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RESEARCH

Assessment of peculiarities of weed formation in oilseed radish agrophytocoenosis using different technological models

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ABSTRACT

There is limited information about the critical period for weed control (CPWC) in oilseed radish (*Raphanus sativus* L. var. *oleiformis* Pers.) This significantly limits the effectiveness of the applied technologies in its cultivation. The article focuses on the results of a long-term study (2013 to 2018) of the peculiarities of weed formation in oilseed radish agrophytocoenosis using different sowing technological models according to seeding rate and row spacing parameters. The study included the peculiarities of the species and generic composition of weeds and the basic attributes of the formation of species-specific amounts. The summed dominance ratio (SDR) was heterogeneous and co-oscillatory in the weed structure for both the formation of the number of individual species and their height dominance, which depended on the phenological stage of growth and crop development. In the general spectrum, the prevailing weed forms were identified with the highest potential for oilseed radish plants with an SDR greater than 1.0, which belong to groups I and VI according to environmental plasticity and stability, given the different conditions of the study period for both hydrothermal conditions and year index. In conclusion, a critical period for weed control (CPWC) in oilseed radish agrocoenosis was defined as a 5% reduction in crops ranging from 5 to 45 d after sprouting (DAS) for row sowing and a seeding rate of 4.0 million similar seeds ha^{-1} and 6 to 60 DAS for a variant of wide row sowing at a seeding rate of 0.5 million similar seeds ha^{-1}.

Key words: Critical weed control period, oilseed radish, oilseed radish-weed competition, weed control, weeds.

INTRODUCTION

Oilseed radish (*Raphanus sativus* L. var. *oleiformis* Pers.) is a well-known crop in Europe, USA, and Canada. It is multifaceted and used as green mass, silage, hay, green manure, grass meal, phytoremediation, intermediate crop (with high nematode resistance), and biofuel production (Lehrsch and Gallian, 2010; Mazzoncini et al., 2011; Oliveira et al., 2011; Ávila and Sodré, 2012; Ratanapariyanuch et al., 2013; Vleugels et al., 2014; Teklu et al., 2014; Brust et al., 2014; Tsytsiura and Tsytsiura, 2015; Kunz et al., 2016).

On the one hand, regardless of the above-mentioned trait of this crop to suppress weeds (Brust et al., 2014; Kunz et al., 2016), the problem of effective weed control in its agrophytocoenosis is the relevant problem of exploiting possible technological options for growing in wide rows, especially for seed production, rapid growth and ripening, a tendency for lodging in the final vegetation stage, and starting at the fruiting stage. All these factors in growth peculiarities and crop development require an intensive decrease in the competitiveness of oilseed radish plants in the second vegetative stage of this radish (Tsytsiura and Tsytsiura, 2015).

On the other hand, despite the technological level of basic crop cultivation, weeds remain a significant and complex problem that restrict the effective realization of the genetic potential of varieties and hybrids of agricultural crops (Yaduraju and Mishra, 2018). However, weeds are an integrated component of the overall functional life of any agrophytocoenosis, and they cannot be considered separately from the resulting total bioproductivity (Shaner and Beckie, 2014). Weeds at different densities and species composition can reduce crop yields between 5% and 80% (Singh et al., 2018; Yaduraju and Mishra, 2018). There is also a risk of weeds spreading and growing due to climate change and emergence of weed resistance to a number of herbicides (Jugulam et al., 2019). Weed control is therefore a complex aspect responsible in the overall technological management of crop growth. A common tactic for weed control and a number of control measures have been developed over a fairly long period of scientific research, which are based on establishing a crop-specific critical period for weed control (CPWC) (Knezevic and Datta, 2015; Swanton et al., 2015; Andrew et al., 2015; Santosh et al., 2018; Merino et al., 2019). This indicator has now been identified and analyzed for many crops (Tursun et al., 2016; Vaishali et al., 2018), including relatives (Brassicaceae) of oilseed radish crops such as radish, spring rapeseed, winter rapeseed, and mustard (Lemerle et al., 2010; Harris et al., 2015). The indicated conceptually methodological approach allows us to specifically exclude those periods in which the crop is the least competitive in relation to weeds from the general growth and development stages of the crop. According to scientific publications, this indicator has not been described for oilseed radish.

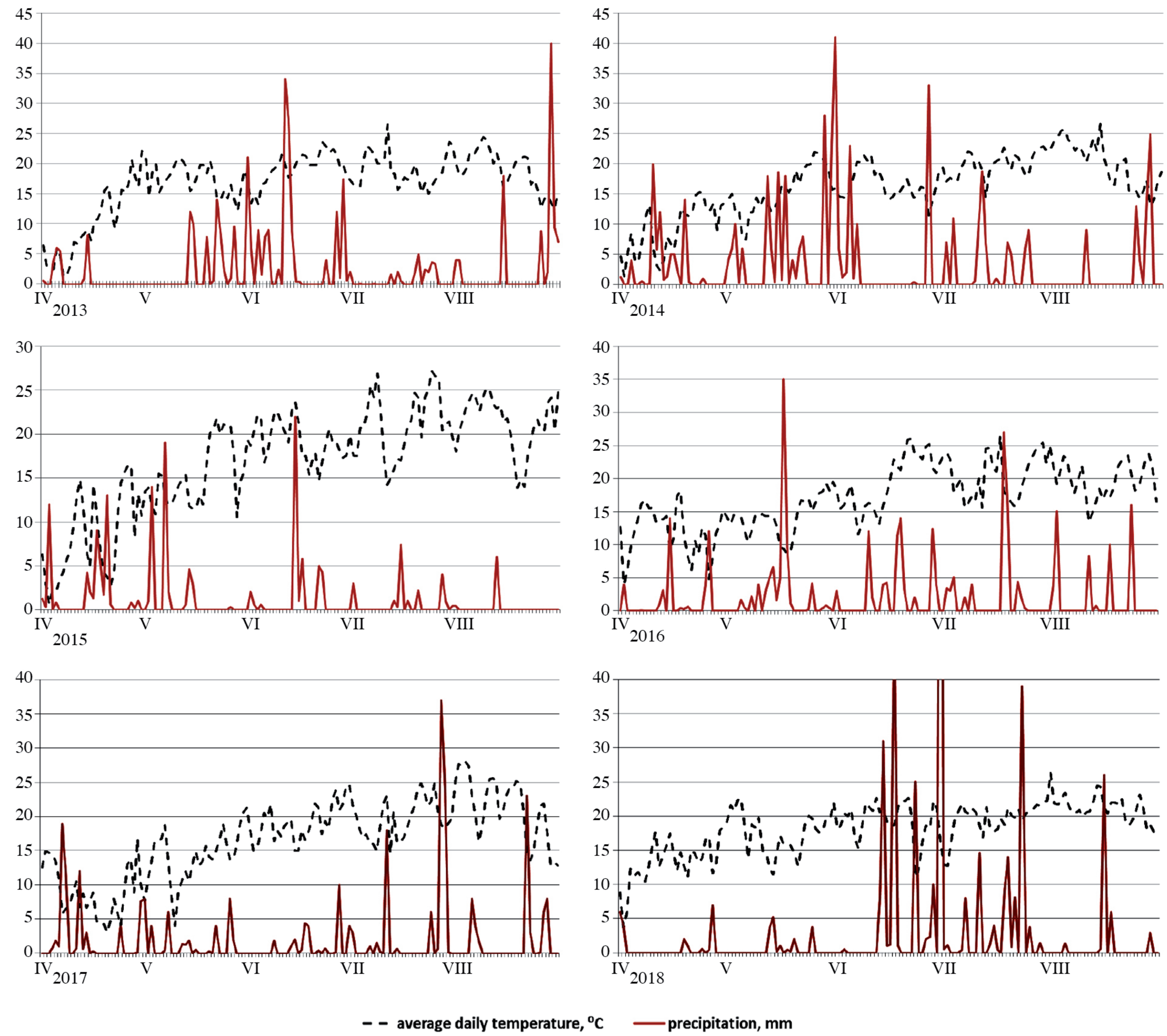
Many scientific publications on this problem highlight that the establishment of a critical weed period allows effective planning and implementation of an integrated weed protection system based on the determination of identified crop losses and establishment of phases and interphase vegetative stages with the lowest levels of competition in relation to growing in grain field vegetation (Rana and Rana, 2016). The critical period indicator also allows effective herbicide control for both the appropriateness of using chemical protection and the justification for these measures considering harvest costs (Knezevic and Datta, 2015).

An important factor in successful weed control in crop coenosis is the competitiveness of a particular crop in relation to weeds in view of the basic technological solutions for the agrophytocoenosis models, such as its density (stocking density and row width). Both factors have been found to influence the intensity of growth processes of both crop and weed plants, causing different intensity levels of quantitative and weighted competition between them (Bajwa et al., 2017; Zimdahl, 2018). It should be noted that the critical period of crop-weed competition (CPCWC) has two aspects. First, a crop has to be kept weed free after planting and for the duration of the crop so that emerging weeds do not reduce grain harvest. Second, the time that emerging weeds in the crop can remain before they begin to interfere with crop growth and reduce yield (Rana and Kumar, 2014). Given the importance of developing efficient technologies and weed control strategies, the aim of tackling the basic aspects of this problem is precisely for oilseed agrophytocoenoses of different technological models for which this indicator does not currently seem to be an urgent task. Methodologically, the important task is to combine both classical approaches to establish the CPCWC and new approaches, which are based on using complete physiological indicators of weeds and their vitality strategy in oilseed radish agrocoenosis for stratification and rank plasticity and stability for weed abundance (Ab). This comprehensive approach has all the hallmarks of scientific novelty and could significantly expand the knowledge of the CPCWC. The objective of the present study was to assess the peculiarities of weed formation in the oilseed radish agrophytocoenosis using different sowing technological models according to seeding rate and row spacing parameters.

MATERIALS AND METHODS

The study was conducted in the Vinnytsia National Agrarian University research field that has dark gray forest soils (Luvic Greyic Phaeozem, World Reference Base for Soil Resources [WRB] classification). The agrochemical potential of the field corresponded to the general characteristics of this type of soil according to the main agrochemical indicators; it included 2.02% to 3.2% humus content, easily hydrolyzed N 67-92 mg kg^{-1}, mobile P 149-220 mg kg^{-1}, and exchange P 92-126 mg kg^{-1} soil at pH 5.5 to 6.0. The study of weed formation in the 'Zhuravka' oilseed radish (*Raphanus sativus* L. var. *oleiformis* Pers.) agrophytocoenosis was conducted on two radically distant technological model variants at the seeding rate of 4.0 million similar seeds ha^{-1} in ordinary row sowing (15 cm) and 0.5 million similar seeds ha^{-1} in wide row sowing (30 cm). Both variants were conducted on an unfertilized background. The estimated plot area was 20 m^2. It was replicated four times. The sowing period for both variants corresponded to 8 to 12 April. The hydrothermal parameters of the oilseed radish vegetative stage varied, having formed certain typological traits of the years under study (Figure 1). The conditions in 2013, and especially in 2014, were the most optimal for the growth processes of oilseed radish due to the combination of a slow increase in average daily temperatures and equal precipitation from the end of May to mid-June; in the study area, this phenologically corresponds to active vegetation, and scarce vegetation coincides with the interphase of the phenological stem-flowering stage (BBCH 30-65). The conditions of the equal rainfall ratio for 2015 and 2018 and the type of average daily temperature curve can be considered stressful for the physiological and growth processes of oilseed radish plants. For example, the precipitation distribution in 2015 was uneven and there was no precipitation from the second decennial of May to the second decennial of June due to the intense and rapid increase of average daily temperatures during that period. This created a double effect on the overall stress of the environmental factor at the start of the budding-flowering interphase (BBCH 38-64) of oilseed radish plants; this made it possible to effectively evaluate the studied indicators in the environmental trait system. A prolonged atmospheric and soil drought with slight humidity until the second decennial of June was observed for 2018 against the background of low average daily temperatures, which, unlike conditions in 2015, affected the magnitude of the architecture of oil radish plants from the rosette formation and further stalking stage (BBCH 19-38). It is for these reasons that 2018, which was stressful, was the most illustrative in the assessment of stress. According to hydrothermal parameters, 2016 and 2017 can be qualified as intermediate in the 6-yr study cycle with a similar dynamic regime of average daily temperatures and

Figure 1. Hydrothermal conditions from April to August (2013 to 2018) in the consecutive order from left to right and from top to bottom in 2013, 2014, 2015, 2016, 2017, and 2018.



IV, V, VI, VII, VIII: Months of the growing season in order, Apr, May, June, July, and Aug, respectively.

uneven atmospheric humidity. Conditions in 2016 were similar to 2013 and 2014, while 2017 was similar to 2015. Thus, the increase in the overall favorable hydrothermal regimes of oilseed radish in the trend of reducing weather risks can be placed in the following order: 2018-2015-2017-2016-2013-2014.

The critical period of weediness after sowing was determined by widely used methodological approaches (Knezevic and Datta, 2015). From the total area of the given technological variant, the subplots (4 m^2 each) for recording were repeated four times. In turn, the number of subplots was divided into two treatments. The first involved the growth of weed-free radish (complete removal) sequentially for a period of 15 to 90 d after sprouting (DAS). The second treatment kept the sites in weed abundance at the same interval of 15 to 90 DAS. Moreover, each subplot was plowed until a certain reporting time (15, 30, etc. DAS) after which it was maintained weed-free until harvesting. This scheme is typical for the study of the critical period for weed control (CPWC) on cross-flowering crops. Afterward, crops and each subplot were harvested, and the results for each plot were compared with the yield of a completely weed-free plot. Observations were focused on the following aspects: the weed-free period, the harvest with a significant increase, and the treatment of weed conditions up to a particular period.

A detailed system of the peculiarities of weed formation of the oilseed radish agrophytocoenosis was established in various technological methods of the model in the green pod phase (BBCH 75-79), on the unfertilized background or any anti-weed measures, implementing widely used methodical approaches for recording weeds (Rana and Kumar, 2014; Tsytsiura, 2019), and defining the following generally accepted indicators:

Density (D) = Total number of individuals of a species in all subplots (TNIS)/Total number of studied subplots (TNSS). The TNSS was 50 for all variants.

Frequency (F) = (Total occurrence of individuals (TOI)/TNSS) × 100.

Abundance (Ab) = TNIS/TOI.

Relative density (RD) = (TNIS)/Number of individuals of all species (NIS)) × 100.

Relative frequency (RF) = (TOI/Total sum of TOI for all weed species in the experiment) × 100.

Relative abundance (RAb) = (Ab/Total sum of abundance of all species in all subplots) × 100.

Importance value index (IVI) = RD + RF+ RAb

Summed dominance ratio (SDR) = IVI/3.

The frequency classes of weed species were determined. There were five weed frequency classes: Class A with species frequency ranging from 1% to 20%, class B 21% to 40%, class C 41% to 60%, class D 61% to 80%, and class E 81% to 100%. Furthermore, weed community frequency patterns were compared with the normal frequency pattern of $A > B > C \geq D < E$. Based on the community frequency pattern, we determined the homogeneity and heterogeneity of the vegetation. If the values were high, that is, belonging to B, C, and D, then the community was considered heterogeneous, and higher values (E) indicated homogeneity.

The layer of weed formation was determined using the tier criterion: $K = (H)\ 1/2$, where K is the average quantitative value of weeds at sowing and the interval of weed height relative to the height of cultivated plants is H. Several layers are detected according to the specified criteria: ground layer (GL) (K = 0.2, H = 0.0-0.1), lower layer (LL) (K = 0.5, H = 0.1-0.5), middle layer (ML) (K = 0.9, H = 0.5-1.0), and upper layer (UL) (K = 1.2, H = 1.0-2.0). Non-tiered plants were attributed to coils and saline weeds, although they were assigned corresponding values by their height development type. Based on the stratification indicators, a generalized estimate of crop weeds (GEW) was calculated as $GEW = K\ D$, where D is an indicator of density. The weed species composition was determined according to the Ukrainian classification of determinants. Latin weed names were refined according to European naming rules (Hatcher and Froud, 2017). Weed classification was conducted according to generally accepted criteria for their life expectancy, developmental cycle, breeding trait, spreading, and type (Rana and Kumar, 2014). The present study was also based on indicators of environmental plasticity (b_i) and environmental stability (Si^2) in relation to abundance (Ab) according to the basic approaches of their calculation (Eberhart and Russel, 1966). Oilseed radish yields were calculated by a standardized methodology for the cruciferous crop group (Saiko, 2011) by experimental statistical approaches (Sokal and Rohlf, 2012) as multivariate analysis of variance (MANOVA), and with the statistical application program package R version 3.5.3 (Foundation for Statistical Computing, Vienna, Austria), Statistica, Exel, and CurveExpert Pro 2.6.5.

The level of variation of indicators was performed according to the coefficient of variation (CV): very low (CV < 7%), low (CV = 8% to 12%), average (CV = 13% to 20%), increased (CV = 21% to 30%), high (CV = 31% to 40%), and very high (CV > 40%).

RESULTS AND DISCUSSION

The peculiarities of weed formation of any coenosis should be considered together with the growth and development characteristics of the main crop (Andrew et al., 2015). The oilseed radish has many characteristics in its vegetative development, including the slow growth rate from the cotyledon phase to the rosette phase (BBCH 8-15), intense reduction of stemming in the full phase of the green pod (BBCH 71-80), cessation of any growth processes at the phenological stage of the yellow-green pod (BBCH 75-85), tendency of stem lodging of the coenosis at the main fruiting stages (BBCH 76-85). These characteristics of the growth processes of oilseed plants cause a high threat level due to the weed growth in the early vegetative stages and intensive weed growth with a thin stalk and a change in the dominance of the general vegetation in the upper layer. In addition, the extended flowering stage, which is combined with a long pod formation and seed ripening phase against the background of the medium sowing rate, leads to increased dominance of weed plants in the microstage period of the complete yellow and brown ripening of the pod (BBCH 75-89). Accordingly, the oilseed radish coenosis (due to the abovementioned traits) is characterized by oscillation in the vertical dominance of certain biological weed groups. The total number of weed species at maximum occurrence, calculated for different research years, was 48 and belonged to genera 47 (Table 1).

Among the species, the most common families are *Asteraceae*, *Brassicaceae,* and *Poaceae* for 50.0% of the overall structure of the ratio. A complex layer structure of weed formation of the oilseed radish agrophytocoenosis in the context of its main phenological phases was also specified during the long-term evaluations (Table 2). Before the phenological phase at the beginning of stalking (BBCH 36-52), the lower layer of the oilseed radish agrocoenosis was occupied by weeds such as *Elytrigia repens* (L.) Desv. ex Nevski, *Equisetum arvense* L., *Taraxacum officinale* F.H. Wigg., *Polygonum scabrum* Moench, *Setaria glauca* (L.) P. Beauv., *Setaria viridis* (L.) P. Beauv., *Lamium purpureum* L., *Thlaspi arvense* L., *Capsella bursa-pastoris* (L.) Medik., and *Stellaria media* (L.) Vill. The following weeds have the same height as oilseed radish plants: *Brassica campestris* L., *Raphanus raphanistrum* L., *Sinapis arvensis* L., *Chenopodium album* L., *Amaranthus retroflexus* L., *Echinochloa crus-galli* (L.) Beauv., *Galium aparine* L., *Barbarea vulgaris* W.T. Aiton, and *Convolvulus arvensis* L. The leading role in the coenosis, for the height gradient, belongs to weeds such as *Sonchus arvensis* L., *Cirsium arvense* (L.) Scop., *Lactuca tatarica* (L.) C.A. Mey., *Artemisia absinthium* L., and *A. vulgaris* L. During the ripening of oilseed radish plants, the type of height dominance changes in favor of weeds that previously occupied the middle and higher layers compared with the height of the oilseed radish plants.

Such characteristics of the growth processes define differences in competitiveness levels of oilseed radish plants and determine the critical susceptibility period to weeds in the germination-stalking interphase (microstages BBCH 10-36). The weed type of the oilseed radish agrocoenosis oscillated from dicotyledonous-cereal-non-perennial in the germinate-rosette interphase to the root-germinating-rhizome-non-perennial in the green-yellow ripeness interphase of the pods (BBCH 70-84). According to the kind of agrocoenosis of weed type formation and the magnitude of the frequency index, individual species can be differentiated, and this concurs with the results of individual studies (Afifi and Swanton, 2012; Harris et al., 2015; Zimdahl, 2018). Limited oilseed radish in a system of intensive planting density in a stand can be attributed to crops with high competitive potential compared with the main weed species.

Table 1. Specific generic weed spectrum in the oil radish 'Zhuravka' agrocoenoses in the system of averaged indicators of technological variants to model a coenosis in the green pod phase (BBCH 71-77) (mean for 2013 to 2018).

Family	Maximum number of species counted	Structure	Maximum number of genera reported	Structure
	Nr	%	Nr	%
Asteraceae	9	18.75	7	14.89
Brassicaceae	7	14.58	8	17.02
Poaceae	7	14.58	6	12.77
Boraginaceae	5	10.42	5	10.64
Caryophyllaceae	5	10.42	4	8.51
Fabaceae	4	8.33	6	12.77
Chenopodiaceae	5	10.42	5	10.64
Euphorbiaceae	3	6.25	3	6.38
Lamiaceae	3	6.25	3	6.38
Total	48	100.00	47	100.00

Table 2. Typology of weed dynamics of the oilseed radish agrophytocoenosis in the context of the main interphase periods of two technological variants models (mean for 2013 to 2018).

The interphase period	Types of weed growth	Main representatives of weeds within each layer and frequency (F, %) of their determination
BBCH 10-19 (germination-rosette)	Non-perennial (dicotyledonous-cereal-annual)	**GL:** *Capsella bursa-pastoris* 8.5* (10.7%**); *Stellaria media* 2.4 (4.2%); *Thlaspi arvense* 7.5* (9.3%**); *Veronica hederifolia* 2.2 (1.3%); *Poa annua* 0.9 (1.3%). **LL:** *Galium aparine* 1.3 (1.9%); *Taraxacum officinale* 1.8 (2.4%); *Equisetum arvense* 2.4 (6.7%); *Elytrigia repens* 7.5 (24.7%); *Sonchus arvensis* 8.4 (14.2%); *Convolvulus arvensis* 12.4 (20.3%); *Brassica campestris* 1.5 (6.9%); *Raphanus raphanistrum* 5.5 (6.7%); *Sinapis arvensis* 2.8 (3.3%); *Carduus acanthoides* 0.5 (0.8%). **ML:** *Barbarea vulgaris* 5.5 (12.8%); *Lactuca tatarica* 10.8 (16.4%); *Cirsium arvense* 11.8 (21.3%).
BBCH 20-39 (rosette–stalking)	Non-perennial-root-sprout-rhizome	**GL:** *S. media* 8.7 (6.5%); *V. hederifolia* 6.8 (3.1%); *Anagallis arvensis* 6.3 (3.9%). **LL:** *C. bursa-pastoris* 10.8 (12.7%); *T. arvense* 9.9 (11.8%); *Artemisia absinthium* 1.2 (2.2%); *Artemisia vulgaris* 0.6 (1.3%); *Chenopodium album* 18.5 (27.3%); *Polygonum scabrum* 7.8 (12.6%); *Amaranthus retroflexus* 22.5 (30.3%); *Echinochloa crus-galli* 33.8 (40.2%); *Setaria glauca* 37.9 (47.2%); *Setaria viridis* 2.8 (3.5%); *Tripleurospermum inodorum* 6.8 (10.1%). **ML:** *Galium aparine* 2.2 (3.4%); *B. vulgaris* 9.3 (15.7%); *E. repens* 9.8 (30.6%); *Sonchus arvensis* 12.8 (21.8%); *C. arvense* 18.1 (25.7%); *C. arvensis* 19.1 (22.8%); *L. tatarica* 12.6 (20.3%); *B. campestris* 3.2 (7.8%); *R. raphanistrum* 2.6 (5.3%); *B. vulgaris* 2.0 (8.7%); *P. annua* 1.9 (2.8%); *S. arvensis* 2.7 (3.5%); *C. acanthoides* 0.9 (1.1%). **UL:** *B. campestris* 6.3 (12.8%); *R. raphanistrum* 7.6 (8.1%); *B. vulgaris* 4.6 (13.5%); *S. arvensis* 3.7 (4.9%).
BBCH 50-69 (budding-flowering)	Non-perennial-root-sprout-rhizome	**GL:** *S. media* 10.6 (6.9%); *V. hederifolia* 10.8 (4.2%); *A. arvensis* 10.5 (5.2%); *Portulaca oleracea* 10.5 (7.7%); *E. repens* 5.6 (11.9%). **LL:** *Galinsoga parviflora* 16.8 (30.2%); *C. album* 10.9 (16.2%); *E. repens* 4.9 (9.7%); *E. crus-galli* 14.2 (17.5%); *Setaria glauca* 21.6 (31.3%); *Cynodon dactylon* 5.6 (8.3%); *Lepidium ruderale* 4.8 (6.1%); *Erigeron canadensis* 7.4 (9.1%); *A. retroflexus* 16.3 (22.7%); *S. glauca* 23.9 (33.5%); *E. crus-galli* 16.7 (24.8%); *Sonchus arvensis* 10.8 (14.7%); *C. arvensis* 9.6 (11.8%); *P. annua* 2.4 (3.2%). **ML**: *E. canadensis* 5.4 (7.5%); *C. album* 20.2 (34.5%); *Polygonum scabrum* 12.6 (20.8%); *A. retroflexus* 24.6 (32.9%); *E. crus-galli* 16.2 (22.7%); *S. glauca* 27.8 (35.6%); *E. repens* 20.8 (32.3%); *S. arvensis* 12.9 (19.1%); *C. arvense* 15.9 (22.7%); *C. arvensis* 15.2 (20.9%); *L. tatarica* 6.8 (11.4%); *A. absinthium* 1.5 (2.6%); *A. vulgaris* 1.7 (2.5%). *T. inodorum* 5.1 (6.4%) *Carduus acanthoides* 1.1 (1.3%). *B. campestris* 2.8 (3.7%); *R. raphanistrum* 1.7 (4.1%); *B. vulgaris* 2.8 (5.4%); *S. arvensis* 2.3 (3.4%). **UL:** *C. album* 18.9 (24.5%); *E. crus-galli* 10.8 (15.9%); *S. arvensis* 5.8 (7.2%); *C. arvense* 6.8 (9.3%); *C. arvensis* 4.2 (5.3%); *A. retroflexus* 10.7 (12.2%); *A. absinthium* 1.8 (2.2%); *A. absinthium* 1.4 (1.7%); *C. acanthoides* 1.2 (1.6%).

*For the technological variant 4.0 million similar seeds ha^{-1}.
**For the technological variant 0.5 million similar seeds ha^{-1}.
GL: Ground layer; LL: lower layer; ML: middle layer; UL: upper layer.

Assessment results of weed vegetation dynamics indicated a steady increase in coenotic tension due to the gradual transition of dominant weed species such as *C. album*, *A. retroflexus*, *E. crus-galli*, *E. repens*, *S. arvensis*, *C. arvense*, and *C. arvensis* in the middle and upper sowing stages when increasing the determination frequency by 1.1 to 1.3 times. The problem with the significant dominance of individual weeds, including the multi-year cycle of development, is common in aspects of effective weed control in all cross-flowering crops (Harris et al., 2015).

Therefore, the phenological periodization of weed formation in the oilseed radish agrocoenosis and the nature of their layer development was confirmed by their basic physiological traits by considering the maximum and minimal density technological model of the oilseed radish coenosis on the phenological phase of the crop (Table 3).

Table 3. Phytosociological attributes of oilseed radish weeds as mean for 2013 to 2018 at the start of the fruiting phase (BBCH 70-74) (Total number of squares studied (TNSS) = 50 for all variants).

Species name	SR[§]	TOI	CV_{TOI}	TNIS	CV_{TNIS}	Ab	D	F	Fcl	RAb	RD	RF	IVI	SDR	K
			%		%			%		%	%	%	%	%	
Thlaspi arvense L.	1	3.83	19.6	5.17	22.6	1.35	0.10	7.67	A	1.30	0.44	1.01	2.75	0.92	0.5
	2	10.50	23.1	12.33	16.7	1.17	0.25	21.00	B	0.89	0.60	2.19	3.68	1.23	0.5
Linaria vulgaris Mill.	1	2.33	22.1	2.17	18.8	0.93	0.04	4.67	A	0.90	0.18	0.62	1.69	0.56	0.9
	2	3.50	53.5	3.50	53.5	1.00	0.07	7.00	A	0.75	0.17	0.73	1.65	0.55	0.9
Xanthoxalis fontana (Bunge) Holub	1	1.33	38.7	2.17	34.7	1.63	0.04	2.67	A	1.57	0.18	0.35	2.10	0.70	0.2
	2	4.33	43.0	5.83	51.3	1.35	0.12	8.67	A	1.02	0.29	0.90	2.20	0.73	0.2
Barbarea vulgaris W.T. Aiton	1	3.33	15.5	4.33	27.9	1.30	0.09	6.67	A	1.25	0.37	0.88	2.50	0.83	0.9
	2	11.33	20.6	16.67	47.3	1.47	0.33	22.67	B	1.11	0.81	2.36	4.28	1.43	0.9
Daucus carota L.	1	1.83	22.3	2.50	21.9	1.36	0.05	3.67	A	1.32	0.21	0.48	2.01	0.67	0.5
	2	3.67	44.5	5.33	64.6	1.45	0.11	7.33	A	1.10	0.26	0.76	2.12	0.71	0.5
Lappula squarrosa (Retz.) Dumort.	1	1.33	38.7	3.17	23.8	2.38	0.06	2.67	A	2.29	0.27	0.35	2.91	0.97	0.9
	2	1.83	41.1	2.83	56.5	1.55	0.06	3.67	A	1.17	0.14	0.38	1.69	0.56	0.9
Lamium purpureum L.	1	3.00	21.1	4.67	17.5	1.56	0.09	6.00	A	1.50	0.39	0.79	2.69	0.90	0.2
	2	2.50	55.1	5.17	62.9	2.07	0.10	5.00	A	1.56	0.25	0.52	2.33	0.78	0.2
Berteroa incana (L.) DC.	1	1.17	35.0	2.17	18.8	1.86	0.04	2.33	A	1.79	0.18	0.31	2.28	0.76	0.5
	2	1.50	36.5	3.33	41.0	2.22	0.07	3.00	A	1.68	0.16	0.31	2.15	0.72	0.5
Veronica hederifolia L.	1	6.00	14.9	11.00	14.1	1.83	0.22	12.00	A	1.77	0.93	1.58	4.28	1.43	0.2
	2	2.33	22.1	4.83	49.7	2.07	0.10	4.67	A	1.56	0.24	0.49	2.28	0.76	0.2
Carduus acanthoides L.	1	3.33	15.5	5.33	28.2	1.60	0.11	6.67	A	1.54	0.45	0.88	2.87	0.96	1.2
	2	4.17	28.1	19.17	32.2	4.60	0.38	8.33	B	3.47	0.94	0.87	5.27	1.76	1.2
Lepidium ruderale L.	1	2.33	22.1	3.83	19.6	1.64	0.08	4.67	A	1.59	0.32	0.62	2.53	0.84	0.5
	2	4.33	34.7	11.33	21.4	2.62	0.23	8.67	A	1.97	0.55	0.90	3.43	1.14	0.5
Erigeron canadensis L.	1	5.67	18.2	10.33	11.7	1.82	0.21	11.33	A	1.76	0.87	1.50	4.13	1.38	0.9
	2	9.67	16.9	24.00	32.6	2.48	0.48	19.33	A	1.87	1.17	2.01	5.06	1.69	0.5
Raphanus raphanistrum L.	1	4.17	18.1	6.33	19.1	1.52	0.13	8.33	A	1.47	0.53	1.10	3.10	1.03	0.9
	2	4.17	18.1	10.67	29.4	2.56	0.21	8.33	A	1.93	0.52	0.87	3.32	1.11	0.9
Amaranthus blitoides S. Watson	1	2.33	22.1	3.33	31.0	1.43	0.07	4.67	A	1.38	0.28	0.62	2.28	0.76	0.9
	2	2.17	34.7	2.33	51.9	1.08	0.05	4.33	A	0.81	0.11	0.45	1.38	0.46	0.5
Anagallis arvensis L.	1	6.33	12.9	8.33	14.5	1.32	0.17	12.67	A	1.27	0.70	1.67	3.65	1.22	0.2
	2	3.00	29.8	5.17	41.4	1.72	0.10	6.00	A	1.30	0.25	0.63	2.18	0.73	0.2
Brassica campestris L.	1	11.17	18.3	19.17	14.2	1.72	0.38	22.33	B	1.66	1.62	2.95	6.22	2.07	0.9
	2	9.67	22.3	14.17	30.7	1.47	0.28	19.33	A	1.11	0.69	2.01	3.81	1.27	0.9
Artemisia vulgaris L.	1	3.33	24.5	4.33	27.9	1.30	0.09	6.67	A	1.25	0.37	0.88	2.50	0.83	1.2
	2	2.83	34.7	7.83	14.9	2.76	0.16	5.67	A	2.08	0.38	0.59	3.06	1.02	0.9
Artemisia absinthium L.	1	2.33	22.1	5.33	19.4	2.29	0.11	4.67	A	2.21	0.45	0.62	3.27	1.09	1.2
	2	2.17	34.7	3.50	30.0	1.62	0.07	4.33	A	1.22	0.17	0.45	1.84	0.61	1.2
Taraxacum officinale F.H. Wigg.	1	5.00	21.9	8.33	25.9	1.67	0.17	10.00	A	1.61	0.70	1.32	3.63	1.21	0.5
	2	11.83	19.6	15.50	24.7	1.31	0.31	23.67	B	0.99	0.76	2.47	4.21	1.40	0.5
Cirsium arvense (L.) Scop.	1	21.33	23.1	114.50	18.6	5.37	2.29	42.67	C	5.18	9.67	5.63	20.48	6.83	1.2
	2	23.83	13.4	149.00	30.6	6.25	2.98	47.67	C	4.71	7.29	4.97	16.96	5.65	1.2
Sonchus arvensis L.	1	14.17	18.1	22.33	17.6	1.58	0.45	28.33	B	1.52	1.89	3.74	7.15	2.38	1.2
	2	17.83	16.0	27.83	28.3	1.56	0.56	35.67	B	1.18	1.36	3.72	6.25	2.08	1.2
Convolvulus arvensis L.	1	9.17	23.3	14.00	12.8	1.53	0.28	18.33	A	1.47	1.18	2.42	5.08	1.69	0.9
	2	12.33	19.0	32.00	26.0	2.59	0.64	24.67	B	1.96	1.56	2.57	6.09	2.03	0.9
Equisetum arvense L.	1	2.17	18.8	6.00	23.6	2.77	0.12	4.33	A	2.67	0.51	0.57	3.75	1.25	0.5
	2	6.17	19.0	14.83	13.1	2.41	0.30	12.33	A	1.81	0.73	1.28	3.82	1.27	0.5
Cynodon dactylon (L.) Pers.	1	5.17	22.6	11.33	15.5	2.19	0.23	10.33	A	2.12	0.96	1.36	4.44	1.48	0.5
	2	6.67	27.9	14.83	16.2	2.23	0.30	13.33	A	1.68	0.73	1.39	3.79	1.26	0.5
Achillea millefolium L.	1	2.33	22.1	4.17	28.1	1.79	0.08	4.67	A	1.72	0.35	0.62	2.69	0.90	0.9
	2	5.17	22.6	9.50	14.5	1.84	0.19	10.33	A	1.39	0.46	1.08	2.93	0.98	0.9
Elytrigia repens (L.) Desv. ex Nevski	1	27.33	25.6	70.17	19.4	2.57	1.40	54.67	C	2.48	5.92	7.22	15.62	5.21	0.9
	2	35.83	15.4	130.00	19.8	3.63	2.60	71.67	D	2.74	6.36	7.47	16.56	5.52	0.9
Delphinium consolida L.	1	6.50	23.3	10.33	22.6	1.59	0.21	13.00	A	1.53	0.87	1.72	4.12	1.37	0.5
	2	7.83	26.1	13.67	15.8	1.74	0.27	15.67	A	1.32	0.67	1.63	3.62	1.21	0.5
Tripleurospermum inodorum (L.)	1	8.17	32.3	15.17	13.5	1.86	0.30	16.33	A	1.79	1.28	2.16	5.23	1.74	0.5
Sch. Bip.	2	21.33	10.1	41.17	24.3	1.93	0.82	42.67	C	1.46	2.01	4.44	7.91	2.64	0.5

Continuation Table 3.

Species name	SR§	TOI	CV_{TOI}	TNIS	CV_{TNIS}	Ab	D	F	Fcl	RAb	RD	RF	IVI	SDR	K
Senecio vernalis Waldst. & Kit.	1	5.50	25.1	7.33	23.9	1.33	0.15	11.00	A	1.29	0.62	1.45	3.36	1.12	0.9
	2	8.83	16.7	13.83	16.7	1.57	0.28	17.67	A	1.18	0.68	1.84	3.70	1.23	0.9
Lactuca tatarica (L.) C.A. Mey.	1	5.33	22.7	6.33	35.5	1.19	0.13	10.67	A	1.15	0.53	1.41	3.09	1.03	0.9
	2	10.83	20.6	22.50	24.5	2.08	0.45	21.67	B	1.57	1.10	2.26	4.92	1.64	0.9
Capsella bursa-pastoris (L.) Medik.	1	10.33	22.6	14.00	20.2	1.35	0.28	20.67	A	1.31	1.18	2.73	5.22	1.74	0.2
	2	10.00	16.7	23.83	13.4	2.38	0.48	20.00	A	1.80	1.17	2.08	5.05	1.68	0.2
Centaurea cyanus L.	1	5.50	15.2	7.33	22.3	1.33	0.15	11.00	A	1.29	0.62	1.45	3.36	1.12	0.5
	2	5.33	19.4	7.67	13.5	1.44	0.15	10.67	A	1.08	0.37	1.11	2.57	0.86	0.5
Portulaca oleracea L.	1	8.33	28.1	16.00	17.7	1.92	0.32	16.67	A	1.85	1.35	2.20	5.40	1.80	0.2
	2	6.00	14.9	13.50	15.4	2.25	0.27	12.00	A	1.70	0.66	1.25	3.61	1.20	0.2
Galinsoga parviflora Cav.	1	12.50	17.3	16.33	21.1	1.31	0.33	25.00	B	1.26	1.38	3.30	5.94	1.98	0.5
	2	23.17	13.8	46.50	24.2	2.01	0.93	46.33	C	1.51	2.27	4.83	8.61	2.87	0.5
Spergula vulgaris Boenn.	1	2.50	21.9	5.33	28.2	2.13	0.11	5.00	A	2.06	0.45	0.66	3.17	1.06	0.5
	2	2.33	22.1	4.67	26.0	2.00	0.09	4.67	A	1.51	0.23	0.49	2.22	0.74	0.5
Amaranthus retroflexus L.	1	31.17	16.5	75.17	22.4	2.41	1.50	62.33	D	2.33	6.35	8.23	16.90	5.63	1.2
	2	35.83	13.5	156.00	18.3	4.35	3.12	71.67	D	3.28	7.63	7.47	18.38	6.13	0.9
Polygonum aviculare L.	1	1.50	36.5	2.33	22.1	1.56	0.05	3.00	A	1.50	0.20	0.40	2.09	0.70	0.2
	2	2.33	22.1	5.00	17.9	2.14	0.10	4.67	A	1.62	0.24	0.49	2.35	0.78	0.2
Sonchus oleraceus L.	1	5.50	19.1	8.17	16.3	1.48	0.16	11.00	A	1.43	0.69	1.45	3.57	1.19	1.2
	2	8.17	19.6	10.50	13.1	1.29	0.21	16.33	A	0.97	0.51	1.70	3.18	1.06	1.2
Polygonum scabrum Moench.	1	12.33	18.3	21.00	12.0	1.70	0.42	24.67	B	1.64	1.77	3.26	6.67	2.22	0.5
	2	17.17	15.8	44.00	20.9	2.56	0.88	34.33	B	1.93	2.15	3.58	7.66	2.55	0.5
Echinochloa crus-galli (L.) P. Beauv.	1	29.33	22.4	77.83	16.6	2.65	1.56	58.67	C	2.56	6.57	7.74	16.88	5.63	1.2
	2	35.83	13.3	97.67	18.5	2.73	1.95	71.67	D	2.06	4.78	7.47	14.30	4.77	1.2
Setaria viridis (L.) P. Beauv.	1	12.50	24.7	34.17	16.4	2.73	0.68	25.00	B	2.64	2.88	3.30	8.82	2.94	0.5
	2	8.33	22.3	19.50	22.6	2.34	0.39	16.67	A	1.76	0.95	1.74	4.45	1.48	0.5
Setaria glauca (L.) P. Beauv.	1	28.00	19.6	267.83	18.1	9.57	5.36	56.00	C	9.23	22.61	7.39	39.24	13.08	0.9
	2	31.17	15.2	690.17	18.6	22.14	13.80	62.33	D	16.70	33.75	6.49	56.94	18.98	0.5
Galium aparine L.	1	5.33	25.6	7.83	27.3	1.47	0.16	10.67	A	1.42	0.66	1.41	3.49	1.16	0.5
	2	2.50	21.9	6.00	21.1	2.40	0.12	5.00	A	1.81	0.29	0.52	2.62	0.87	0.5
Chenopodium album L.	1	21.33	16.7	205.33	14.7	9.63	4.11	42.67	C	9.29	17.34	5.63	32.26	10.75	1.2
	2	27.00	11.2	243.50	18.7	9.02	4.87	54.00	C	6.80	11.91	5.63	24.33	8.11	0.9
Sinapis arvensis L.	1	4.33	23.8	8.00	23.7	1.85	0.16	8.67	A	1.78	0.68	1.14	3.60	1.20	0.9
	2	4.00	22.4	19.33	21.1	4.83	0.39	8.00	A	3.64	0.95	0.83	5.42	1.81	0.9
Polygonum convolvulus L.	1	2.50	21.9	6.33	12.9	2.53	0.13	5.00	A	2.44	0.53	0.66	3.64	1.21	0.9
	2	2.33	22.1	1.83	41.1	0.79	0.04	4.67	A	0.59	0.09	0.49	1.17	0.39	0.9
Poa annua L.	1	2.33	22.1	3.33	15.5	1.43	0.07	4.67	A	1.38	0.28	0.62	2.28	0.76	0.5
	2	2.33	22.1	2.00	44.7	0.86	0.04	4.67	A	0.65	0.10	0.49	1.23	0.41	0.5
Stellaria media (L.) Vill.	1	6.17	19.0	14.33	10.5	2.32	0.29	12.33	A	2.24	1.21	1.63	5.08	1.69	0.2
	2	4.00	27.4	10.83	21.4	2.71	0.22	8.00	A	2.04	0.53	0.83	3.41	1.14	0.2
Total sum	1	378.80	22.3*	1184.30	20.4*	103.60	23.70	757.70	-	100.00	100.00	100.00	300.00	100.00	33.9
	2	480.00	24.1*	2045.20	28.6*	132.60	40.90	960.00	-	100.00	100.00	100.00	300.00	100.00	31.8

SR: Souringrate; TOI: total occurrence of individuals; CV_{TOI}: coefficient of variation of the total occurrence of individuals; TNIS: total number of individuals of a species in all squares; CV_{TNIS}: coefficient of variation of the total number of individuals of a species in all squares; Ab: abundance; D: density; F: frequency; Fcl: frequency classes; RAb: relative abundance; RD: relative density; RF: relative frequency; IVI: importance value index; SDR: summed dominance ratio. K: tier criterion.

§1: 4.0 million similar seeds ha^{-1}; 2: 0.5 million similar seeds ha^{-1}.

*Mean values of indicators.

The weed population in the oilseed radish agrophytocoenosis of two radically remote technological variants is heterogeneous according to the given indicators. This is shown by the ratio of the frequency classes (F) A > B > C ≥ D < E. Specifically, the given indicators determine the degree of dominance in the crop, and the highest indicator was observed among such weed species as *C. album*, *A. retroflexus*, *E. crus-galli*, *S. glauca*, and *Galinsoga parviflora* Cav. to wintering annuals *Lactuca serriola* L., *G. aparine*, *B. vulgaris*, *T. arvense*, *C. bursa-pastoris*, *Tripleurospermum inodorum* (L.) Sch. Bip., and *S. media*. The marked spectrum of perennial weeds is represented in the oilseed radish agrocoenosis by the rhizome forms of *E. repens* and *E. arvense*, root-sprout forms of *S. arvensis*, *C. arvense*, and *C. arvensis*, and stalky-root forms *T. officinale*, *L. tatarica*, *A. absinthium*, and *A. vulgaris*. Contrary to the revealed peculiarities for spring rapeseed (Zimdahl, 2018) and white mustard (Rana and Kumar, 2014), more distinctive layer differentiation of weed species was typical of the oilseed radish agrocoenosis and strongly marked inhibition of the soil and lower layer, especially the stalking-flowering interphase (BBCH 25-55).

Both quantitative and structured weed abundance in the oilseed radish coenosis with a density of 4.0 million similar seeds ha^{-1} were substantially lower than in the density with 0.5 million similar seeds ha^{-1}. Therefore, total weed abundance in the first variant over the study period was 17.2 ppm less than in the second variant of the coenosis density. With the preservation of the weed species structure, the layering level of their formation was less than 2.1 seeds of the displaced dominant by the level coefficient (K) in the variant of 0.5 million similar seeds ha^{-1}, which indicates the increase in the vitality of the oilseed radish plants when decreasing seeding rates; an overall increase in F of 26.7% in this setting indicates an overall increase in the number of weeds in the lower and middle layers. The effect of the competitiveness of weed plants in relation to weeds tends to decrease as their plant density decreases, but this decrease is not directly proportional because it is limited by the redistribution of the weed layering structure and the change in the vitality tactics of oilseed radish.

It should also be specified that within the variation in the TOI and TNIS indices, the number of specific weed species depended on the hydrothermal conditions of the year because in this case the coefficient of variation determined the annual fluctuations in the number of definite individual species. Different types of weeds have different degrees of adaptation to the changing hydrothermal conditions of vegetation by the magnitude of the variation coefficient from low to very high. At the same time, the variation in the number of annual plants was on average 5.6% higher than the variation in the number of perennial forms. The variability of weed species composition was 1.4 times higher than the sowing rate of 0.5 million similar seeds ha^{-1} according to the results of the mean value of the variation coefficient in the TNIS expression. This confirms the findings of the present study as to the expansion of the range of vitality tactics of weed species in the oilseed radish agrocoenosis by reducing the total coenotic pressure per unit area. The same is also demonstrated by the overall weed estimation (GD) score for two general coenosis constructs. This indicator averaged 22.13 seeds m^{-2} in the layers for the study period for the 4.0 million similar seeds ha^{-1} variant, and 0.5 million similar seeds ha^{-1} included 29.79 units m^{-2} in the layers. This is evidence of a denser spatial orientation of the weed plants over reduced seeding norms of oilseed radish and a more complete filling of the free layer niches with the vegetative parts of the actual weeds. Such characteristics correspond to certain general laws of phytocoenology and to indicators such as the consideration of weed vitality to determine the critical agrocoenosis weed status of the respective crop (Rao, 2017).

Identifying the relevant indicators of weed formation stability in the oilseed radish agrocoenosis is also important. As previously specified, the weather conditions varied during the different years of the study, which allowed ranking them for favorability to ensure the growth processes of the oilseed radish. A similar dynamic in the favorability of growth processes was also found for weed plants. The following were the indices for the abundance index (Ab) in the years of assessment: 2018 (-0.09), 2015 (-0.26), 2017 (-0.05), 2016 (0.21), 2013 (0.26), and 2014 (0.32) according to the methodology for assessing the stability and ductility of indicators. The evaluation of environmental plasticity (b_i) and environmental stability (Si^2) for the two technological options for modelling oilseed radish coenosis is shown in Table 4. These indices are divided in the following rank groups according to their value: I indicators $b_i < 1$ and $Si^2 > 0$ have better results under unfavorable conditions, unstable; II indicators $b_i < 1$ and $Si^2 = 0$ have better results under unfavorable conditions, stable; III indicators $b_i = 1$ and $Si^2 = 0$ respond well under improved conditions, stable; IV indicators $b_i = 1$ and $Si^2 > 0$ respond well under improved conditions, unstable; V indicators $b_i > 1$ and $Si^2 = 0$ have better results under favorable conditions, stable; VI indicators $b_i > 1$ and $Si^2 > 0$ have the best results under favorable conditions. The results lead to many important conclusions. First, dominance among the weed species considered by the b_i/Si^2 correlation of the I and VI rank groups indicated a clear differentiation of the weed species by resistance to unfavorable conditions. Species with rank I, which showed higher abundance under unfavorable conditions, but with the unstable variant of reaction to the specified conditions, were estimated at 26 (54.2% of the total number of considered species) for the first technological modelling variant of oilseed radish agrocoenosis. Species with the VI rank responding positively to favorable weather conditions for the first variant were marked as 5 (31.3%). The marginal species of other groups included 7 (14.5%). In the case of changes in planting density of oilseed radish, this factor is consistent in the system of plasticity assessment and stability of the definite weed species of which 27 species (56.3%) were assigned to the first rank, 19 (39.6%) to the sixth rank with the presence of two marginal species in the rank group (4.1%). These results confirm that the competitive potential of weeds in the composition of oilseed radish agrocoenosis for hydrothermal conditions of vegetation is high, and the change in rank from I to VI in some species to reduce stand density of oilseed plants is a manifestation of its competitive potential as to the plant vegetation, which complies with the concept of plasticity. It is necessary to highlight

Table 4. Ecological plasticity (b_i) and ecological stability (S_i^2) of abundance (Ab) indicator under different technological variants of oilseed radish growing at the beginning of the fruiting phase (BBCH 70-74). 2013-2018.

	A variant of construction of oilseed radish agrocoenosis					
	4.0 million similar seeds ha^{-1}			0.5 million similar seeds ha^{-1}		
Species name	b_i	S_i^2	Rank*	b_i	S_i^2	Rank*
Thlaspi arvense	-0.87	0.09	I	-0.56	0.02	I
Linaria vulgaris	0.60	0.11	I	0.01	0.00	II
Xanthoxalis fontana	6.03	0.17	VI	-0.08	0.12	I
Barbarea vulgaris	0.69	0.11	I	0.87	0.20	I
Daucus carota	-3.16	0.08	I	1.17	0.03	VI
Lappula squarrosa	4.58	1.01	VI	1.16	1.10	VI
Lamium purpureum	-1.46	0.05	I	2.31	0.12	VI
Berteroa incana	-3.05	0.52	I	0.98	0.72	I
Veronica hederifolia	1.76	0.08	VI	2.73	0.47	VI
Carduus acanthoides	-1.08	0.06	I	2.30	0.18	VI
Lepidium ruderale	1.70	0.43	VI	-0.09	0.37	I
Erigeron canadensis	-2.20	0.14	I	1.69	0.05	VI
Raphanus raphanistrum	0.10	0.01	II	0.60	0.09	I
Amaranthus blifoides	2.25	0.10	I	-2.82	1.10	I
Anagallis arvensis	-0.21	0.01	II	0.71	0.48	I
Brassica campestris	-1.01	0.01	II	0.15	0.03	I
Artemisia vulgaris	-2.74	0.17	I	0.35	0.79	I
Artemisia absinthium	1.01	0.07	IV	-0.76	0.20	I
Taraxacum officinale	-1.08	0.15	I	0.03	0.04	I
Cirsium arvense	5.51	0.20	VI	5.61	0.56	VI
Sonchus arvensis	0.03	0.07	I	1.00	0.03	IV
Convolvulus arvensis	-0.52	0.16	I	0.55	0.10	I
Equisetum arvense	4.08	1.00	VI	-0.18	0.32	I
Cynodon dactylon	-0.35	0.04	I	-0.62	0.15	I
Achillea millefolium	1.14	0.05	VI	-0.61	0.06	I
Elytrigia repens	0.66	0.06	I	1.33	0.09	VI
Delphinium consolida	-0.36	0.03	I	0.06	0.22	I
Tripleurospermum inodorum	3.05	0.70	VI	1.77	0.17	VI
Senecio vernalis	3.34	0.01	V	-0.16	0.21	I
Lactuca tatarica	-0.93	0.04	I	0.66	0.01	I
Capsella bursa pastoris	2.42	0.14	VI	0.52	0.09	I
Centaurea cyanus	2.89	0.21	VI	-0.31	0.07	I
Portulaca oleraceae	2.56	0.10	VI	0.18	0.04	I
Galinsoga parviflora	0.35	0.00	II	1.49	0.00	VI
Spergula vulgaris	-1.00	0.62	I	0.59	0.16	I
Amaranthus retroflexus	-0.39	0.04	I	1.62	0.20	VI
Polygonum aviculare	1.07	0.72	VI	0.48	0.35	I
Sonchus oleraceus	0.36	0.01	II	-0.85	0.01	I
Polygonum scabrum	0.73	0.04	I	1.37	0.03	VI
Echinochloa crus-galli	-0.20	0.08	I	1.48	0.10	VI
Setaria viridis	0.21	0.09	I	0.49	0.45	I
Setaria glauca	11.22	0.63	VI	6.30	0.23	VI
Galium aparine	-0.19	0.08	I	0.23	0.29	I
Chenopodium album	7.71	0.48	VI	5.35	1.19	VI
Sinapis arvensis	0.55	0.10	I	4.34	0.98	VI
Polygonum convolvulus	-1.54	0.21	I	1.47	0.12	VI
Poa annua	1.15	0.07	VI	1.99	0.08	VI
Stellaria media	0.33	0.11	I	1.29	0.56	VI

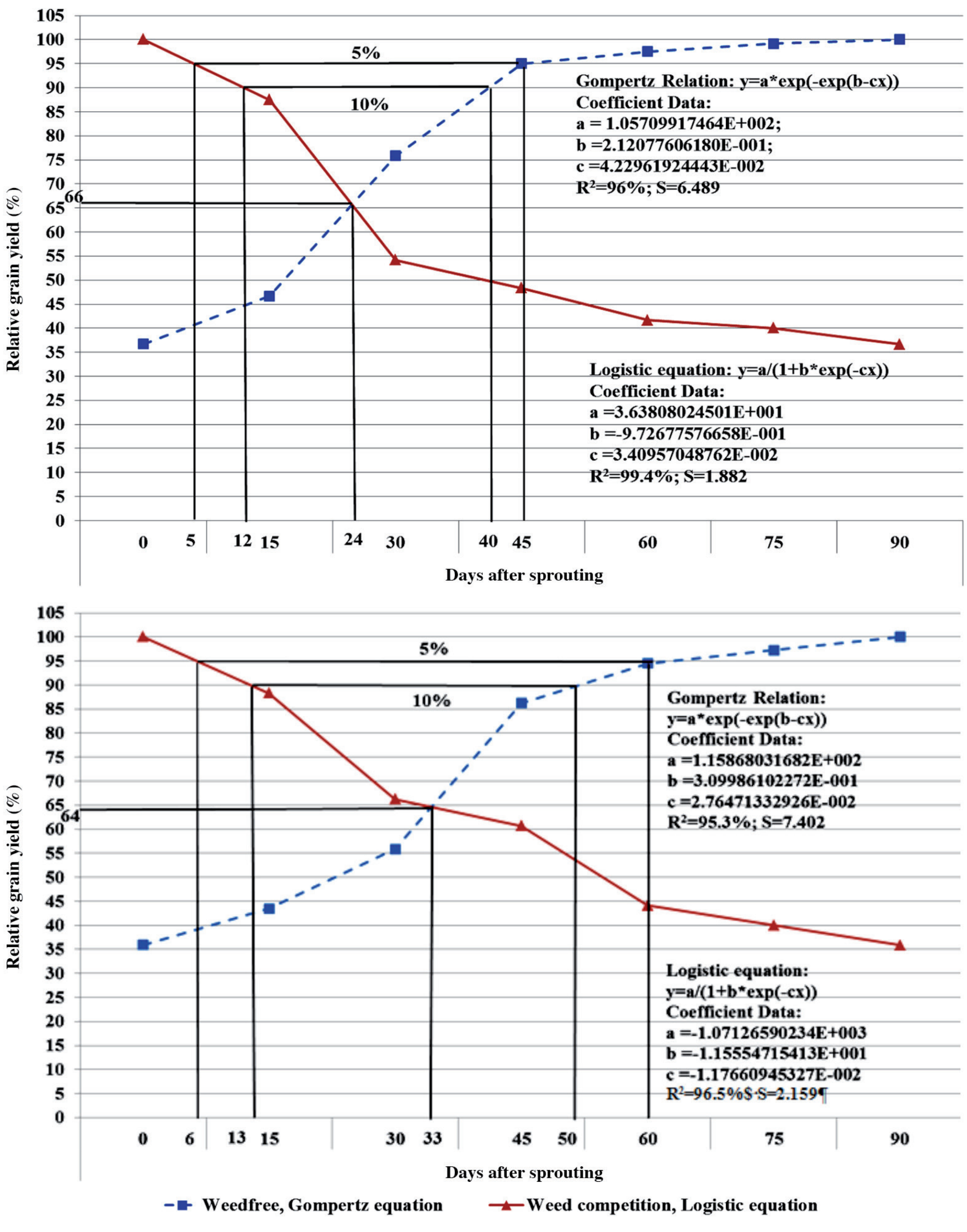
Parameters of year conditions: Actual Fisher's criterion (F_f) 1960; 2 Fisher's criterion at 5% significance level ($F_{0.}$) 2.46; Abundance (Ab) F_f 425.5 ($F_{0.5}$ 1.82); Ab × Year conditions F_f 96.3 ($F_{0.5}$ 1.48).

*I: $b_i < 1$ and $Si^2 > 0$ have better results under unfavorable conditions, unstable; II: $b_i < 1$ and $Si^2 = 0$ have better results under unfavorable conditions, stable; III: $b_i = 1$ and $Si^2 = 0$ respond well under improved conditions, stable; IV: $b_i = 1$ and $Si^2 > 0$ respond well under improved conditions, unstable; V: $b_i > 1$ and $Si^2 = 0$, have better results under favorable conditions, stable; VI: $b_i > 1$ and $Si^2 > 0$ have the best results under favorable conditions.

that weeds of the VI rank of the group should be attributed to species with numbers to significantly increase when improving both edaphic conditions and the introduction of additional elements in crop technology, namely, use of mineral fertilizers increase in feeding areas of cultivated plants among others. This is the case for the oilseed species that are dominant in the radish coenosis such as *C. arvense*, *E. repens*, *G. parviflora*, *A. retroflexus*, *E. crus-galli*, *S. glauca*, *C. album*, *Erigeron canadensis* L., and *Carduus acanthoides* L.

The peculiarities of weed formation in the oilseed radish agrophytocoenosis with different technological variants were analyzed in the present study, which recognized the change in the critical period for weed control (CPWC) indicator (Figure 2).

Figure 2. Critical period of weed competition of the oilseed radish agrophytocoenosis with different seeding technological models (top position for seeding rates of 4.0 million similar seeds ha^{-1}, bottom position for seeding rates of 0.5 million similar seeds ha^{-1}), 2013 to 2018 mean (determination of graph parameters in CurveExpert Pro 2.6.5).



a, b, c: Free terms of equations; R^2: approximation coefficient; S: error of approximation coefficient.

The duration of the post-emergence period in the system for determining this indicator was applied, although as observed by Rana and Rana (2016), the format of the post-emergence study of weed competition under early spring sowing is more relevant. The use of classical approaches to determine the CPWC (Knezevic and Datta, 2015), 5% in particular and 10% of the rate of decline. For the variant of forming oilseed radish agrocoenosis with a seeding rate of 4.0 million similar seeds ha^{-1}, the 5% reduction rate of the average crop during the study period was ranged from 5 to 45 DAS, 10% of the crop loss rate was ranged from 12 to 40 DAS. For the technological variant of 0.5 million similar seeds ha^{-1}, the indicated yield reduction levels varied between 6 and 60 and 13 and 50 DAS, respectively. The interval itself differs from similar indicators for oilseeds close to radish: spring and winter rapeseed and white mustard in particular. Overall, the total critical period was shown for rapeseed, which included 5% and 10% crop reduction levels, and the specified critical period ranged from 15 to 40 DAS (Rana and Kumar, 2014) and 15 to 60 DAS (Lemerle et al., 2010). Therefore, the oilseed radish has identical characteristics for competitiveness with the main weeds. However, the present study has shown a number of differences. The first difference, previously mentioned, is related to the peculiarities of oilseed radish plant growth; these were slow growth rates to the rosette phase of the beginning of stalking (BBCH 10-30) and the intensive rapid growth rates from the stem stage to the flowering stage (BBCH 31-50). The level of competition of weed radish plants compared with other weeds increased from the rosette stage and reached its maximum value at budding due to these peculiarities (BBCH 42-50). With increased density of agrocoenosis, and for the oilseed radish in the study area, this was the maximum applied technological option, in addition to increasing the overall competitiveness of the plants compared with weeds due to the corresponding higher cover also increased internal competition between cultivated oilseed radish plants. In this case, the critical interval between 5% and 10% yield reduction levels was restricted to 5 to 7 DAS instead of 9 to 10 DAS in the of 0.5 million similar seeds ha^{-1} variant. For this reason, the CPWC for the first technological variant was shortened, and the intersection point of the Gompertz curve and logistics for the first variant was 24 DAS, and 33 DAS, respectively. These characteristics have been found in several other crops and generalized by a number of researchers (Swanton et al., 2015; Rana and Rana, 2016).

Another peculiarity of the oilseed radish is related to the type of seed yield formation compared with the formation of the total leafy biomass. By increasing the seeding rate to the critical maximum limit, an overall decrease in the reproductive and increase of the vegetative plant architectonics were observed. A complex proportion of the crop decrease occurred due to both weeds and the unique characteristics of the depressing influence of the intraspecific competition. The opposite processes occurred for the variant of critically low seeding rates. The growth curve (Gompertz relation) had lower approximation values (R^2) than the logistic curve. Many publications highlight these observations for the evaluation of CPWC curves (Knezevic and Datta, 2015; Zimdahl, 2018). In addition, due to the higher weed level and the decrease in overall sowing competitiveness by reducing the potential project surface coverage of the soil surface by one plant, the relevance of weed control extends to later phenological phases in the development of the oilseed radish plants than for the variant of denser coenoses of a crop.

The determined CPWC showed that herbicides should be applied for effective herbicide control over the oilseed radish agrocoenosis in the period from germination to the beginning of rosette formation (BBCH 4-12) at the high technological density of the coenosis, and in the period from the beginning of rosette formation to the beginning of stalking (BBCH 10-20) in the variants of extremely low density values. This complies with conventional weed control strategy (Harker and O'Donovan, 2013; Andrew et al., 2015; Jugulam et al., 2019).

CONCLUSIONS

The heterogeneous quality of weed formation has been determined for agrophytocoenoses of oilseed radish. The overall species diversity was represented by 48 species that constitute four consecutive layers within the height of the oilseed radish stalk. The characteristics of the weed types change one after another in the light of the major stages of the growing season. The prevailing weed type for the structure is non-perennial-rooting-sprouting-rhizome. The dominant forms with a higher level of competitiveness, as for the oilseed radish plants, were represented by cereals of the early and late spring groups summed dominance ratio (SDR) = 22.4 overall for 4.0 million similar seeds ha^{-1}, and 25.6 for 0.5 million seeds ha^{-1}, and the perennial rhizome forms (SDR 5.2 and 5.5, respectively). The dominant role among the broadleaf (dicotyledonous) weeds was assumed by representatives of the late spring group (SDR 24.1 and 24.4, respectively) and the perennial rootstock group (SDR 12.6 and 11.8, respectively). The attributed weed characteristics reported in the oilseed radish agrocoenosis at different densities were 39.2% by species identity mean representation for the 0.5 million similar seeds ha^{-1} technological variant. In general, the prevailing weed types belonged to groups I and VI according to the parameters of the ecological plasticity and ecological stability of parameter abundance (Ab). The critical period of crop-weed competition (CPCWC) depended on the technological density of the oilseed radish agrocoenosis, and its value for the 5% reduction level in the yield of 4.0 million similar seeds ha^{-1} was 5 to 45 DAS, which was 14 DAS less than in for the 0.5 million similar seeds ha^{-1} variant. This indicator was also lower for the denser study of the oilseed radish agrocoenosis at 9 DAS for the 10% reduction level at harvest. The most appropriate period to use herbicides to effectively control their number, taking into account the CPWC criterion for the full range of technological parameters of forming the oilseed radish agrocoenosis, corresponds to the period from seedling to the start of sprouting (BBCH 4-20). The results are an opportunity to recommend changing the tactics of herbicide application and carrying out anti-weed agronomic measures in oilseed radish crops in Ukraine and the neighboring regions. Existing technological solutions require such measures in the formation of true leaf phase.

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