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Evaluation of the efficiency of oil radish agrofitocenosis construction by the factor of reproductive effort

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Abstract

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The expediency and capability of application of criteria of reproductive effort (RE) and index of vitality of coenopopulation (IVC) of the reproductive part of plants for effective estimation of vitality tactique of oilseed radish agrophytocenoses of different technological construction (row spacing (15 and 30 cm) and seeding rates (4.0, 3.0, 2.0, 1.0 mln of germinable seeds per ha under the row spacing of 15 cm, and 2.0, 1.5, 1.0, 0.5 million of germinable seeds under row spacing of 30 cm) against the background of four variants of mineral nutrition (no fertilizer- $N_{90}P_{90}K_{90}$ with an equal interval of 30 kg of active ingredient per ha of) were generalized. Based on the evaluation of the vitality tactics dynamics in a specific cenosis, the most expedient technological intervals of seeding parameters and fertilization of oilseed radish were determined to ensure the fulfilment of the reproductive individual potential of plants in combination with their density per unit of area and final maximum level of the biological yield capacity. An effective quantitative regulation of the application of mineral fertilizers for the appropriate variants of the planting method and seeding rates was substantiated.

Keywords: index of vitality; oilseed radish; reproductive strategy; reproductive effort; vitality

Introduction

The genetic program of plant development involves implementation of the program of their organism development as a holistic system in interaction with environmental factors and weed plant competition both at the level of interspecific and intraspecific competition. Implementation of this program results in obtaining a certain phenotypic series of plants of this species, which refer to the idiotype of plants in many publications (Savinykh & Maltseva, 2008; Zlobin, 2009). The ratio of these idiotypes is called a plant development tactic (strategy), which in its turn is closely linked to the adaptive properties of the organism and its ability to be cultivated in a wide range of technological options for agrophytocenosis construction of different species density (Zlobin, 2009). The strategy itself is expressed by the rate of morphogenesis of the individual parts of the plant and formation of the corresponding plant architectonics on the basis of the indicated processes (Hara et al., 1988). There are different levels of plant development strategies in the multifactorial ecological environment, including root-mycorrhizal, vegetative and reproductive. Each of them can be analyzed both individually and separately from the development of the plant organism and systematically in the context of the relevant patterns of growth processes of this species of plants, which ensures formation of the appropriate relationship between the share of the root system, leaf assimilation apparatus, stem part and share of reproductive organogenesis, i.e. fruits, seeds, etc. (Rabotnov, 1975; Markov, 1986; Magomedmirzayev, 1997; Chebotar, 1986).

The problem of adaptive plant strategies in terms of modern botany is considered from two main points. One of them is related to the definition of a coordinated set of traits and characteristics of plants that provide reproduction and support for the number of individuals, populations and species. Having emerged in the 1970s, nowadays it has become one of the leading trends in the evolutionary ecology and morphology and it relies mainly on the analysis of two types of reproductive strategies, K and g-types (Harper, 1977; Kawano & Masuda, 1980; Pianca, 1981; Markov, 1986; Ishbirdin & Ishmuratova, 2004). The second position is related to the development of the ideas by Ramensky (1938) and Graime (Grime et al., 1988) regarding the types of adaptations of species under different ecological-and-cenotic conditions (Rabotnov, 1975; Myrkin, 1985). The second type is also called ecological-and-coenotic strategies.

The strategy itself is treated as a combinatorial one of ecological-and-morphological adaptations of the plant organism and the rate of phenotypic implementation of the genotypic program of its development. It makes it possible to distinguish the following types of strategies: C – competitors, S – stress tolerants, R – ruderis (Titov, 1978; Mirkin et al., 1999).

When applied to these adaptations, the factor of plant coenosis density, causing an appropriate level of a biological competitive stress, causes overall pressure on the morphological plant development and the effect of such pressure leads to a general miniaturization of plants and decrease in the average range of their morphological features (Wolfe, 1983; Samson & Werk, 1986). This effect also influences the severity of the morphological variability of plants, formation of their various idiotypes and enhanced manifestation of the matricular variability of plants. For these reasons, it is important to determine the rate of coenoticpressuree of the coenosis to determine the potential growth of the morphological trait variation.

The rate of such pressure has several levels of identification. The first one refers formation of the general plant morphology starting from the stage when free living space is conditionally reduced to zero and the overall competition between the plants per unit of area increases (Zlobin, 2009). Another one relates to identification of the reproductive effort, which is a variant of optimization of specific parameters of the formation of agrophytocenosis and a determining factor in the so-called vitality spectrum of coenosis (Titov, 1978).

When studying reproductive strategies, special attention is paid to the ways of rational use of material and energy resources over a given period of time or throughout the life cycle, as well as the efficiency of consumption of organic resources of the environment for the reproduction of the generation, which is finally expressed in the formation of a certain level of seed productivity (Romanovsky, 1981)and reproductive effort, which is estimated by the proportion of the mass of generative parts and elements in the weight of the whole plant or only its above ground part (Newell &Tramer, 1978; Markov & Pleshchinskaya, 1987). In the process of the generative sphere formation in the life cycle of plants, there takes place a redistribution of material and energy resources: in monocarpic annuals, they are completely directed to this sphere and used for seed progeny, while in perennials a smaller part of resources is usually used for seed generation, a large part is used for survival of maternal individuals through accumulation of the nutrient supply (Agaev, 1978; Kawano & Masuda, 1980; Mirkin, 1985; Niklas & Enquist, 2003).

At the same time, modern approaches to differentiation of reproductive strategies distinguish their typification by three basic variants of influence of environmental factors, in particular, low, medium and high stress conditions. According to the presented gradations, technological parameters of the pre-planting construction of agrophytocenoses of crops can either reduce or enhance the severity of environmental stress (Mirkin, 1985; Symonides, 1987; Niklas & Enquist, 2003; Liu et al., 2008; Dimitrov et al., 2019; Marjanovi´c-Jeromela et al., 2019).

On the other hand, it should be argued that plant development and its holistic morphogenesis is a polydynamic system that includes a taproot, a stem, leaves, fruits, and the seeds. It is accepted to express the peculiarities of the ratio of each part of the system in the diagram of ratios in percentage terms both in the variant of the accumulated energy and in the variant of the percentage ratio to the total mass of the plants in a particular phenological phase or on a calendar date. As a result of such comparison, it is possible to obtain a complete diagram of plant architecture with the separation of the vegetative and reproductive parts of the plant. The latter can be divided into flowers, fruits and seeds for effective detailing (Hickman & Pitelka, 1975; Nagai & Kawano, 1986; Klinkhamer et al., 1990; McConnaughay &Coleman, 1999; Bazzaz et al., 2000; Obeso, 2004; Weiner, 2004).

It should also be noted that the structured index of the indicated percentage ratio of some parts of a plant in the process of its development is the index of vitality. Vitality is considered as a complex expression of the general life strategy of plants, since it allows to evaluate both the overall intensity of the morphological development of plants and its individual parts. In fact, the index of vitality is a similar expression of the correlation dependencies between the size of the individual parts of the plant, since regular features of the formation of certain plant organs in a single system of correlative pleiades of plant morphogenesis have been established and confirmed (Rostova, 2002). Under these conditions, the index of vitality (IVC) is calculated using equalization by the method of weighing individuals having average size spectrum (Ishbirdin & Ishmuratova, 2004) and it allows to establish a specific dimensional indicator of the viability of agrophytocenosis and its optimality according to the technological parameters of functioning.

Problem statement and research objective

The object of research was oilseed radish (*Raphanussativusvar. oleifera Metzg.*) defined as a species of radish (*Raphanus sativus* L.), genus *Raphanus* L., subtribe II *Raphanusae* DC., tribe 5 *Brassiceae* Hayek and referred to the family *Brassicaceae*, order *Capparidales*, order *Capparidales*, class *Dicjtyledaneae* (Al-Shehbaz, 2012; Tsitsiura &Tsitsiura, 2015). According to the results of some studies, it belongs to the group of species *Convar. oleiferus* L., that is a group of varieties of oilseed radish with the following characteristics: plants are annual, the taproot is not formed, it is grown to produce oil from the seeds and for forage purposes, vegetative and generative organs are similar to the forms of root crops (Dorofeev, 2002).

The urgency of studying the aspects of the vitality strategy of oilseed radish plants is caused by some specific features of its growth processes, which distinguish it from other cabbage families, in particular, a sensitive response to the change in the plant density in the early stages of vegetation, formation of heterogeneous system of the ideotypestructure of plants, long period of flowering-and-yellow maturity of the fruit elements, deterministic signs of matricular diversity of plants and its fruit elements (Tsytsiura, 2015, 2018). In addition, in the system of long-term study of technologies for growing oilseed radish (Tsitsiura & Tsitsiura, 2015) there has been confirmed the possibility of using an indicator of differentiation of its agrophytocenosis known as Sukachev effect (Sukachev, 1935; Zlobin, 2009): in pure and single-stage agrophytocenosis individuals there can be observed differentiation of the individuals into small and large ones, which is especially noticeable in the variants of fertile soils and under a certain limit of increase in the planting density – to the completeplant extinction.

Thus, the reproductive effort of oilseed radish plants can be used as a criterion for the appropriate nature and tactics of vitality and, therefore, to determine the most optimaloptions for the formation of agrophytocenosis from the technological point of view. It enables to carry out qualitative analysis of the system of vitality tactics of interaction to the change of such factors as row spacing, quantitative seeding rate, fertilization.

Materials and Methods

The objects of the research were oilseed radish varieties ‘Zhuravka’, ‘Raiduha’, ‘Lybid’ referred to the group of the main varieties grown in Ukraine and belonging to the combined type of use, i.e. for seed and forage purposes. Based on the similarity of the obtained results and established similar trends in the formation of indicators during the growing season in the genotypes mentioned, the experimental data on ‘Zhuravka’ variety are presented.

The study of peculiarities of formation of the vitality strategy indicators of oilseed radish plants under changes in the technological parameters of constructing its agrophytocenosis was carried out during 2013-2018 on the experimental field of Vinnytsia National Agrarian University on dark gray forest soils of mid-loamy mechanical composition with the fluctuationin terms of rotation:humus of 2.16-2.52%, pH of 5.8-6.7, content of easily hydrolyzed nitrogen of 71-77 mg/kg, mobile phosphorus (according to Chirikov) of 187-251 mg/kg, exchangeable potassium (according to Chirikov) 95-143 mg/kg.

The vitality strategy of oilseed radish plant varieties was studied using a scheme that includes all the recommended range of planting parameters of its agrophytocenosis formation in the area under research, including the format of the recommended mineral nutrition (Table 1).

The planting period for all variants of research ranged within April 8-12 and it was determined by the conditions of the similar parameters of the physical soil maturity and values of average daily temperatures.

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

Factors of the trial		
A – planting method	B – seed ingrates (mln germinable eseeds per ha)	C – fertilization
A_1 – row method (15 cm)	B_1 – 1.0 (15 seeds/l m per row*) B_2 – 2.0 (30 seeds/l m per row) B_3 – 3.0 (45 seeds/l m per row) B_4 – 4.0 (60 seeds/l m per row)	C_1 – without fertilizers C_2 – $N_{30}P_{30}K_{30}$ C_3 – $N_{60}P_{60}K_{60}$ C_4 – $N_{90}P_{90}K_{90}$
A_2 – wide-row method (30 cm)	B_4 – 0.5 (15 seeds/l m per row) B_5 – 1.0 (30 seeds/l m per row) B_6 – 1.5 (45 seeds/l m per row) B_7 – 2.0 (60 seeds/l m per row)	

Note: seeds/l m per row – germinable seeds per linear metre in a row.

Hydrothermal regime of the period under research varied (Table 2). According to the value of hydrothermal coefficient (HTC) in terms of moisture supply, 2013 appeared to the most optimal for ensuring the growth processes of oilseed radish plants, so that HTC was 1.527 during the growing season.

Vegetation conditions were the most arid in 2015 with HTC of 0.430 during the growing season with a decrease in the indicator to 0.061 in the period of August. It should be noted that the distribution of precipitation within the defined HTC was also uneven in terms of ensuring growth processes and providing optimal growth rates until the phase of stemming in 2013, 2014, and 2016. Under the conditions of 2018, there was observed a combination of both atmospheric and soil humidity deficits throughout the period of April-May with a change in the situation in the third decade of June due to the intense atmospheric humidity, which reflected in the averaged HTC at the average monthly level of 3.124.

A more detailed analysis of the peculiarities of weather conditions is presented in Table 2. Thus, vegetation conditions in 2013 were characterized by a steady increase in av-

Table 2. Precipitation sums and average daily temperature compared to the average long-term regime over the period studied

Months	Decades	Years						Average long-term indicator (30-year averaging period)
		2013	2014	2015	2016	2017	2018	
Average daily temperature,°C								
April	I	3.9	6.5	4.3	12.3	10.9	10.3	6.0
	II	10.5	7.5	9.0	13.1	6.6	14.3	7.3
	III	15.8	13.1	11.2	10.2	9.4	15.1	9.7
May	I	18.1	12.0	13.1	13.3	12.6	19.5	11.9
	II	20.7	16.6	16.1	13.4	14.0	15.9	13.8
	III	15.3	19.5	18.2	17.4	17.1	19.0	15.0
June	I	17.2	18.1	20.4	15.9	18.0	19.2	15.9
	II	19.9	16.3	19.2	18.7	18.1	20.7	16.7
	III	20.8	15.7	18.2	23.7	21.4	17.9	17.5
July	I	19.7	19.2	21.5	19.3	18.2	18.6	18.2
	II	18.6	19.7	19.0	20.6	19.2	19.1	18.8
	III	18.6	21.3	22.7	21.6	21.7	21.5	19.0
August	I	21.4	23.3	23.4	20.6	23.7	21.3	18.7
	II	19.5	20.8	19.3	17.8	23.3	22.2	18.7
	III	15.3	15.6	21.3	21.0	16.2	19.6	16.7
Average for the period, °C		17,0	16.3	17.1	17.2	16.7	18.3	14.9
Sum of precipitation, mm								
April	I	15.9	25.8	14.3	4.2	34.4	10.0	12.5
	II	9.0	46.3	36.6	19.3	16.6	3.0	22.3
	III	0.0	1.0	2.6	16.0	11.7	8.0	14.4
May	I	0.0	26.3	36.0	8.3	18.4	0.0	18.1
	II	30.5	72.7	8.2	67.5	5.1	12.6	20.0
	III	55.9	100.0	0.3	5.9	14.0	3.8	23.5
June	I	36.0	43.1	3.2	15.0	1.8	0.5	22.8
	II	71.0	0.0	28.8	38.9	11.9	91.3	24.7
	III	37.0	33.4	9.3	18.3	15.2	156.3	25.9
July	I	0.2	28.5	3.0	17.4	5.7	10.0	25.2
	II	11.1	39.0	11.9	44.0	18.6	44.0	23.8
	III	15.4	15.0	5.8	6.7	67.7	52.3	29.2
August	I	4.0	9.0	0.0	19.0	13.7	1.3	23.5
	II	18.0	0.0	6.0	19.0	0.0	32.6	22.6
	III	67.2	56.1	0.0	16.0	40.1	2.9	22.7
Amount for the period, mm		371.2	496.2	166	315.5	274.9	428.6	331.2
Hydrothermal coefficient over the growing season of oilseed radish		1.527	1.269	0.430	0.663	0.824	1.179	

Note: * –the period of flowering and fruiting of oilseed radish plants for the phenological conditions of the zone under research aremarked gray.

erage daily temperatures with a peak value at the level of 27-28°C under conditions of concentration of the main precipitation during May-first decade of June.

The conditions of 2014 were characterized by the temperature similar to that of 2013 with a cooler period of April-May. The distribution of precipitation was more even, especially during the period of active vegetation of oilseed radish in May-June. In 2015, there was noted an intensive increase in average daily temperatures (maximum interval and steady background of high temperatures compared to the same period of other years) against the background of active atmospheric humidity in the period of April-May, and its minimum values in the summer period, so that in the dynamics of years studied the defined year appeared to be the driest and the most stressful one concerning the development of oilseed radish agrophytocenoses of different variants.

The weather conditions in 2016 and 2017 were similar and they were characterized by the average rates of increase in average daily temperatures against the background of pronounced interval distribution of precipitation, which was more quantitatively intense in the conditions of 2016 than that of 2017. In addition, the temperature regime of the first period of April-May was cooler in 2017. In 2018, the growing season was characterized as the coolest with a pronounced deficit of moisture during the interval of April-first decade of June due to the displacement of the main amount of precipitation for the period of the third decade of June-the second decade of July, which distinguishes this year of growing with the features of extremely irregular moisture supply against the background of slow rates of temperature growth during the period from sprouting to stemming of oilseed radish to those moderately stressful for the crop. It should be noted that throughout all the years of study, long flowering and fruiting periods were observed, which were in the calendar interval of the third decade of May-the first decade of July, depending on the HTC. Favorable conditions of moisture supply during the spring period against the background of intensive temperature increase shifted the dates of the beginning of plant flowering for at least one decade. The duration of flowering and fruiting also depended on hydrothermal conditions of growing and ranged within 25-40 days, depending on HTC of this period.

Evaluation of the morphological parameters of plants was performed with sampling of 25 plants in each replication (total sampling of 100 plants). The total number of replications of each variant was 4. The plant analysis involved estimation of a group of 5 plants in 5 places along the length of the line stochastically along the width of the plot with the offset in a row horizontal starting from the phase of plant flowering BBCH 64-65 (Hocking, 1997; Meier, 2001; Scinner & Moore, 2010) to the phase when all pods reached the size that is typical for the variety (BBCH 78-79).

Estimation of the intensity of development of the generative part of plants in different variants was carried out according to the indicators of reproductive effort both by the number of flowers per plant and by the number of pods (Thompson & Stewart, 1981; Lovett Doust, 1989; Ishbridin & Ishmuratova, 2004).

Determination of the peculiarities of competitive relationships in the form of influence on the formation of productive architectonics by the general morphological development of the generative part, fruits and seeds in oilseed radish agrophytocenosiswas carried out using the appropriate methodology (Zlobin, 1989) with the calculation of the coefficient of vitality in accordance with formula I (modified by Ishbridin & Ishmuratova, 2004):

$$IVC = \frac{1}{\mathrm{N}} * \sum_{i=1}^{N} \frac{x_i}{X_i}, \tag{1}$$

where *IVC* is index of vitality of coenopopulation; *N* is the total number of traits determined in agrophytocenosis; x_i is the value of the i^{th} trait in agrophytocenosis with certain parameters of cultivation technology; X_i is the average value of the i^{th} trait for all agrophytocenoses in the range of the variants studied.

The ratio of the intensity of growth processes of different organs of oilseed radish plants was determined by the calculation of reproductive effort (RE) using formula 2 (Bazzaz & Reekie, 1985):

$$RE = \frac{M_r}{M_g} * 100, \tag{2}$$

where *RE* is reproductive effort, % (we used the unit of measure in the form of numerical dimension of the ratio of significant parts of the ratio); M_r is the mass of the reproductive part of the plant (inflorescences, pods) (in absolute terms or dry matter), g (kg); M_g is the total mass of the plant (in absolute terms or dry matter), g (kg).

Characteristics of the mass of plant parts and seeds were determined using a laboratory scale RADWAG PS 1000.R1 with discretion of 0.001 g.

Analysis of the morphology of plant pods was conducted within the selected generalized typical inflorescence zones recording such traits as pod length (cm), pod diameter (mm), thickness of the pod walls in the middle zone (mm). To determine these morphometric characteristics, there was used an electronic caliper Didital Caliper (measurement accuracy of 0.01 mm), method of USB microscopy using Sigeta MCMOS 5100 5.1 MP USB 2.0 with the corresponding software.

Measurements and observations were accompanied by the use of an electronic scanning method to obtain digital images of the generative parts of the plant and subsequent analysis of the peculiarities of the spatial arrangement of the inflorescence parts and the magnitudes of the reproductive effort. To do this, we used the CanoScan LIDE 700F scanner with its corresponding software to process the resulting scanned images.

Accounting of phenological phases and other related observations and records were performed in accordance with the basic recommendations of studies on cruciferous crops (Sayko, 2011) and methodological description guidelines for classifications of rating tables of the variety testing (Test Guide lines for the conduct of tests for distinctness, uniformity and stability of Fodder Radish (*Raphanus sativus* L. *var. Oleiformis* Pers., 2001) using approaches of experimental statistics (Snedekor, 1961) in the format of Multivariate Analysis of Variance (MANOVA) and the package of Statistical Application Programs R (Foundation for Statistical Computing Platform version 3.5.3 (2019-03-11), Statistica 10, Exel 2013, Past 324.

The level of variability of morphological features and grouped indicators was conducted according to Zaytsev's scale (Zaytsev, 1984): very low (CV < 7%); low (CV = 8-12%); average (CV = 13-20%); increased (CV = 21-30%); high (CV = 31-40%); very high (CV > 40%).

Results and Discussion

In our research, the reproductive effort (RE) was divided into two components, namely, the reproductive effort by the mass of inflorescences during the period of full flowering (BBCH 65) and the reproductive effort by mass of pods during two phases, in particular, full green pod phase (BBCH 77-78) and full yellow pod phase (BBCH 81-83). It should be noted that the reproductive tactics of oilseed radish plants has certain characteristics that are to some extent typical for all crucifers. One of these features is the long flowering, which causes simultaneous presence on the plant of flowers, fruiting buds and pods in different stages of development and size starting from BBCH 64 to BBCH 84 (Figure 1). This is caused primarily by the peculiarities of the inflorescence formation due to the elongation of its main axis and the gradual formation of new flowers in the direction from the base of the peduncle to its apex, which is traced both on the main axis of the inflorescence and its lateral branches and inflorescences of lateral shoots. In addition, the specified features of the formation of the spatial structure of the inflorescence cause a long period of fruit formation and seed ripening and a significant difference in the time of pod formation and duration of seed filling depending on its placement in the inflorescence: lower fruit elements have a correspondingly longer formation period, and as a consequence, higher values of morphological development than the fruiting elements of the middle, and especially the upper tiers (Figures 1 and 2).

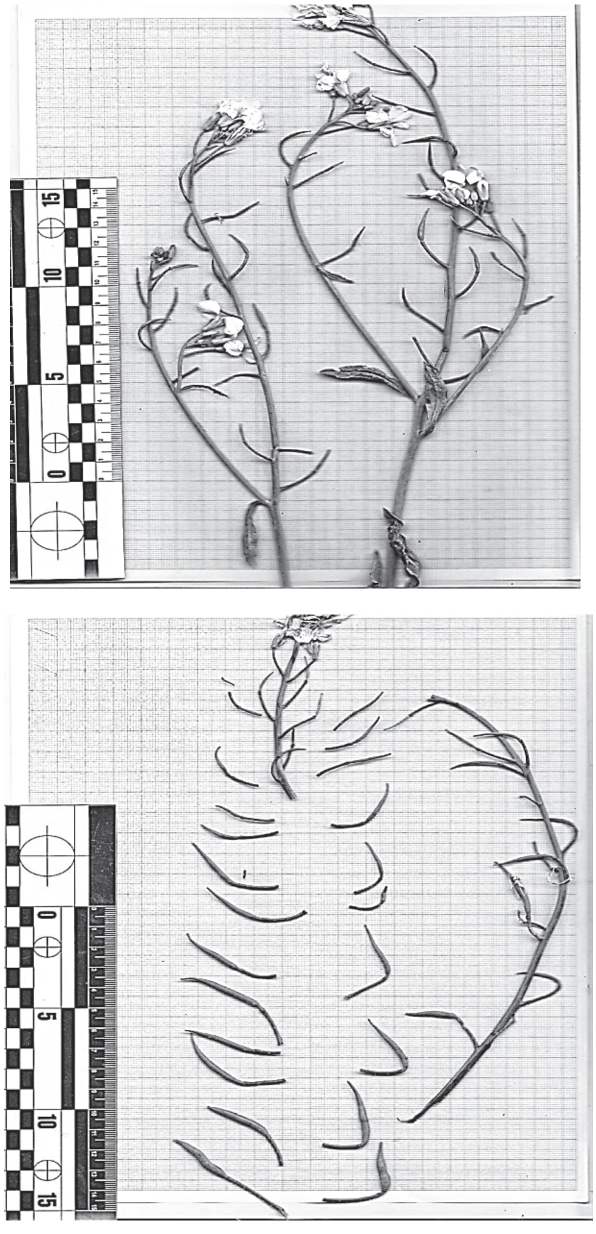

Fig. 1. Layering in the formation of elements of oilseed radish inflorescence in 'Zhuravka' variety with a pronounced gradient from the inflorescence base to its apex in the direction of growth of the peduncle axes, 2018

Fig. 2. Spatial structure of the generative part ofoilseed radish plants (plants in the phase BBCH 69-71 of the variant: on the left – the seeding rate of 0.5 million germinable seeds per ha, wide row planting
$N_{60}P_{60}K_{60kg}$ of a.i./ha, on the right – the seeding rate of 2.0 million germinable seeds per ha, wide row planting, $N_{60}P_{60}K_{60}$ kg of a.i./ha (2017, black square with dimension 2×2 cm)

Due to the above-mentioned arguments, at different stages of flower and fruit formation, the hierarchical structure of oilseed radish inflorescence has corresponding layer features, the nature of which, according to our research, is determined precisely by the features of the crop field coenosis construction. The effectiveness of such processes determines the reproductive effort of plants (Table 3), which in the system of formation of their total productivity determines the potential proportion of seed potential, as well as in relation to yield recording – the rate of abortiveness of both flowers and rudiments of pods in the process of formation of inflorescences and lateral axes. The results of long-term research have shown that the index of reproductive effort by the flower proportion tends to increase both in terms of fertilization variants compared to the control and in terms of increasing the nutrition area of one plant in coenosis combined with the increase in row spacing and decrease in seeding rates. As for the proportion of pods, the value of the indicator under the same features has certain features of formation.

Minimum values of the reproductive effort by the proportion of inflorescence on average over long term studies were set in variants of row planting with the seeding rate of 4.0 million germinable seeds per ha against unfertilized background, and the maximum ones in the case of wide row planting with the seeding rate of 0.5 million germinable seeds per ha in the variant with the maximum mineral nutrition. This confirms the fact that oilseed radish belongs to the plants with a well-pronounced Sukachev's effect in the expression of a general decrease in reproductive architectonics in relation to both general morphology of plants and the mass proportion of inflorescences in the total weight of the whole plant. Thus, a comparison of two polar variants of the technological system of oilseed radish agrophytocenosis construction can be empirically expressed as 1.00 to 2.52-3.37 by the mass proportion of inflorescences. Figure 3 clearly demonstrates this. Mineral fertilizers performing a certain stress-regulating role in some variants of plant density, on the contrary, lead to an overall increase in coenotic tension due to the intensification of the overall plant growth processes and increased competition. This impact results in a gradual decrease in the positive growth of RE by the proportion of inflorescences and general decrease in RE by the proportion of pods in the variants of row planting and the seeding rate of 3-4 million germinable seeds per ha against the background of fertilization with $N_{90}P_{90}K_{90}$kg of a.i per ha. Thus, for the mentioned variants of plant density, the optimal variant of fertilization aimed to provide an effective fruiting element structure of oilseed radish ranges within 30-60 kg of

Table 3. Reproductive effort of 'Zhuravka' oilseed radish variety depending on the planting method, seeding rate and fertilization, % (average for 2013-2018) (under N = 100 plants and n = 25 (in each replication) under 23 degrees of freedom for criterion t_{05} in comparison the average by replications in the product per number of years of study)

Seeding rate (factor C) (mln germinable seeds per ha), planting method (Factor B)	Fertilization (factor D)	Reproductive effect t(RE), by the share of correlation in numerical terms:						For the system of replication–year for BBCH 64-65			
		Inflorescence in the flowering phase (phenophase BBCH 64-65)			Pods in the green pod phase (phenophase BBCH 78-79)			C_{st} control vari-ants	$C_{st (4-2)-1}$	$C_{st (4-3)-2}$	C_{st4-3}
		$\dot{x}$	(±$ts_{\dot{x}}$)	CV	$\dot{x}$	(±$ts_{\dot{x}}$)	CV				
4.0 mln, row	$N_0P_0K_0$	0.051	0.0037	17.01	0.329	0.0257	18.48	1			
	$N_{30}P_{30}K_{30}$	0.055	0.0042	18.05	0.353^{a***}	0.0291	19.54	2	5.76^{a}		
	$N_{60}P_{60}K_{60}$	0.061	0.0049	18.98	0.360^{a}	0.0309	20.33	3	9.03^{a}	6.59^{a}	
	$N_{90}P_{90}K_{90}$	0.066	0.0060	21.63	0.357^{d}	0.0382	25.31	4	7.91^{a}	6.65^{a}	4.27^{a}
3.0 mln, row	$N_0P_0K_0$	0.076	0.0067	20.84	0.399	0.0391	23.19	11.96^{a}			
	$N_{30}P_{30}K_{30}$	0.082	0.0072	20.84	0.421^{a}	0.0421	23.65	10.33^{a}	7.82^{a}		
	$N_{60}P_{60}K_{60}$	0.089	0.0081	21.50	0.431^{b}	0.0442	24.25	9.83^{a}	7.07	3.50^{b}	
	$N_{90}P_{90}K_{90}$	0.097	0.0097	23.51	0.430^{d}	0.0463	25.48	11.21^{a}	10.65	6.62^{a}	4.36^{a}
2.0 mln, row	$N_0P_0K_0$	0.097	0.0109	26.62	0.492	0.0503	24.20	10.56^{a}			
	$N_{30}P_{30}K_{30}$	0.105	0.0120	26.93	0.506^{a}	0.0537	27.13	10.54^{a}	3.30^{b}		
	$N_{60}P_{60}K_{60}$	0.112	0.0130	27.43	0.539^{a}	0.0551	28.20	10.48^{a}	3.54^{b}	1.71^{d}	
	$N_{90}P_{90}K_{90}$	0.119	0.0138	27.47	0.526^{b}	0.0546	28.58	12.19^{a}	5.63^{a}	4.19^{a}	4.49^{a}
1.0 mln, row	$N_0P_0K_0$	0.098	0.0086	20.70	0.412	0.0406	23.32	16.01^{a}			
	$N_{30}P_{30}K_{30}$	0.106	0.0100	22.39	0.446^{a}	0.0457	24.24	14.04^{a}	8.43^{a}		
	$N_{60}P_{60}K_{60}$	0.114	0.0108	22.47	0.481^{a}	0.0472	23.21	14.48^{a}	11.54^{a}	13.44^{a}	
	$N_{90}P_{90}K_{90}$	0.129	0.0127	23.23	0.487^{d}	0.0510	24.76	15.95^{a}	13.13^{a}	15.07^{a}	11.32^{a}
2.0 mln, wide row	$N_0P_0K_0$	0.087	0.0083	22.56	0.415	0.0472	26.88	12.60^{a}			
	$N_{30}P_{30}K_{30}$	0.095	0.0095	23.63	0.444^{a}	0.0518	27.64	11.68^{a}	6.77^{a}		
	$N_{60}P_{60}K_{60}$	0.104	0.0107	24.19	0.475^{a}	0.0563	28.03	11.91^{a}	10.57^{a}	8.51^{a}	
	$N_{90}P_{90}K_{90}$	0.111	0.0121	25.87	0.441^{a}	0.0536	28.73	11.44^{a}	9.88^{a}	8.03^{a}	5.62^{a}
1.5 mln, wide row	$N_0P_0K_0$	0.117	0.0125	25.28	0.457	0.0481	24.93	12.87^{a}			
	$N_{30}P_{30}K_{30}$	0.127	0.0138	25.76	0.484^{a}	0.0552	27.01	12.74^{a}	9.72^{a}		
	$N_{60}P_{60}K_{60}$	0.142	0.0164	27.31	0.510^{a}	0.0617	28.67	12.10^{a}	9.40^{a}	7.41^{a}	
	$N_{90}P_{90}K_{90}$	0.161	0.0191	28.11	0.503^{c}	0.0656	30.85	13.00^{a}	11.70^{a}	11.16^{a}	10.50^{a}
mln, wide row	$N_0P_0K_0$	0.116	0.0138	28.33	0.362	0.0453	29.63	11.08^{a}			
	$N_{30}P_{30}K_{30}$	0.132	0.0164	29.49	0.379^{a}	0.0493	30.78	10.80^{a}	10.52^{a}		
	$N_{60}P_{60}K_{60}$	0.145	0.0184	30.00	0.398^{a}	0.0507	30.14	11.09^{a}	11.83^{a}	9.17^{a}	
	$N_{90}P_{90}K_{90}$	0.166	0.0220	31.40	0.423^{a}	0.0606	33.87	11.30^{a}	11.80^{a}	10.54^{a}	9.87^{a}
0.5 mln, wide row	$N_0P_0K_0$	0.129	0.0182	33.49	0.340	0.0434	30.19	9.64^{a}			
	$N_{30}P_{30}K_{30}$	0.140	0.0213	35.86	0.362^{a}	0.0508	33.24	8.96^{a}	5.74^{a}		
	$N_{60}P_{60}K_{60}$	0.159	0.0257	38.16	0.380^{a}	0.0578	36.03	8.76^{a}	7.41^{a}	7.68^{a}	
	$N_{90}P_{90}K_{90}$	0.172	0.0287	39.39	0.403^{a}	0.0649	38.05	8.95^{a}	8.06^{a}	8.16^{a}	6.98^{a}

Table 3. Continued

LSD_{05} (Factor A – conditions of year) Statistical significance in R (average long-term matrix: RE (flowering phase) F value Pr (> F) (144.9 < 2e-16 ***; C *** T 0.001). RE (green pod phase) 37.89 <2e-16 ***, C***T 0.001)	A – 0.024[a] (share of influence in the indicator formation 35.63 %). B – 0.0014[a] (23.06 %). C – 0.0020[a] (20.41 %). D – 0.0021[a] (8.00 %). AB – 0.0035[a] (5.45 %). AC – 0.0049[a] (3.41 %). AD – 0.0049[a] (1.13 %). BC – 0.0028[a] (0.71 %). BD – 0.0028[a] (0.66 %). CD – 0.0040[a] (0.48 %). ABC – 0.0069[a] (0.38 %). ABD – 0.0069[b] (0.20 %). ACD – 0.0098 (0.20 %). BCD – 0.0056[b] (0.14 %). ABCD – 0.0138 (0.13 %)	A – 0.082[a] (share of influence in the indicator formation 22.98 %). B – 0.0047[a] (3.38 %). C – 0.0067[a] (12.19 %). D – 0.0067[a] (4.92 %). AB – 0.0116[a] (12.27 %). AC – 0.0164[a] (11.14 %). AD – 0.0164 (0.04 %). BC – 0.0095[a] (20.30 %). BD – 0.0095 (0.08 %). CD – 0.0134 (0.27 %). ABC – 0.0232[a] (11.85 %). ABD – 0.0232 (0.04 %). ACD – 0.0327 (0.14 %). BCD – 0.0189 (0.29 %). ABCD – 0.0463 (0.11 %)	Significance levels: a – 0.1%; b – 1%; c – 5%; d – no significant difference; *** – probability of the following variant in relation to the previous one

a.i. per ha. In the variants of wide row planting, a significant increase in the reproductive effort was observed from the gradation of the seeding rate of 1.5 million germinable seeds per ha with a gradual rise of positive increase to the rate of 0.5 million germinable seeds per ha compared to 60 and 90 kg of a.i. per ha of mineral fertilizers from 2.1 to 4.16%.

Peculiarities of cenotic pressure in different variants of cultivation of oilseed radish are confirmed by the value of variation of the index by the coefficient of variation (CV): a steady increase in its value from the minimum valuesof the average degree of variation 17.01-18.48% in the variant of the maximum density against unfertilized background up to high of 38.5-39.9% in the variant with the minimum density and fertilization rate of $N_{90}P_{90}K_{90.}$

Therefore, application of mineral fertilizers enhances intraspecific competition and contributes to the formation of a more complex idiotypic structure of oilseed radish agrophytocenosis, as reported in the previous publication (Tsytsiura, 2018). The intensity of idiotypic plant differentiation and formation of layering enhances with the increase in plant nutrition area and gradual increase in fertilization rates, which is a consequence of the decrease in coenotic stress and simultaneous optimization of growth processes due to increasing mineral nutrition. At the same time, the nature of the effect of fertilizers on the variant component of the plant reproductive development is preserved and enhanced, in accordance with the value of the coefficient of variation in the process of their phenological development. Although the long-term develop-

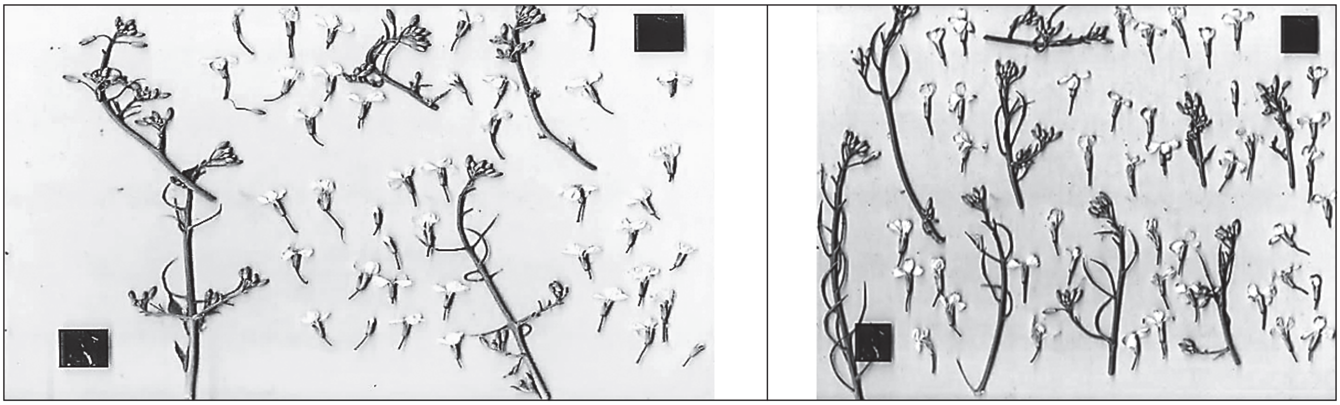

Fig. 3. The nature of reproductive effort of oilseed radish plants by the proportion of flowers on the background of $N_{60}P_{60}K_{60}$ kg of a.i. per ha sequentially from left to right: under the seeding rates of 4.0 million germinable seeds per ha (row planting); 0.5 (wide row planting with predominant intensive formation of flower buds in different parts of the inflorescence branch (black square with dimension of 2×2 cm), 2016

mental cycle has been noted in some variants and decrease in variability during maturation, but these variants are rather an exception and refer to unapproved variants of the experiment. In this regard, it is important to establish an effective relationship between the intensity of growth processes with the evaluation of the uniformity of agrophytocenosis by morphogenesis and the density of plant placement per unit of area. Based on the indicators of reproductive effort in the green pod phase, which demonstrates the approximate biological productivity of agrophytocenosis precisely by the number of fruit elements in the product per plant density (potential biological seed productivity), the variant with 1.5 million germinable seeds per ha is considered to be optimal for oilseed radish under wide row planting and 2.0 million germinable seeds per ha under row planting.

The conclusions made are confirmed by assessment of the influence of systemic factors of the trial by the results of a 4-factor analysis of variance. Thus, the share of conditions of the year in the formation of RE ratio by inflorescences comprises 35.63%, planting method – 23.06%, seeding rate – 20.41%, fertilizers – 8.0%. During oilseed radish plant maturation, RE ratio by proportion of pods has already been largely determined by the interaction of the main factors, such as the planting method and seeding rate, conditions of the year and plant density, and to a lesser extent year conditions of the year. Thus, the probability of the technological component of the construction of oilseed radish agrophytocenosis tends to increase during plant maturation.

To conduct an in-depth study of Sukachov's effect and determine the optimal variant that provides amaximum combination of plant density and productive architectonics in our studies, we have used the integral index, i.e. the index of vitality applying it to morpho-indicators of the generative parts of plants. The summary module for quantitative and morphometric features of fruits and seeds includes reproductive effort by pods (number fraction), total number of pods per plant (pc), number of seeds per pod (pc), seed weight per plant (g), average seed weight (mg), average pod length (cm), average pod diameter (mm), pod wall thickness in the middle zone (mm), total number of inflorescence twigs(branchiness) (pc). The results of IVC calculation for the period studied are presented in Table 4.

According to the data given above, the index of vitality in the presented scheme of experience tends to increase from the most dense agrophytocenosis on the unfertilized background (4 million germinable seeds per ha) to the least dense on the background of $N_{90}P_{90}K_{90}$. The average data system itself shows statistically significant results by both the findings of the dispersion

Table 4. Indexes of vitality by morphological characteristics of the reproductive part of oilseed radish plants of 'Zhuravka' variety under different variants of agrophytocenosis formation in the phase of yellow pods (BBCH 79) on the average for 2013 - 2018 (for N characteristic groups = 9 at n = 25 (in each replication)

Seedingrate (mln germinable seeds peer ha), planting method (rowspacing – factor B, seeding rate – factor C)	Fertilization (factor D)	Conditions of the year – factor A						C_{st} control variants	$C_{st\ (4-2)-1}$	$C_{st\ (4-3)-2}$	$C_{st\ 4-3}$
		2013	2014	2015	2016	2017	2018				
4.0 mln row	Without fertilizers[1]	0.749	0.622	0.408	0.522	0.502	0.413	1			
	$N_{30}P_{30}K_{30}$[2]	0.793	0.672	0.407	0.571	0.534	0.433	2	3.97c		
	$N_{60}P_{60}K_{60}$[3]	0.794	0.678	0.422	0.580	0.544	0.439	3	5.72b	4.08b	
	$N_{90}P_{90}K_{90}$[4]	0.685	0.542	0.344	0.486	0.432	0.370	4	-8.72a	-8.47a	-9.96a
3.0 mln row	Without fertilizers	0.800	0.746	0.473	0.653	0.614	0.502	7.17[1]b			
	$N_{30}P_{30}K_{30}$	0.945	0.863	0.546	0.741	0.727	0.586	18.36[2]a	9.51a		
	$N_{60}P_{60}K_{60}$	1.053	0.973	0.583	0.822	0.820	0.641	11.78[3]a	8.28a	6.72b	
	$N_{90}P_{90}K_{90}$	1.013	0.954	0.551	0.800	0.768	0.586	9.48[4]a	6.22b	2.99c	-5.97b
2.0 mln row	Without fertilizers	0.825	0.774	0.509	0.667	0.716	0.541	7.00[1]b			
	$N_{30}P_{30}K_{30}$	0.952	0.898	0.607	0.798	0.821	0.652	12.90[2]a	21.42a		
	$N_{60}P_{60}K_{60}$	1.081	1.003	0.695	0.901	0.912	0.738	22.65[2]a	19.34a	15.27a	
	$N_{90}P_{90}K_{90}$	1.062	0.953	0.692	0.882	0.887	0.727	24.35[3]a	18.84a	10.29a	-3.23b
1.0 miln row	Without fertilizers	0.928	0.878	0.520	0.726	0.814	0.565	6.86[1]b			
	$N_{30}P_{30}K_{30}$	1.140	1.050	0.684	0.945	0.954	0.750	17.14[2]a	14.92a		
	$N_{60}P_{60}K_{60}$	1.249	1.191	0.767	1.034	1.117	0.842	13.98[3]a	25.99a	8.56a	
	$N_{90}P_{90}K_{90}$	1.255	1.332	0.802	1.105	1.126	0.870	12.00[4]a	13.29a	6.18b	2.32d

Table 4. Continued

2.0 mln wide row	Without fertilizers	0.879	0.804	0.573	0.701	0.695	0.622	15.97[1]a			
	$N_{30}P_{30}K_{30}$	1.044	0.977	0.658	0.894	0.843	0.707	22.45[2]a	7.52a		
	$N_{60}P_{60}K_{60}$	1.070	1.030	0.710	0.927	0.909	0.763	21.96[3]a	11.32a	7.74a	
	$N_{90}P_{90}K_{90}$	1.076	1.061	0.723	0.949	0.926	0.769	18.26[3]a	10.39a	8.04a	4.00c
1.5 mln wide row	Without fertilizers	0.969	0.971	0.703	0.898	0.819	0.739	14.32[4]a			
	$N_{30}P_{30}K_{30}$	1.172	1.131	0.825	1.048	1.112	0.877	16.66[1]a	6.93a		
	$N_{60}P_{60}K_{60}$	1.341	1.329	0.950	1.197	1.368	1.021	14.25[2]a	7.99a	8.96a	
	$N_{90}P_{90}K_{90}$	1.354	1.385	0.949	1.235	1.393	1.042	13.94[3]a	8.12a	8.36a	3.13c
1.0 mln wide row	Without fertilizers	1.044	1.005	0.739	0.906	0.840	0.794	23.53[4]a			
	$N_{30}P_{30}K_{30}$	1.222	1.130	0.868	1.133	1.016	0.922	25.97[2]a	9.66a		
	$N_{60}P_{60}K_{60}$	1.362	1.297	0.996	1.269	1.133	1.058	33.56[3]a	18.81a	20.17a	
	$N_{90}P_{90}K_{90}$	1.404	1.355	1.016	1.306	1.169	1.090	31.45[4]a	18.37a	15.50a	7.36a
0.5 mln wide row	Without fertilizers	1.223	1.169	0.876	1.173	1.049	0.941	19.79[1]a			
	$N_{30}P_{30}K_{30}$	1.308	1.350	1.095	1.434	1.248	1.176	15.22[2]a	7.85a		
	$N_{60}P_{60}K_{60}$	1.547	1.591	1.226	1.614	1.508	1.392	20.95[3]a	17.58a	10.80a	
	$N_{90}P_{90}K_{90}$	1.577	1.638	1.243	1.660	1.553	1.427	21.57[4]a	16.47a	10.81a	7.61a
LSD_{05} of the resulting IVC Statistical significance in R (average long-term matrix: F value Pr(>F) (655.6 <2^{d}-16 ***; C***T 0.001).	$F_Ф > F_{т\ 0.05}$ and $F_{т\ 0.01}$ for all factors and their interaction A – 0.025 (share of influence in the indicator formation 20.19 %). B – 0.0015 (31.70 %). C – 0.0021 (29.35 %). D – 0.0021 (12.16 %). AB – 0.0036 (0.37 %). AC – 0.0050 (0.56 %). AD – 0.0050 (0.23 %). BC – 0.0029 (0.47 %). BD – 0.0029 (1.40 %). CD – 0.0041 (2.29 %). ABC – 0.0071 (0.61 %). ABD – 0.0071 (0.08 %). ACD – 0.0101 (0.26 %). BCD – 0.0058 (0.19 %). ABCD – 0.0142 (0.13 %)							Level of significance: a – 0.1 %; b –1 %; c – 5 %;			

system on the average annual platform and the results of the conventional scheme of dispersion multifactor analysis. Under the studied combination of the seeding rate and planting method, the highest cenotic pressure was observed under the row planting with a seeding rate of 4.0 mln germinable seeds per ha on the background of nutrition with $N_{90}P_{90}K_{90}$ that is based on the lowest levels of the vitality index compared to other variants. Based on IVC specificity in oilseed radish agrophytocenosis, the vitality tactics of oilseed plants by the variation of plant morphological parameters and layer differentiation in both vertical and horizontal directions will grow with the increase of plant density and reduction of row spacing. At the same time, due to the increase of phenotypic pressure in the norm of response of agrophytocenosis components, the proportion of plants of the average level of ideotypic response increases, and the general plant architectonics tends to decrease by all morphological parameters that are decisive in the seed productivity formation. Mineral fertilizers weaken the biological pressure between plants in coenosis.

However, the nature of this effect, according to our estimations, will only be positive up to a certain value of the gradation of nutrition doses. Under an adequate level of density, attritional nutrition with over 60 kg of a.i. per ha for oilseed radish increases competition in agrophytocenosis both through more intensive differentiation of the stem stand into different layers and stimulation of the most competitive plants, and by the general improvement of the growth processes of all components without exclusion, including the segetal one. Thus, in the case of the general growth of phytomass per unit of area, additional nutrition only enhances the process of interspecific antagonism and provides a clear stratification in the vertical profile of the sowing into substantially different plant idiotypes, as evidenced by the decrease in IVC against the background of fertilization with $N_{90}P_{90}K_{90}$ in the variants of 4.0 million germinable seeds per ha. According to our estimates, the index of vitality is determined not only by the technological factors of the trial variants, but also by the conditions of oilseed radish vegetation. Comparison of Tables 2, 3 and 4 shows that in the most stressful year of 2015 the average value of IVC was 33.7% lower than the one in the conditions of 2013 that was wet. The role of hydrothermal conditions is also confirmed by the results of the analysis of dispersion analysis where the share of the year conditions in the formation of the indicator individually and in the interaction is 22.43%. Factor analysis within the framework of dispersion analysis also confirmed the findings on different effects of fertilizers in the range of 60-90 kg of active ingredient per ha under the share of impact in the indicator formation at the level of 12.16%, which is significantly lower than the factor of planting method (31.70%) and seeding rate (29.35%).

On the other hand, it should be noted that evaluation of the comparison of group averages of the experiment using Tukey's test (Zar, 1984) in the variants without fertilization and under application of 90 kg of a.i. per ha (Figure 4) has showed that in three variants with non-fertilized backgrounds of the experiment and in two variants with maximum fertilization the confidence intervals include a zero value, which indicates that there is no difference in the data on the groups compared. In most cases, these variants range with 1.5-2.0 million germinble seeds on both unfertilized and fertilized backgrounds with row spacing of 30 and 15 cm.

Considering peculiarities of the analysis of relationships by Tukey's test (Zar, 1984), the specified interval is the most expe-

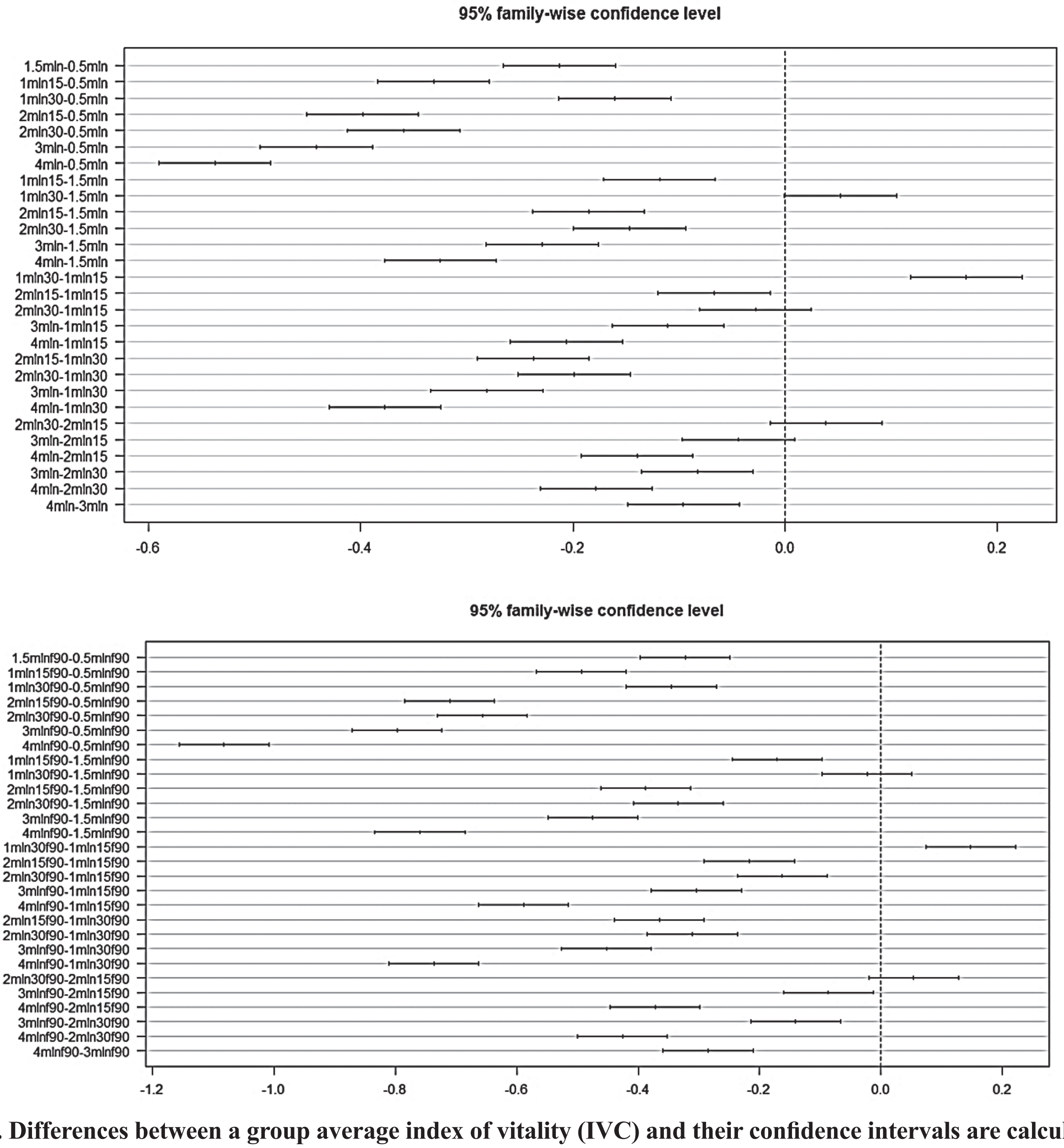

Fig. 4. Differences between a group average index of vitality (IVC) and their confidence intervals are calculated taking into account 95% family-wise confidence level control (top position – variants without fertilization, bottom position – variants with applying fertilizers $N_{90}P_{90}K_{90}$). Indexing in the notes 2 mln 30 – variant with a seeding rate of 2 million germinable seeds per ha with a row spacing of 30 cm; 2 mln 3 of 90 – all the same under application of $N_{90}P_{90}K_{90}$.

dient in the technological regulation of construction of oilseed radish agrophytocenoses for high indexes of reproductive architectonics.

The same conclusions are clearly confirmed by the results of the regression analysis in the comparison of the factors studied in the form of regression projection IVC (Figure 5).

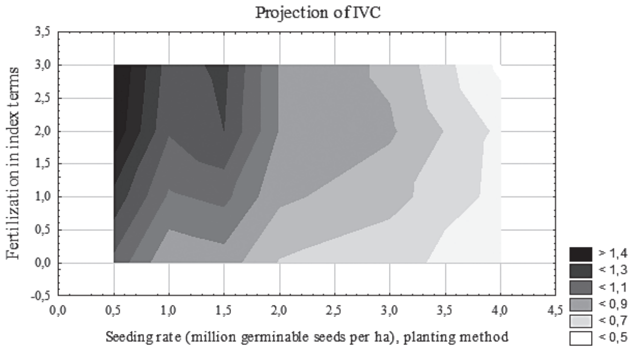

Fig. 5. Graphs of projections of the vitality index dependence on the seeding rate (combined with the planting method) and fertilization in index terms (average for 2013-2018) (For components of the multiple regression equation: free term 1.159, beta 1 (for the seeding rate and planting method) -0.821, beta 2 (for fertilization in index terms) -0.371, total: R2 = 0.811, F = 62.33, cc = 2.29, p = 0.0000)

The presented visualization of the regression projection of vitality index in a complex of the factors studied has testified by the dimension of the projection axes that optimal combination of the biological rate of productivity (as the product of the individual plant productivity and density of cenosis) is achieved generally in the range of 1.5-1.7 million germinable seeds and fertilization within 45-75 kg/ha of the NPK active ingredient that provides IVC in the range of 1.100-1.300. A complex configuration of the projection curves in the range of seeding rates within 2.5-4.0 million germinable seeds, which to a small extent is determined by increasing rates of fertilizers with a subsequent steady decrease in the index of vitality from 0.900 to 0.500, indicates the extensiveness of such technological parameters in the constructing highly productive oilseed radish agrophytocnosis.

Under similar conditions, a positive effect on the growth of the total IVC due to the index increase in the rates of mineral fertilizers (the index expression implies a ratio of unfertilized background: зо kg of active ingredient per ha corresponds to 1.0, 60 kg/ha – 2.0 and 30 kg/ha – 3.0, respectively) up to 90 kg/ha of the active ingredient is expedient under wide planting in the interval of seeding rate of 0.5-0.8 mln germinable seeds per ha, which provides a vitality index of 1.300-1.400.

Conclusion

According to these results, factors of reproductive effort (RE) and index of vitality (IVC) can be effectively used to evaluate the effectiveness of the oilseed radish agrophytocenosis construction from the stand point of the integrated approach in generalizing the morphological development of the reproductive part of plants. According to our estimations, considering the combined use of oilseed radish to produce leaf-and-stem mass and seeds, the index of vitality can be considered from two positions, i.e. vegetative one and reproductive. Their ratio starting from the flowering phase will be a successful indicator of the agrophytocenosis targets and selection of the relevant parameters of its pre- planting formation. Consideration of the vitality tactics of oilseed radish based on multiprofile IVCs from the beginning of flowering phase to the later stages of pod maturity is to be the subject of our further research and the theme of our subsequent publications.

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