and its regularities, is effective in evaluating the technological feasibility of cenosis construction at the stage of sowing of crops in general and oilseed radish in particular. The analysis of the vitality strategy, which was based on the in-depth analysis of the modular and morphological, and ideotypical blocks, made it possible to comprehensively assess the efficiency of the studied technological variants of oilseed radish cultivation and select for the production implementation the most appropriate of them from the position of productive ontogenetic tactics of oilseed radish plants with strengthening the function of mineral fertilizers in the format of the regulator of agrophytocenosis quality coefficient.

The study of dynamic aspects of the formation of the vitality strategy of oilseed radish agrophytocenosises is promising for further research, considering climatological models of the vegetation period of the crop.

References

Abuelgasim, E.H. 1991. Plant type concept in crop improvement. – In Advances in Plant Breeding, Vol. 2. CBS Publishers, Delhi, pp. 254–260.

Ana, M.J., Radovan, M., Anto, M. 2008. Correlation and path analysis of quantitative traits in winter rapeseed (*B. napus* L.). – Agriculturae Conspectus Scientificus, 73(1):13–18.

Anderson, N.O. 2019. Selection tools for reducing generation time of geophytic herbaceous perennials. – Acta Horticulturae, 1237:53–66. DOI: 10.17660/ActaHortic.2019.1237.7

Andrivon, D., Giorgetti, C., Baranger, A., Calonnec, A., Cartolaro, P., Faivre, R., Guyader, S., Lauri, P.E., Lescourret, F., Parisi, L. 2013. Defining and designing plant architectural ideotypes to control epidemics? – European Journal of Plant Pathology, 135:611–617. DOI: 10.1007/s10658-012-0126-y

Anten, N.P., Vermeulen P.J. 2016. Tragedies and crops: understanding natural selection to improve cropping systems. – Trends in Ecology & Evolution, 31:429–439. DOI: 10.1016/j.tree.2016.02.010

Araus, J.L., Cairns, J.E. 2014. Field high-throughput phenotyping: the new crop breeding frontier. – Trends in Plant Science, 19(1):52–61. DOI: 10.1016/j.tplants.2013. 09.008

Barot, S., Allard, V., Cantarel, A., Enjalbert, J., Gauffreteau, A., Goldringer, I., Lata, J.C., Le Roux X., Niboyet, A., Porcher, E. 2017. Designing mixtures of varieties for multifunctional agriculture with the help of ecology. A review. – Agronomy for Sustainable Development, 37(2):13. DOI: 10.1007/s13593-017-0418-x

Bassu, S., Brisson, N., Durand, J.-L. 2014. How do various maize crop models vary in their responses to climate change factors? – Global Change Biology, 20:2301–2320. DOI: 10.1111/gcb.12520

Burstin, J., Rameau, C., Bourion, V., Tayeh, N. 2018. The PeaMUST project: defining ideotypes for the pea crop development. – OCL. 25(6):D604. DOI: 10.1051/ocl/2018056

Calonnec, A., Burie, J.B., Langlais, M., Guyader, S., Saint-Jean, S., Sache, I., Tivoli, B. 2013. Impacts of plant growth and architecture on pathogen processes and their consequences for epidemic behavior. – European Journal of Plant Pathology, 135(3):479–497. DOI: 10.1007/s10658-012-0111-5

Chapin, S.F. 1980. The mineral nutrition of wild plants. – Annual Review of Ecology and Systematics, 11:233–260. DOI: 10.1146/ annurev.es.11.110180. 001313

Cilas, C., Bar-Hen, A., Montagnon, C., Godin, C. 2006. Definition of architectural ideotypes for good yield capacity in Coffea canephora. – Annals of Botany, 97:405–411. DOI: 10.1093/aob/mcj053

de Kroon, H., Huber, H., Stuefer, F., van Groenendael, J.M. 2005. A modular concept of phenotypic plasticity in plant. – New Phytologist, 166(1):73–82. DOI: 10.1111/j.1469-8137.2004.01310.x

Debaeke, P., Quilot-Turion, B. 2014. Conception d'idéotypes de plantes pour une agriculture durable. – Collection École-chercheurs INRA FormaSciences *FPN INRA*. pp. 25–67. (In French)

Desclaux, D., Nolot, J.M., Chiffoleau, Y., Gozé, E., Leclerc, C. 2008. Changes in the concept of genotype x environment interactions to fit agriculture diversification and decentralized participatory plant breeding:

pluridisciplinary point of view. – Euphytica, 163:533. DOI: 10.1007/s10681-008-9717-2

Dickmann, D.I., Gold, M.A., Flore, J.A. 1994. The ideotype concept and the genetic improvement of tree crops. – Plant Breeding Reviews, 12:163–193. DOI: 10. 1002/9780470650493.ch6

Dolotovsky I.M. 2003. Phytocoenotic aspects of the formation of quantitative traits of plants. – Agrarian Russia, Moscow, pp. 89–106. (In Russian).

Donald, C.M. 1968. The breeding of crop ideotypes. – Euphytica. 17(3):385–403. DOI:10.1007/BF00056241

Ellisséche D., Pellé R., Lejeune B., Andrivon D., Mathieu G. 2002. An attempt to define ideotypes of potato varieties designed for adaptation to organic farming. – In Proceedings 15th Triennial Conference of EAPR. Hamburg, Germany. 14–19.07.2002, p. 105.

Foltyn, J. 1977. Determination of the quantitative characteristics of wheat and barley ideotype for Central Europe. – Scientia Agriculturae Bohemoslovaca UVTIZ. 9(1):13–19.

Gauffreteau, A. 2018. Using ideotypes to support selection and recommendation of varieties. – OCL, 25(6):D602. DOI: 10.1051/ocl/2018042

Glukhov, O.Z., Prokhorov, C.I. 2008. Indication of the state of the technogenic environment by morphological variability of plants. – Industrial botany, 8:3–11. (In Ukrainian)

Grime, J.P. 1979. Plant strategies and vegetation processes. – Chichester: J. Wiley Publ., pp. 11–16.

Grime, J.P., Hodgson, J.G., Hunt, R. 1988. Comparative plant ecology: a functional approach to communities of British species. – L.: Unwin Hyman Publ. pp. 19–23.

Grodzinskiy, A.M. 1973. The fundamentals of chemical interaction of plants. – Kyiv: Scientific thought, pp. 93–97 (in Ukrainian).

Hamblin, J. 1993. The ideotype concept: Useful or outdated. – In: International Crop Science I, Crop Science Society of America, Madison, WI, USA, pp. 589–597. DOI: 10.2135/1993.internationalcropscience.c93

Haverkort, A.J., Kooman, P.L. 1997. The use of systems analysis and modelling of growth and development in potato ideotyping under conditions affecting yields. – Euphytica, 94:191–200. DOI: 10.1023/A:1002965428704

Heslot, N., Akdemir, D., Sorrells, M.E., Jannink, J.L. 2014. Integrating environmental covariates and crop modeling into the genomic selection framework to predict genotype by environment interactions. – Theoretical and Applied Genetics, 127:463–480. DOI: 10.1007/ s00122-013-2231-5

Isaacs, K.B., Snapp, S.S., Kelly, J.D., Chung, K.R. 2016. Farmer knowledge identifies a competitive bean ideotype for maize-bean intercrop systems in Rwanda. – Agriculture & Food Security, 5:15. DOI: 10.1186/s4006601600628

Ishbirdin, A.R., Ishmuratova, M.M. 2004. Adaptive morphogenesis and ecological and coenotic survival strategies for herbaceous plants. – Methods of population biology. Collection of materials VII All-Russian Population Seminar (Syktyvkar, February, 16–21, 2004). – Syktyvkar 2, pp. 113–120. (In Russian).

Ishbirdin, A.R., Ishmuratova, M.M., Zhirnova, T.V. 2005. Life strategies of the coenopopulations of *Cephalanthera rubra* (L.) Rich. on the territory of Bashkir State Reserve. – Vestnik of Lobachevsky University of Nizhni Novgorod. Series: Biology. Issue 1(9). Nizhni Novgorod, pp. 85–98 (in Russian).

IUSS Working Group. 2015. WRB: World Reference Base for Soil Resources. – World Soil Resources Reports 106, FAO, Rome. pp. 85–90.

Jeuffroy, M.H., Casadebaig, P., Debaeke, P., Loyce, C., Meynard, J.M. 2014. Agronomic model uses to predict cultivar performance in various environments and cropping systems: a review. – Agronomy for Sustainable Development, 34:121–137. DOI: 10. 1007/s13593-013-0170-9

Khan, F.A., Ali, S., Shakeel, A., Saeed, A., Abbas, G. 2006. Correlation analysis of some quantitative characters in *Brassica napus* L. – Pakistan Journal of Agricultural Research, 44(1):7–14.

Khmelyanchyshyn, Yu.V. 2005. Optimal combination of the variety, sowing method and fertilizer in an energy-saving technology for growing spring rape seeds in the southwestern part of the Ukrainian forest-steppe. – PhD thesis. State Agrarian and Engineering University in Podilia, pp. 10–14 (in Ukrainian).

Labana, K.S., Badwal, S.S., Gupta, M.L. 1976. Path analysis of yield and its components in *B. juncea*. – In Recent Advances in Plant Sciences. PBA., 47:29.

Laman, N.A., Vlasova, N.N., Poplavskaya, R.S., Prorohov, V.N. 1999. Bioenvironmental characteristics of the formation of highly productive crops of bread grains: selection aspects. – Proceedings of the National Academy of Sciences of Belarus.Agrarian Series, Minsk. 3:52–58. (In Russian).

Le May, C., Ney, B., Lemarchand, E., Schoeny, A., Tivoli, B. 2009. Effect of pea plant architecture on the spatio-temporal epidemic development of ascochyta blight (*Mycosphaerella pinodes*) in the field. – Plant Pathology, 58:332–343. DOI: 10.1111/j.1365-3059. 2008.01947.x

Loison, R., Audebert, A., Debaeke, P., Hoogenboom, G., Leroux, L., Oumarou, P., Gerardeaux, E. 2017. Designing cotton ideotypes for the future: reducing risk of crop failure for low input rainfed conditions in Northern Cameroon. – European Journal of Agronomy, 90:162–173. DOI: 10.1016/j.eja.201708.003

Ly, D., Huet, S., Gauffreteau, A., Rincent, A., Touzy, G., Mini, A., Jannink, J.L, Cormier, F., Paux, E., Lafarge, S., Le Gouis, J., Charmet, G. 2018. Whole-genome prediction of reaction norms to environmental stress in bread wheat (*Triticum aestivum* L) by genomic random regression. – Field Crop Research, 216:32–41. DOI: 10.1016/j.fcr.2017.08.020

Ma, N., Yuan, J., Li, M., Li, J., Zhang, L., Liu, L., Naeem, M.S., Zhang, C. 2014. Ideotype population exploration: growth, photosynthesis, and yield components at different planting densities in inter oilseed rape (*Brassica napus* L.). – PLOS. 9(12):e114232. DOI: 10.1371/journal.pone.0114232

Mamun, F., Ali, M.H., Chowdhury, I.F. 2014. Performance of rapeseed and mustard varieties grown under different plant density. – Scientia Agriculturae, 4(2):70–75.

Mangin, B., Casadebaig, P., Cadic, E. 2017. Genetic control of plasticity of oil yield for combined abiotic stresses using a joint approach of crop modelling and genome-wide association. – Plant, Cell and Environment, 40:(10)2276–2291. DOI: 10.1111/pce.12961

Martre, P., Quilot-Turion, B., Luquet, D., Ould-Sidi, M., Chenu, K., Debaeke, P. 2015. Model assisted phenotyping and ideotype design. – Crop physiology (2nd ed). Applications for genetic improvement and agronomy. (Eds. D. Calderini, V.O. Sadras). Academic Press, pp. 349–373. DOI: 10.1016/B978-0-12-417104-6.00014-5

Mirkin, B.M. 1985. Theoretical basics of modern phytocenology. –Nauka, Moscow, pp. 103–109. (In Russian)

Mirkin, B.M., Usmanov, I.Yu., Naumova, L.G. 1999. Types of plant strategies: The place in species classifications and tendencies of development. – Zhurnal Obshcheĭ Biologii, 60(6):581–594. (In Russian)

Mock, J.J., Pearce, R.B. 1975. An ideotype of maize. – Euphytica, 24:613–623. DOI: 10.1007/BF00132898

Mukhortov, S.Ya., Ryabchikova, V.V. 2012. Dictionary-reference book on agrometeorology. – State Agrarian University, Voronezh, pp. 16–17. (In Russian)

Murren, C.J. 2002. Phenotypic integration in plants. – Plant Species Biology, 17(2–3):89–99. DOI: 10.1046/j.1442-1984.2002.00079.x

National Standard of Ukraine 4362:2004: Soil quality. Indicators of soil fertility. 2006. Valid from 01.01.2006.– Kyiv: State standard of Ukraine. 23 p. (In Ukrainian).

Notov, A.A. 1999. On the specifics of the functional organization and individual development of modular objects. – Zhurnal Obshcheĭ Biologii, 60(1):1–23. (In Russian).

Pivoshenko, I.M. 1997. Climate of Vinnytsia region. – Vinnytsia: OJSC Vinoblodobrachnya, pp. 12–23. (In Ukrainian).

Poluektov, R.A., Smolyar, E.I., Terleev, V.V., Topazh, A.G. 2006. Models of the crop production process. – Publishing House S. of Saint Petersburg State University. pp. 98–109. (In Russian).

Rabotnov, T.A. 1998. Experimental phytocenology: Textbook manual for university students enrolled in the direction and special. "Biology". – Publishing house of Moscow State University, Moscow, 240 p. (In Russian).

Rais, E. 1978. Allelopathy. – Mir, Moscow, pp. 11–14. (In Russian).

Rasevich, V.V. 2008. Ecological and coenotic features of the popularity in the natural flora of Ukraine. – Ukrainian Botanical Journal, 65(1):92–102 (In Ukrainian).

Rasmusson, D.C. 1991. A plant breeder's experience with ideotype breeding. – Field Crop Research, 26:191–200. DOI: 10.1016/0378-4290(91)90035-T

Rostova, N.S. 2002. Correlations: structure and variability. – St. Petersburg University Publishing House, pp. 23–30. (In Russian).

Rumsey, D.J. 2016. Statistics for Dummies (2nd Edition). – John Wiley & Sons Inc. 408 p.

Rötter, R., Tao, F., Höhn, J., Palosuo, T. 2015. Use of crop simulation modelling to aid ideotype design of future cereal cultivars. – Journal of Experimental Botany, 66(12): 3463–3476. DOI: 10.1093/jxb/erv098

Qia, R., Mab, Y., Hub, B., Reffyed, P., Cournude, P.H. 2010. Optimization of source-sink dynamics in plant growth for ideotype breeding: A case study on maize. – Computers and Electronics in Agriculture, 71(1): 96–105. DOI: 10.1016/j.compag.2009.12.008

Samson, D.A., Werk, K.S. 1986. Size-dependent efects in the analysis of reproductive effort in plants. – American Naturalist, 127:667–680. DOI: 10.1086/284512

Sayko, V.F. 2011. Features of research on cruciferous oil crops. –Institute of Agriculture of the NAAS of Ukraine, Kiev, pp. 26–42. (In Ukrainian).

Semenov, M.A., Stratonovitch, P. 2013. Designing high-yielding wheat ideotypes for a changing climate. – Food and Energy Security, 2:185–196. DOI: 10.1002/fes3.34

Shanda, V.I., Yevtushenko, E.O., Voroshilova, N.V., Malenko, Y.V. 2017. Agrophytocenology: aspects of theory, methodology and related sciences. – Monograph. Kryvyi Rih State Pedagogical University, pp. 105–110. (In Ukrainian).

Sinyagin, I.I. 1975. Plant nutrition areas. – Rosselkhozizdat, Moscow, pp. 11–14, (In Russian).

Skliar, V., Sherstuk, M., Skliar, Iu. 2016. Algorithm of comprehensive assessment of individual's morphological integration of plants contrast biomorfs. – QUAERE 2016 (vol. VI), Interdisciplinary Scientific Conference for PhD students and assistance. May 23–27, 2016). Praha, pp. 393–403.

Skliar, V., Sherstuk, M. 2016. Sizestructure of phytopopulations and its quantitative evaluation. – Eureka: LifeSciences, 1:9–16. DOI: 10.21303/2504-5695.2016.00047

Sokal, R.R., James, R.F. 2012. Biometry: the principles and practice of statistics in biological research (4th ed). – New York: W.H. Freeman, pp. 67–90.

Sukachev, V.N. 1956. About modern problems of studying the vegetation cover. – Botanicheskij zhurnal SSSR, 41(4):476–486. (In Russian).

Sultan, S. 2004. Promising direction in plant phenotypic plasticity. – Perspectives in Plant Ecology, Evolution and Systematics, 6(4):227–233. DOI: 10.1078/1433-8319-00082

Tandon, J.P., Jain, H.K. 2004. Plant ideotype: The concept and application. – Plant Breeding, pp. 585–600. DOI: 10.1007/978-94-007-1040-5_25

Temesgen, T., Keneni, G., Sefera, T., Jarso, M. 2015. Yield stability and relationships among stability parameters in faba bean (*Vicia faba* L.) genotypes. – The Crop Journal, 3(3):258–268. DOI: 10.1016/j.cj. 2015. 03.004

Test Guidelines for the conduct of tests for distinctness, uniformity and stability of Fodder Radish (*Raphanus sativus* L. var. oleiformis Pers.) (TG/178/3, UPOV). – Geneva, 2017-03-15, pp. 6–18.

Thurling, N. 1991. Application of the ideotype concept in breeding for higher yield in the oilseed brassicas. – Field Crop Research, 26(2):201–219. DOI: 10.1016/0378-4290(91)90036-U

Tonin, P., Gosselet, N., Halle, E., Henrion, M. 2018. Ideal oil and protein crops – what are users expectations ideotypes, from the farmer to the consumer? – OCL, 25(6):D605. DOI: 10.1051/ocl/2018060

Tsytsiura, Ya.H. 2018. Features of layering formation in the oilseed radish agrophytocenosis under conditions of the right-bank forest-steppe of Ukraine. – Scientific bulletin of the National University of Life and Environmental Sciences of Ukraine, Issue 286. Series: Agronomy, pp. 205–215. (In Ukrainian).

Tsytsiura, Y.H. 2019. Evaluation of the efficiency of oil radish agrophytocoenosis construction by the factor of reproductive effort. – Bulgarian Journal of Agricultural Science, 25(6):1161–1174.

Usmanov, I.Yu., Martynova, A.B. 1990. Physiological reactions of plants with different types of ecological and coenotic strategies to changes in growing conditions. – In Proceedings of the USSR Academy of Sciences. Series: Biology, No. 3, pp. 427–433. (In Russian).

Van der Meulen, A., Chauhan, B.S. 2017. A review of weed management in wheat using crop competition. – Crop Protection, 95:38–44. DOI: 10.1016/j.cropro. 2016.08.004

Van Oijen, M., Höglind, M. 2016. Toward a Bayesian procedure for using process-based models in plant breeding, with application to ideotype design. – Euphytica, 207:627–643. DOI: 10.1007/s10681-015-1562-5

Van Tassel, D.L., Albrecht, K.A., Bever, J.D., Boe, A.A., Brandvain, Y., Crews, T.E., Gansberger, M., Gerstberger, P., González-Paleo, L., Hulke, B.S. 2017. Accelerating domestication: An opportunity to develop new crop ideotypes and breeding strategies informed by multiple disciplines. – Crop Science, 57(3):1274. DOI: 10.2135/cropsci2016.10.0834

Vijaya Kumar, C.H.M., Arunachalam V., Chakrabarty, S.K., Kesava Rao, P.S. 1996. Ideotype and relationship between morpho-physiological characters and yield in Indian mustard. – Indian Journal of Agricultural Sciences, 66:(11)633–637.

Vincourt, P., Carolo, P. 2018. Alternative breeding processes: at which extent participatory breeding should modify the concept of ideotypes in plant breeding? – OCL, 25(6):D606. DOI: 10.1051/ocl/2018061

Yadav, T.P., Yadava, A.K., Singh, A. 1978. A concept of plant ideotype in Indian mustard (*Brassica juncea* L.) – 5th International rapeseed conference. Malmö, Sweden, pp. 66–70.

Zaytsev, G.N. 1984. Mathematical statistics in experimental botany. – Nauka, Moscow, pp. 87–92. (In Russian).

Zeven, A.C. 1975. Editorial: Idiotype and ideotype. – Euphytica, 24:565–567. DOI: 10.1007/BF00132891

Zhang, D.Y., Sun, G.J., Jiang, X.H. 1999. Donald's ideotype and growth redundancy: A game theoretical analysis. – Field Crops Research, 61(2):179–187. DOI: 10.1016/S0378-4290(98)00156-7

Zhilyayev, G.G. 2005. Plant population vitality. – Academy of Sciences of Ukraine, Lviv, pp. 106–118. (In Ukrainian).

Zhuchenko, A.A. 2001. Adaptive system of plant selection. – Ecological basics. Agrorus, Moscow, pp. 20–29. (In Russian).

Zlobin, Yu.A. 1989. Principles and methods of studying the cenotic populations of plants. –Kazan University, Kazan, Russia, pp. 88–96. (In Russian).

Zlobin, Yu.A. 1993. The mechanisms underlying the dynamics of plant populations. – Zhurnal Obshhej Biologii, 54(2):210–222. (In Russian).

Zlobin, Yu.A. 2009. Popular ecology of plants: current status, points of growth. – University Book, Sumy, Ukraine, pp. 78–105. (In Russian).

Zlobin U.A., Skliar V.G., Klimenko A.A. 2013. Populations of rare plant species: theoretical basis and tutorial method: monography. – University Book, Sumy, Ukraine, 439 p. (In Russian).