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Formation and determination of the individual area of oilseed radish leaves in agrophytocenosises of different technological construction

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Abstract. For the successful control of the production process, determining the leaf area is a basic requirement. In this context, it is important to determine the regularities of leaf formation within the plant, considering technological parameters of agrophytocenosis construction. These are the important issues covered in this paper based on the years of research conducted between 2013 and 2018 on three cultivars of oilseed radish: one of the poorly explored members of the cruciferous family of multipurpose use. The conducted researches allowed to distinguish features of longline leaf formation of oilseed radish cultivars and mathematically describe features of formation of their area, length and width at the early flowering phase according to the Richards growth curve. The peculiarities of formation of individual leaf area depending on the combination of the variations of the stand density and fertilization in the context of the recommended process regulation of oilseed radish cultivation are also determined. It has been proved possible to use a non–destructive method of determining the individual leaf area of oilseed radish, basing on the evaluation of 29 models, using the following formula $S = 7.9316–2.3613L + 0.6897 (LW)+0.0458L^2–0.0005 (LW)^2$ (under the following test parameters of the model: R^2 0.9106; *RMSE* 9.75; *d* 0.956; *BIAS* –0.1523).

Key words: oilseed radish, leaf formation, leaf area estimation, non-destructive methods, mathematical model.

INTRODUCTION

Assimilating surface of agrophytocenosis of any crop is a complex longline structure, which reacts sensitively enough to the hydrothermal vegetation regime, technological nature of cenosis creation, phenotypic features of the main crop forming cenosis, level of soil and additional mineral nutrition, and nature of weediness (Long et al., 2006; Lamptey et al., 2017; Seetseng et al., 2020). On the other hand, the area of the assimilating surface of a plant is a combination of the number of leaves per plant and their individual area (Kotula, 1951; Lewis, 1972; Smith et al., 1997; Tsukaya, 2003; Doust, 2007). A common scientific challenge is the fact that a simple product of the number of leaves per leaf area is only appropriate in case of equal leaf sizes by their placement on the plant's stem (Stewart & Dwyer, 1999; Gielis, 2003; Watanabe et al., 2005; Dornbusch et al., 2011). In the majority of cases there are significant deviations for the plant body both in the size of leaves and in their shape in the direction from the first leaves to the upper leaves (Terashima & Hikosaka, 1995; Terashima et al., 2001; Bylesjö et al., 2008; Pérez-Pérez et al., 2010). Such nature of the formation of differences may take the form of a change in the leaf type (due to a combination of different separation moduses) and is called pinnation, and is expressed in a change in the character of the complexity of the leaf blade, starting with juvenile leaves to leaves which are formed at late stages of growth and development of plants (Corona & Vasilyev, 2007). Another type of differences is related to the parameters of fluctuating asymmetry of leaves, which in fact reflects the format of lateral leaf blade variability (Parsons, 1992; Semiarti et al., 2001; Shi et al., 2018). It should be remembered that there is one more component of the differences between the leaves of plants of different tiers, in particular the thickness of the leaf blade, venetion nature, anatomical differences in the tissue texture, space angular orientation towards the stem (Wofford & Allen, 1982; Ivanov et al., 1994; Rosa & Forseth, 1995; Deckmyn et al., 2000; Terashima et al., 2001; Runions et al., 2005; Milla & Reich, 2007; Ford et al., 2008; Nam et al., 2008; Nicotra et al., 2011; Dornbusch et al., 2011). In summary, there is an appropriate level of morphological variability for plants, which can be characterized as a morphological gradient, which in some research works is expressed as a ratio of leaf area of certain upper tiers to lower tiers, or their individual linear sizes, in particular leaf length, leaf width or other morphological parameter (Ivanov et al., 1994; Gielis, 2003; Breda, 2003; Efroni et al., 2010). It is also believed that the nature and value of the mentioned variability is determined by the main technological aspects of agrophytocenosis formation (Loomis et al., 1967; Nanda et al., 1995; Long et al., 2006; Ro´zyło & Pałys, 2014). Most researches show that the intensive variability of leaf morphological parameters in the vertical gradient is determined by a number of factors from the most to the least determinant: the density of agrophytocenosis considering the feeding area of one plant, the level of fertilization in interaction with the density, the edaphic conditions of growth and development of plants (Morrison & Stewart, 1995; Nanda et al., 1995; Schurr et al., 2000; Jullien et al., 2009; Biskup et al., 2009; Ma et al., 2014; Boudaoud, 2016). The above mentioned number of factors has a determining basis from the perspective of hydrothermal conditions of vegetation with the maximum reduction in morphometry of individual leaves of the plant in combination with the maximum formats of stand density, fertilization and favorable ground conditions, as well as the most favorable, and vice versa the most unfavorable hydrothermal regimes of the vegetation period of the respective crop (Stefanowska et al., 1999; Nicotra et al., 2008; Hosoi & Omasa, 2012; Li et al., 2013; Wright et al., 2017).

On the other hand, it is noted that the nature of individual leaf parameters, considering the linear growth of plants and the multiple–age staging of functioning of leaves from different tiers, is in some degree determining in providing the appropriate levels of photosynthesis productivity in cruciferous crops, and as a result provides both the formation of the appropriate leaf–stem complex structure and the formation of appropriate seed yield levels (Freyman et al., 1973; Thurling, 1974; Clarke, 1977 and 1978; Pecham & Morgan, 1985; Kasa & Kondra, 1986; Gabrielle et al., 1998; Khan, 2003 and 2005; Mullen et al., 2006; Jansen et al., 2009; Kirkegaard et al., 2012; Cargnelutti Filho et al., 2015; Fochesatto, et al., 2016).

It should be also noted that there is an important aspect of leaf variability expressed in heterophylly. Almost all plants are heterophyllous, as it is difficult to find morphologically identical leaf blades on the stem. The approaches to this issue distinguish the typification of heterophylly: dimensional, geometric, venational, etc.

(Korona and Vasilyev, 2007; Chitwood & Sinha, 2016; Nakayama et al., 2017). Due to heterophylly on the plant stem, different morphotypes (categories or formations) of leaves can be found sequentially: basal, middle and apical (Baker–Brosh & Peet, 1997; Kuwabara et al., 2001; Corona and Vasilyev, 2007; Merks et al., 2011; Nakayama et al., 2012; Yamaguchi et al., 2012; Maugarny-Cales & Laufs, 2018). Basal leaves perform a protective function and therefore have a simplified structure. Middle leaves are typical for this species and constitute the basic mass of the shoot. Their primary function is photosynthesis. Within this formation, they differ. In the beginning, they have a simplified structure. In complex leaves of the basal formation a smaller number of leaves are formed, then the number of leaves increases towards the middle part of the stem, and then decreases up to the top. The apical leaves are formed in the upper part of the stem. They cover flowers (bracts) or inflorescences, have a poorly developed leaf blade, as well as basal leaves, sometimes change their color and function.

Given the above aspects of the importance of exploring the formation of individual leaf morphological parameters, the researches show evidence of scientific novelty and topicality. The developments in modern approaches to determining the area of both individual leaves and the entire assimilation surface of plants should also be considered. In this context, the defining methodological approach is the determination of regression models of leaf area dependencies on its linear parameters, such as leaf length and width or a combination of these parameters in product or power expressions. Nowadays, this method of estimation of leaf area formation regularities is applied for many crops from different botanical families and leaf morphological complexity (Robbins & Pharr, 1987; Elsner & Jubb, 1988; Firman & Allen, 1989; Schultz, 1992; Uzun & Celik, 1999; Montero et al., 2000; Kandiannan et al., 2002; Blanco & Folegatti, 2003; Stoppani et al., 2003; Lizaso et al., 2003; de Swart et al., 2004; Demirsoy et al., 2004; Demirsoy et al., 2005; Tsialtas & Maslaris, 2005; Gamper, 2005; Rouphael et al., 2006; Serdar & Demirsoy, 2006; Cristofori et al., 2007; Rouphael et al., 2007; Mendoza–de Gyves et al., 2007; Cristofori et al., 2007; Rivera et al., 2007; Peksen, 2007; Ramesh et al., 2007; Carmassi et al., 2007; Tsialtas & Maslaris, 2008; Mendoza–de Gyves et al., 2008; Antunes et al., 2008; Cristofori et al., 2008; Fallovo et al., 2008; Kumar, 2009; Mazzini et al., 2010; Rouphael et al., 2010a and 2010b; Bakhshandeh et al., 2011; Giuffrida et al., 2011; Cemek et al., 2011; Chavarria et al., 2011; Pompelli et al., 2012; Richter et al., 2014; Buttaro et al., 2015; Corcoles et al., 2015; Zanetti et al., 2017) including members of cruciferous family (Stoppani et al., 2003; Salerno et al., 2005; Olfati, 2010; Tartaglia et al., 2016; Aminifard et al., 2019). This issue, however, remains unexplored and conceptually important for oilseed radish plants in order to clarify the features and regularities of leaf apparatus formation among members of the cruciferous family.

MATERIALS AND METHODS

The research was conducted on the experimental field of the VNAU (N 49°11′31″, E 28°22′16″) on dark gray forest soils Luvic Greyic Phaeozem soils (IUSS Working Group WRB, 2015). Agrochemical field potential: humus content: 2.02–3.2%, lightly hydrolyzed nitrogen 67–92, mobile phosphorus 149–220, exchangeable potassium 92–126 mg kg^{-1} of soil at pH_{kcl} 5.5–6.0. The research on peculiarities of leaf apparatus formation of the oilseed radish Zhuravka variety plants was carried out on the basis of two cardinally distant technological options of its construction at the rate of sowing of

4.0 million pcs. ha^{-1} of germinable seeds of row sowing (15 cm) and 0.5 million pcs. ha^{-1} of germinable seeds of wide-row (30 cm) sowing. The research of both options was conducted on a nonfertilized ground. The sowing period for both options corresponded to the end of the first and beginning of the second ten-day period of April. The climate of the region is moderately continental (Dfb according to the Köppen-Geiger climate classification (Pivoshenko, 1997)), average January temperature: -5 °C, average July temperature: 20 °C; annual precipitation: 420–590 mm, 80% of which occurs during a warm period. The increase in the overall favorability of hydrothermal vegetation regimes of oilseed radish towards reduction of weather risks should be placed in the following order: 2018–2015–2017–2016–2013–2014 (Table 1). The research covered three varieties of oilseed radish (*Raphanus sativus L.* var. *oleiformis Pers.*), namely ‘Zhuravka’, ‘Raiduha’ and ‘Lybid’. The study of the variability of the fodder radish fruits was carried out with a scheme including extreme gradations of the technological spectrum of agrophytocenosis formation in the study area, taking into consideration the borderline formats of the recommended mineral nutrition of the specimen (Table 2).

Table 1. Monthly average hydrothermal coefficient* over the growing season of oilseed radish, 2013–2018

Year of research	Months					Average for the years of vegetation
	V	VI	VII	VIII	IX	
2013	1.305	2.202	0.377	1.047	3.441	1.527
2014	2.783	1.078	1.137	0.750	0.736	1.269
2015	0.719	0.613	0.230	0.061	0.684	0.430
2016	1.227	0.893	0.682	0.486	0.063	0.663
2017	0.645	0.349	0.806	0.563	1.983	0.824
2018	0.258	3.124	1.349	0.349	0.680	1.179

* – $GTC = \frac{\sum R}{0.1 \cdot \sum t_{>10}}$, where the amount of precipitation (ΣR) in mm over a period with temperatures above 10 °C, the sum of effective temperatures (Σt > 10) over the same period, decreased by a factor of 10.

Table 2. The range of acceptable common options for the formation of oilseed radish agrophytocenosis in the study area (Tsytsiura, 2019)

Planting method and seeding rates (million germinable seeds·ha^{-1})		Fertilization (of the active substance), kg·ha^{-1}
row method (15 cm)	wide-row method (30 cm)	
1.0	0.5	without fertilizers
2.0	1.0	$N_{30}P_{30}K_{30}$
3.0	1.5	$N_{60}P_{60}K_{60}$
4.0	2.0	$N_{90}P_{90}K_{90}$

** – underlined are variants for studying.

The experiments were set in randomized blocks, in a split–plot scheme, with four replicates. Three manual weedings were performed for weed control, while pests (*Phyllotreta crusiferae* Kutsch.), *Ph. atra var. cruciferae* Goeze., *Ph. armoraciae* Koch., *Meligethes aeneus* F.) were controlled through the application of insecticide in the vegetative stage.

Samples were collected in different phenological stages and in leaves of different sizes and shapes, because radish plants produce leaves of different shapes along the cycle. After plant collection, the leaves were separated from the stem and only those photosynthetically active, with no damage or deformation caused by diseases, insects or other external factors, were selected. The annual number of the analyzed leaves was determined by the foliage level of plants in different years of observations, and according to the principle of single elimination, it provided for the analysis of leaves from 10 typical plants in non–contiguous repetitions for each technological variation of agrophytocenosis construction. The typicality of plants was determined for the middle dominating tier of oilseed radish plants of each studied variety according to a number of recommendations (Rabotnov, 1978; Ramensky, 1971).

Leaf parameters were determined using the Digimizer image analysis software (v 4.2) (Schoonjans, 2019). This software allows determining such leaf parameters as length (L), width (W), perimeter (P), area (LA). The specified morphometric parameters were determined in cm and cm^2, according to the image processing calibration system. The image of the leaves to be processed in the specified program is obtained by scanning with a CanoScan LIDE 700F scanner with the appropriate software for processing the obtained scanned images. Scanning of leaves within individual phenological periods of growth and development of oilseed radish plants was performed according to the order of their placement on the plant from the bottom to the top.

Typification of morphotypes of the leaf blade was performed in accordance with Fedorov et al. (1956), considering Cuptar (2019). Comparison of the significance of average values in comparison with the studied technological variations of the agrophytocenosis construction was carried out using a four-factor system of dispersion analysis. The general research methodology, associated observations and surveys were conducted in accordance with the baseline recommendations for studies on cruciferous crops (Saiko et al., 2011) with the methodological and descriptive recommendations of the classification ranking tables of variety examination (Test Guidelines for the conduct of tests for distinctness, uniformity and stability of Fodder Radish (*Raphanus sativus* L. var. *oleiformis* Pers., 2017) using correlation and regression methods of analysis (Sharma, 2005) and using a software package of statistical application programs Statistica 10, Exel 2013, Past 324.

RESULTS AND DISCUSSION

According to the results of morphometric analysis of oilseed radish leaves in their successive placement from the lower to the upper tiers, the presence of longline heterophylly with complex transient types of leaf blade between the tiers along the stem height was determined. For the oilseed radish, two types of changes were observed. In the early stages of vegetation up to the rosette phase – the beginning of the stem formation (BBCH 10–21), there is a gradual complication of the leaf blade from a simple morphotype in the cotyledons (obcordate) to a more complex morphotype (pinnatisect lyrate) for the leaves, which are formed during the period of the rosette formation and the beginning of the stem prolongation. In the subsequent process of plant growth from the stage of stooling to the stage of budding (BBCH 22–52), there is a domination of morphotypes of the middle tier leaves mainly of various transitional shapes of pinnatisect divided lyrate shape with signs of symmetry, asymmetry and disproportions with a marked deformation of the central vein. Already at the stage of the budding beginning (BBCH 48–50) in the zone of formed buds, the leaves of morphotypes of the upper tier are distinguished (pinnately divided and pinnatisect lyrate leaves, pedate, subulate, linear, wedge–shaped, sagittate, palmate, ovoid leaves, etc.). The morphotypes of oilseed radish leaves are shown in Fig. 1. According to the presented character of the longline morphology of leaves, oilseed radish plants can be attributed to the highly differentiated heterophyllous type according to Corona & Vasilyev (2007) with a clear division into the morphological types of leaf according to its height placement on the stem. In addition, by the nature of the dominance of a certain leaf fraction, i.e. the prevalence of the corresponding tier of leaf morphotypes, by the tier of their placement it is possible to evaluate the optimality of applied technological parameters in the construction of agrophytocenosis, which corresponds to the general conclusions in a number of researches on other cruciferous crops (Clarke, 1977; Mullen et al., 2006; Maugarny-Cales & Laufs, 2018; Aminifard et al., 2019).

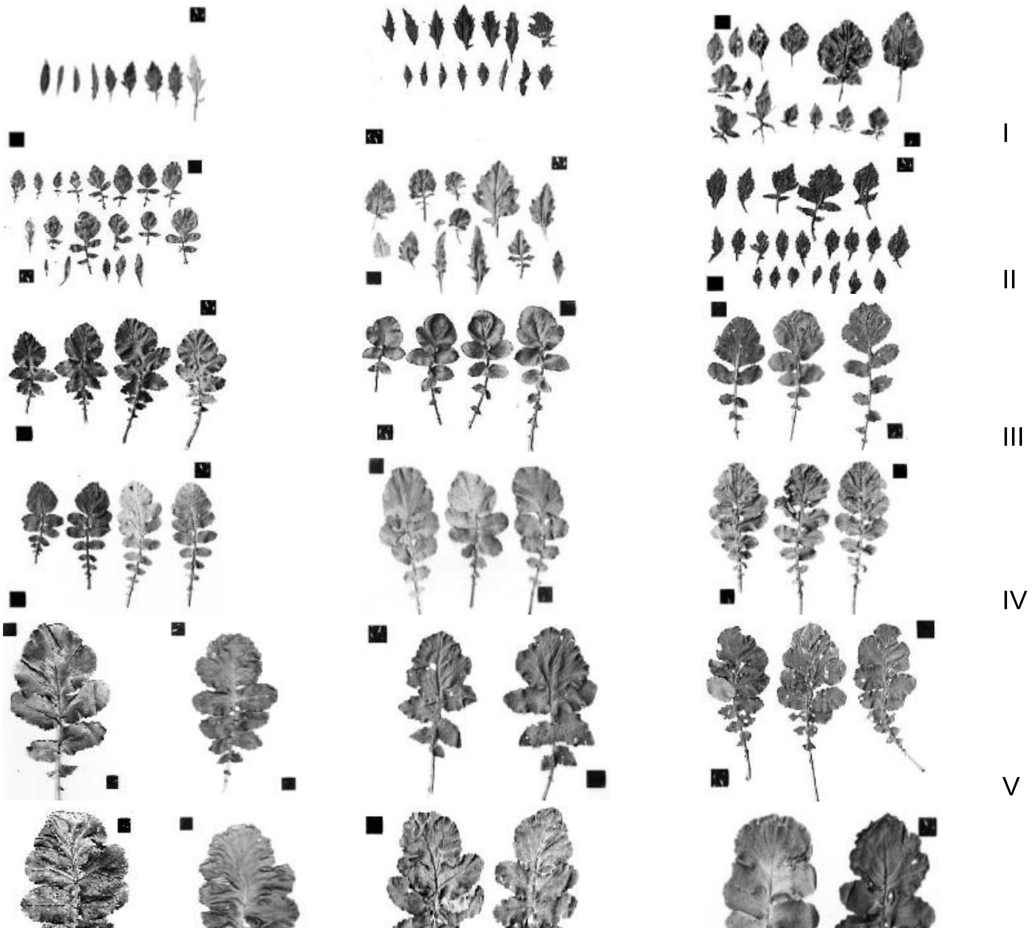


Figure 1. Morphotypes of oilseed radish leaves by tiers at the phenological flowering phase (BBCH 59–61) (I–II – upper tier leaves (zone of inflorescence branches and inflorescence itself)); III–IV – middle tier leaves; V–VI – lower tier leaves). Positioning of specimens sequentially from the lowest to the highest in a vertical sequence along the stem (composed for three varieties, marker black square with an area of 2 cm^2).

Considering the determined tier features in the morphology of oilseed radish leaves, different character of the structural complexity of leaves by the nature of their dwelling structure was also determined, including the character of the right–hand and left–hand placement of the serratures of the leaf blade edge, the presence of signs of fluctuating asymmetry and other signs, which are expressed in the total points of the number of differences (dwells) (Corona & Vasilyev, 2007). Given the above features, several basic types (metamers) of the leaf and a number of intermediate types, which are transitional between the main metamers within the selected axial stem tiers by leaf arrangement, can be considered in the oilseed radish, which is clearly demonstrated in Figs 1–3. Thus, leaves of the lower tier are characterized by the formation of an ovoid-lyrate type with dissected or divided almost symmetrical type of leaf blade lobes, which often overlap each other, or form a complex morphological growth type which artificially masks the dissection of the general morphology of the leaf. Leaves of the lower tier are typical for cruciferous crops of lyrate-sected type with 3–8 one-sided lobes of the leaf blade with the maximum width of the leaf on the last or penultimate leaf lobe.

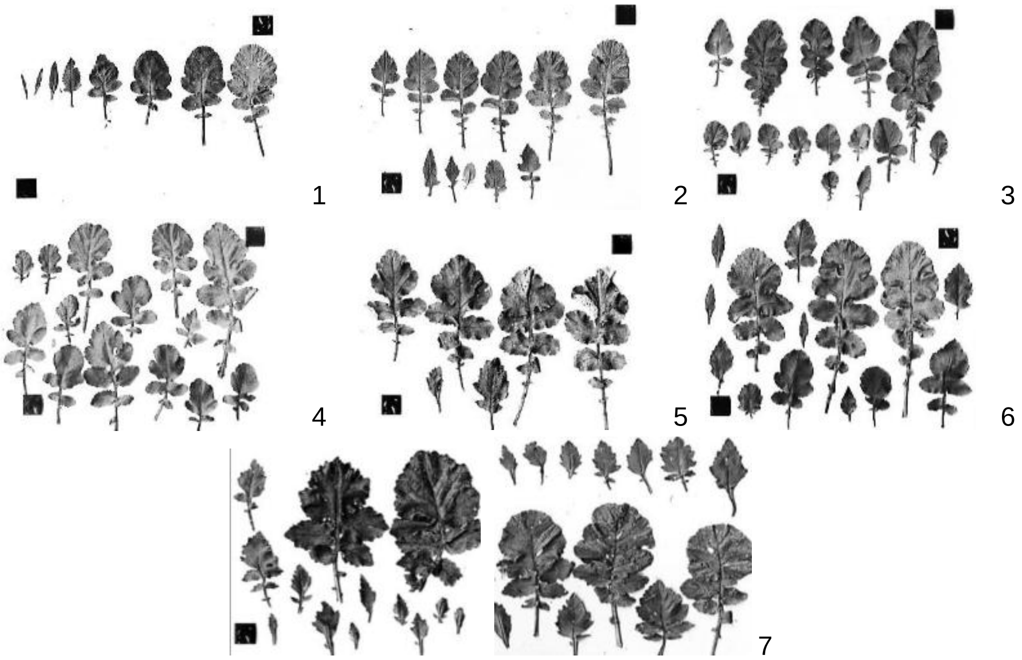


Figure 2. General morphotypology of oilseed radish leaves with different stand density during the flowering phase (BBCH 59–61) on a nonfertilized ground for 'Raiduha' variety (for inter-row spacing of 15 cm: 1 – 4.0 million pcs. ha^{-1} of germinable seeds; 2 – 3.0 million pcs. ha^{-1} of germinable seeds; 3 – 2.0 million pcs. ha^{-1} of germinable seeds; 4 –1.0 million pcs. ha^{-1} of germinable seeds; for inter-row spacing of 30 cm: 5 – 2.0 million pcs. ha^{-1} of germinable seeds; 6 – 1.5 million pcs. ha^{-1} of germinable seeds; 7–0.5 million pcs. ha^{-1} of germinable seeds), 2017. (marker black square with an area of 2 cm^{2}).

Progressively to the upper zone, transitional leaf morphotypes with different asymmetrical number of leaf parts of the distinct dissected leaf blade appear. These leaves show signs of fluctuating asymmetry with less development of the left side of the leaf by the field of view. Leaves of the upper tier, which are mainly adjacent to the generative part of plants, both behind the main flower stalk and lateral reproductive branches, have the most diverse morphological structure, which consistently passes from the dissected 1–4 lobular leaf blades to the already specified morphotypes: subulate, linear, wedge–shaped, sagittate, palmate, ovoid, etc. Similar, but less distinct, nature of formation of morphological parameters of the leaf is noted in other cruciferous crops of spring rape (Pecham, P.A. & Morgan et al., 1985; Chavarria et al., 2011; Cargnelutti Filho et al., 2015), winter rape (Jullien et al., 2009), white mustard (Khader & Bhargava, 1984; Kumar et al., 1997) and other cruciferous crops (Paul, 1980; Gupta, 2009; Weraduwage et al., 2015). As a result, morphological rows with certain regular changes of both morphological types and morphological parameters in length, width and perimeter of the leaf can be identified for oilseed radish plants (Fig. 2). Moreover, the character of dynamic increase of linear parameters of a leaf (Fig. 3) during the flowering phase differs in different technological variations of oilseed radish agrophytocenosis construction, distinguishing two types: stably descending, providing for a constant decrease in the linear size of a leaf and its area from leaves of the lower tier to leaves of the upper tier, and oscillating – with a gradual increase in the morphological parameters of a leaf to 3–5 leaves in a row and a subsequent constant decrease in the specified parameters for subsequent leaves in a row up to the uppermost ones. We marked the first type for technological variations of 2.0–4.0 million pcs. ha^{-1} of germinable seeds, and the second type for all other variations under study. For the variation of 0.5–1.0 million pcs. ha^{-1} of germinable seeds in the dynamic row for the first 2–6 leaves a relative constancy in morphological development with subsequent decrease towards the upper tier was noted. It should also be noted that the total number of leaves on the plant during the flowering phase differs significantly from 5–10 leaves in variations of 4.0 million pcs. ha^{-1} of germinable seeds to 15–22 leaves in variations of 0.5 million pcs. ha^{-1} of germinable seeds. However, for the indication of the number of leaves for the various technological variants under study, a significant scale of the indicator values was also noted. So, if for a variation of 4.0 million pcs. ha^{-1} of germinable seeds it was within the range of 5–11 leaves during the period of estimations, then for a variation of 0.5 million pcs. ha^{-1} of germinable seeds it was within the range of 11–19 and even up to 40–75 leaves. It should be noted that with a decrease in sowing rate and fertilizer growth, the number of leaves of the upper tier of the plant, which belong to its generative zone, increases intensively, and the majority of leaves, which determine the main course of the assimilation process, remains relatively stable and is within the limits from 5–8 to 10–17 leaves with a range of values up to 12–24 depending on the variation. This is clearly illustrated by Figs 1–4.

The specified features of the dynamic changes of the leaf blade area within the plant by their height gradation of placement are most noticeable in the period of the end of budding (BBCH 53–57) – the beginning of flowering (BBCH 61–62), since during this period it is possible to distinguish the entire typology of leaf morphological forms within the plant's upper tiers.

We researched the nature of these changes in the form of graphical interpretation with the description of the corresponding dependence on the basis of selection of the corresponding classical function. For our technological variations with averaging of values on the variety factor, year of research and technological variation, these dependencies are shown in Fig. 4.

Figure 3. Dynamic rows of leaves in the order of their placement on the plant from the base to the top during the flowering phase (BBCH 59–61) for different technological variations of agrophytocenosis construction for 'Zhuravka' variety (1 – 3.0 million pcs. ha^{-} of germinable seeds (inter–row spacing of 15 cm); 2 – 2.0 million pcs. ha^{-1} of germinable seeds (inter-row spacing of 15 cm); 3 – 1.0 million pcs. ha^{-1} of germinable seeds (inter–row spacing of 15 cm); 4 – 1.0 million pcs. ha^{-1} of germinable seeds (inter–row spacing of 30 cm); 5 – 0.5 million pcs. ha^{-1} of germinable seeds (inter–row spacing of 30 cm), 2016.

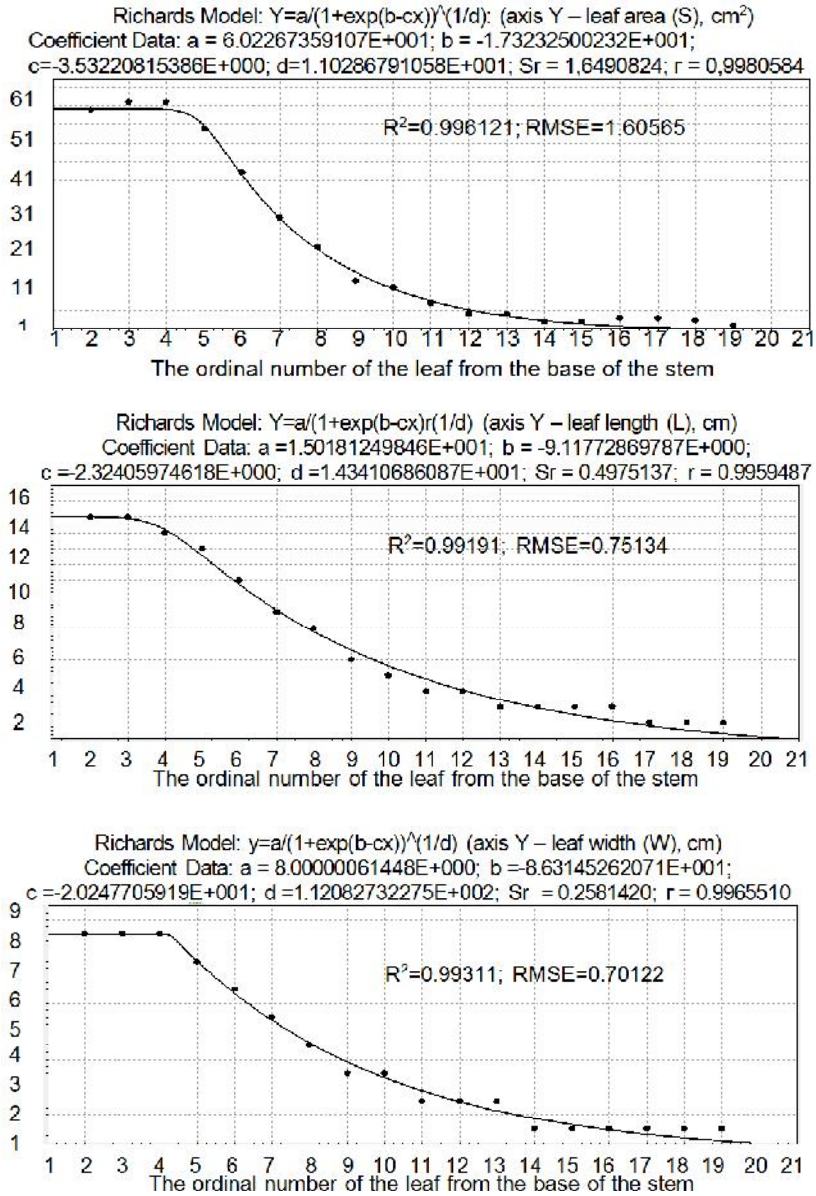


Figure 4. The change model of leaf area and its morphological parameters for the average row of three oilseed radish varieties and 32 technological variations of their agrophytocenosis construction for the consolidated period between 2013–2018 during the phase of the end of budding – the beginning of flowering (BBCH 57–61).

The results of selection of the corresponding dependence of changes in both the area of the average model leaf of oilseed radish varieties and its morphological parameters with the use of CurveExpert Pro: 2.6.5 software package allowed describing its character with maximum approximation according to the Richards model (at R^2 99.01–99.31). The Richards curve or generalized logistic is a widely used growth model that will fit a wide range of S-shaped growth curves. Among the closest in terms of approximation R^2 to describe the regularities of the specified changes in leaf morphology we have considered the Weibull model (leaf area parameters (S) $R^2 = 0.98974$; $RMSE = 1.92674$, for the leaf length parameter (L) $R^2 = 0.990527$; $RMSE = 0.87914$, for the leaf width parameter (W) $R^2 = 0.98756$; $RMSE = 0.91257$) and the Rational Function model (corresponding parameters (S) $R^2 = 0.97956$; $RMSE = 2.2584$; L: $R^2 = 0.980421$; $RMSE = 1.17894$; W: $R^2 = 0.97456$; $RMSE = 1.21475$). Given that the Richards model belongs to the category of complex asymmetric models, formation of linear parameters of an oilseed radish leaf has certain regularities determined by us, but it also has certain cautions and features. Particularly, the general regularities in the budding–flowering period include the evident persistence of the reduction of leaf length and width in the height gradient. Moreover, 1–5 leaves should be attributed to morphological forms with the largest linear sizes and area located in the lower and main middle tier of the stem, 6–11 leaves to transitional forms of the middle and upper tier, and the rest to morphological forms of the upper (generative) tier.

The plateau presence in 3–4 initial points indicates a certain oscillatory nature of leaf size formation from the rosette phase to the flowering phase noted by us, in particular the formation of intermediate leaves by the order of their appearance from the seedling phase to the rosette phase with a gradual increase of linear parameters of the following leaves by the order of their formation on the stem up to the phase of the beginning of budding and, accordingly, a constant decrease in leaf size by the order of their formation from the phase of the end of budding to the phase of the end of flowering.

Similar observations on the search for regularities in the formation of shape and size of the leaf within the plant by the height gradient of the stem have been made in application to higher plants during the 80s–90s of the last century (Meinhardt & Gierer, 1974; Green & Poething, 1982; Cote et al., 1992; Gould et al., 1992; LAWG 1999) and in modern times (Pugnaire et al., 2007; Shi et al., 2018). Nevertheless, the real actions, except for the general approaches to plant modeling on the basis of botanical specification of plant parts (Lintermann & Deussen, 1999; Prusinkiewicz, 2004) have not been made. In this context, our researches in some aspects allow us to re-evaluate the peculiarities of formation of individual parameters of the assimilation surface of plants from the cruciferous family.

Also important is the assessment of both the variability in leaf morphology and the influence of major technological approaches on its value, the results of which are presented in Table 3. On the one hand, the data provided indicate both the high degree of variability in the morphological parameters of the leaves and the corresponding changes in the application of different combinations of sowing rate, row-width spacing and fertilization. In terms of the spread of values, the overall variability of the forms and area of the leaf has a strong tendency to increase both within the range of row and wide-row sowing method with a decrease in sowing rate. The application of the growing fertilization rates enhances both the overall size of the leaves and their area, and provides for an intensive increase in the variability of leaf morphotypes, widening the differentiation of the leaf row to the extreme morphological gradations between large and small leaves and an overall widening of the spread of values. In addition, we noted that this dynamics is more typical for the leaf length than its width. Thus, from this perspective the elongation of the oilseed radish leaf blade is more sensitive to the coenotic tension in agrophytocenosis than width changes.

Table 3. Summary morphological individual parameters of oilseed radish leaf at the flowering phase (BBCH 59–61) depending on the technological variation of agrophytocenosis construction, 2013–2018

Sowing rate (million pcs.ha of germinable seeds) (C), sowing method (B)	Fertilizer (D)	Average for 3 varieties (Zhuravka, Raiduha and Lybid)								
		Range of			S, cm^2	W, cm	L, cm	V_R[*]		
		S, cm^2	W, cm	L, cm				S	W	L
4.0, row	1[**]	0.38–31.54	0.29–7.15	1.41–15.14	16.27	3.46	8.6	1.92	1.98	1.60
	2	0.31–40.82	0.37–7.63	1.58–16.29	18.82	3.87	8.95	2.15	1.88	1.64
	3	0.27–46.24	0.31–7.89	1.45–17.91	19.64	4.06	9.44	2.34	1.87	1.74
	4	0.22–42.29	0.28–6.71	1.24–16.18	19.44	4.04	9.32	2.16	1.59	1.60
3.0, row	1	0.53–44.94	0.43–8.25	1.75–16.50	18.88	4.45	9.59	2.35	1.76	1.54
	2	0.48–60.37	0.43–8.48	1.52–19.19	23.40	4.8	10.49	2.56	1.68	1.68
	3	0.46–70.61	0.43–9.25	1.49–21.21	24.88	5.08	10.88	2.82	1.74	1.81
	4	0.35–68.92	0.35–8.69	1.18–20.69	23.11	4.94	9.86	2.97	1.69	1.98
2.0, row	1	0.59–48.11	0.51–6.85	1.49–14.66	19.39	3.95	8.51	2.45	1.61	1.55
	2	0.63–98.04	0.49–18.54	1.71–25.53	23.95	5.16	11.3	4.07	3.50	2.11
	3	0.36–105.91	0.34–19.44	1.63–26.85	29.41	5.25	10.55	3.59	3.64	2.39
	4	0.28–99.69	0.27–18.72	1.36–25.69	31.12	5.89	11.25	3.19	3.13	2.16
1.0, row	1	0.72–82.89	0.70–12.77	1.69–20.57	24.87	4.19	9.05	3.30	2.88	2.09
	2	0.92–92.14	0.67–16.83	1.74–21.17	34.69	5.63	12.01	2.63	2.87	1.62
	3	1.34–166.22	0.67–18.86	1.99–29.12	37.37	5.95	12.44	4.41	3.06	2.18
	4	1.28–174.82	0.55–19.48	1.51–32.87	40.53	6.74	12.97	4.28	2.81	2.42
2.0, wide-row	1	0.63–88.71	0.42–11.52	1.47–16.56	21.59	4.3	9.02	4.08	2.58	1.67
	2	1.19–109.74	0.96–14.82	1.84–17.68	28.74	5.4	9.89	3.78	2.57	1.60
	3	1.68–141.87	1.28–16.29	1.67–19.12	33.54	5.86	10.4	4.18	2.56	1.68
	4	1.44–126.81	1.19–15.12	1.48–18.20	33.75	5.93	10.52	3.71	2.35	1.59
1.5, wide-row	1	0.72–106.84	0.50–10.70	2.53–29.43	27.58	4.87	10.38	3.85	2.09	2.59
	2	3.14–193.85	1.65–16.45	3.72–29.68	33.45	5.94	12.09	5.70	2.49	2.15
	3	2.02–191.1	1.03–30.34	2.39–33.13	42.39	6.34	13.29	4.46	4.62	2.31
	4	1.54–172.63	1.02–27.28	1.89–27.44	45.84	6.98	13.72	3.73	3.76	1.86
1.0, wide-row	1	1.13–101.33	0.63–9.97	2.13–23.56	40.19	5.35	11.2	2.49	1.75	1.91
	2	0.96–294.84	0.65–26.39	2.26–31.92	49.27	5.99	12.08	5.96	4.30	2.46
	3	4.52–310.48	1.46–27.05	3.94–31.80	57.36	6.71	12.2	5.33	3.81	2.28
	4	4.18–339.47	1.28–28.57	2.73–32.82	64.44	7.6	13.43	5.20	3.59	2.24
0.5, wide-row	1	3.87–277.64	1.63–24.02	3.74–29.96	51.12	6.19	12.59	5.36	3.62	2.08
	2	2.67–286.91	1.47–26.97	2.68–31.51	64.6	8.24	16.08	4.40	3.09	1.79
	3	3.02–359.57	1.64–30.62	2.96–34.33	70.68	8.31	16.48	5.04	3.49	1.90
	4	2.84–396.80	1.55–33.61	2.75–36.27	79.22	9.16	17.87	4.97	3.50	1.88
For average values		S	W	L	Impact share	S	W		L	
LSD_{05} factor A		0.21	0.05	0.09	A	19.77	15.91		21.64	
LSD_{05} factor B		0.12	0.03	0.05	B	30.80	24.42		15.36	
LSD_{05} factor C		0.17	0.04	0.08	C	28.60	28.18		32.78	
LSD_{05} factor D		0.17	0.04	0.08	D	9.82	22.46		17.38	
LSD_{05} interaction AB		0.30	0.07	0.13	AB	1.45	0.26		0.23	
LSD_{05} interaction AC		0.42	0.10	0.19	AC	1.33	0.36		0.46	
LSD_{05} interaction AD		0.42	0.10	0.19	AD	0.48	0.20		0.15	
LSD_{05} interaction BC		0.24	0.06	0.11	BC	4.99	4.00		7.32	
LSD_{05} interaction BD		0.24	0.06	0.11	BD	1.32	0.87		0.60	
LSD_{05} interaction CD		0.34	0.08	0.15	CD	1.01	2.76		3.19	
LSD_{05} interaction ABC		0.60	0.14	0.27	ABC	0.22	0.11		0.15	
LSD_{05} interaction ABD		0.60	0.14	0.27	ABD	0.06	0.01		0.01	
LSD_{05} interaction ACD		0.85	0.20	0.38	ACD	0.06	0.07		0.08	
LSD_{05} interaction BCD		0.49	0.12	0.22	BCD	0.08	0.35		0.64	
LSD_{05} interaction ABCD		1.20	0.29	0.54	ABCD	0.01	0.02		0.02	

[*] – oscillation coefficient by Gumbel (1947);

[**] – 1 – without Fertilizer, 2 – $N_{30}P_{30}K_{30?}$, 3 – $N_{60}P_{60}K_{60}$, 4 – $N_{90}P_{90}K_{90}$.

This effect is more noticeable in the variations of row sowing than in wide-row sowing, and corresponds to the general typology of reaction of plants with relatively tolerant type to clotting (Rabotnov, 1978). The high variability of the leaf morphological parameters also confirms the value of the oscillation coefficient (V_R). The proximity of the values of this indicator for all the studied parameters S, L, and W indicates the possibility of a non-destructive method of determining the leaf area by the corresponding ratio of its length and width. On the other hand, its constant growth in comparison with non–fertilized and fertilized variations indicates that the application of additional fertilizer contributes to the expansion of the spread of variation and the corresponding range of leaf parameters within the plant. At the same time, the maximum variation of the leaf morphological features is maximum in the variants of 0.5 million pcs. ha^{-1} of germinable seeds. For this variation, the average V_R for certain leaf parameters was 3.43 with the same indicator in the variation 4.0 million pcs. ha^{-1} of germinable seeds 1.87.

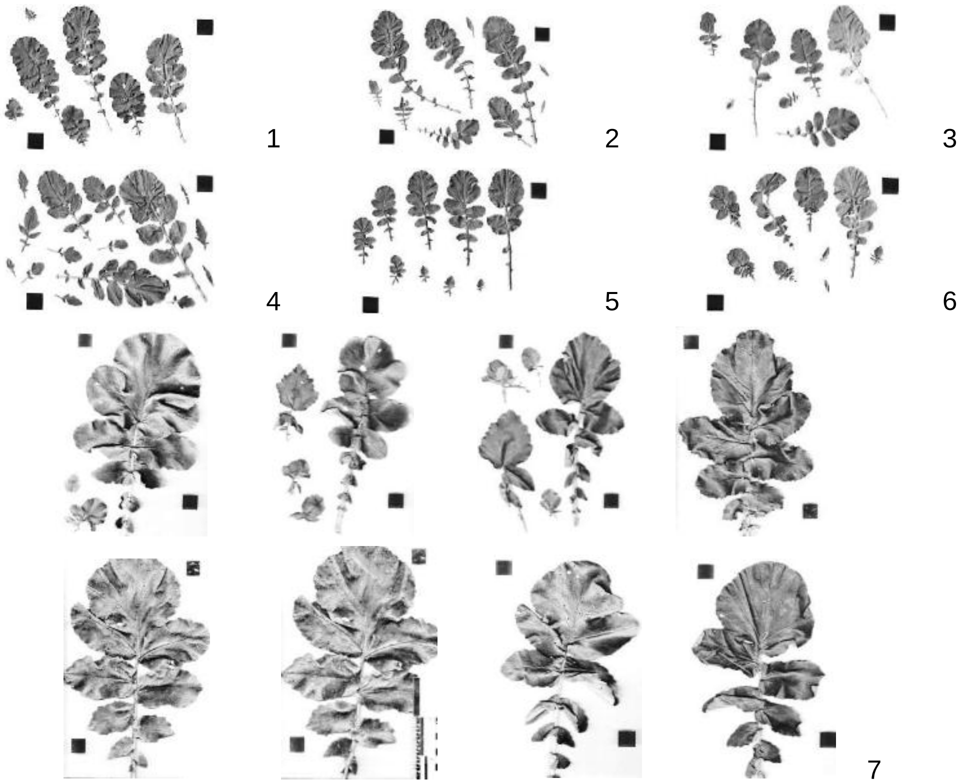


Figure 5. Scanned assimilation surface of 6 typical oilseed radish plants of 'Lybid' variety in the flowering phase with a sowing rate of 3.0 million pcs. ha^{-1} a of germinable seeds in the ground with the application of $N_{60}P_{60}K_{60}$ (position 1–6) and one typical plant with a sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds in the same fertilization ground (position 7) (marker black square with an area of 2 cm^2), 2014.

This is clearly confirmed by the data presented in Fig. 5, which shows a comparable comparison of the morphological row of leaves of the plant, namely for variations 4.0 and 0.5 pcs. ha^{-1} of germinable seeds of the 'Lybid' variety in 2014, which was favorable for intensive growth processes. It should also be noted that wide-row sowing variations ensured much higher variability of leaf morphological features than ordinary row sowing: the average V_R for row sowing was 2.40, meanwhile for wide-row sowing variations this value was 3.22. For different fertilizer options in comparison of non–fertilized ground and ground at application of 90 kg ha^{-1} of the primary material – 2.46 and 2.85, respectively. The conducted 4-factor dispersion analysis of morphological features of oilseed radish leaf confirms the previously made summaries concerning the influence of technological parameters of oilseed radish agrophytocenosis construction on the size of its leaf (the share of corresponding B and C factors is from 15 to almost 33% with the maximum combined effect on the leaf area indicator).

The results of the dispersion analysis also showed the determinant role of hydrothermal conditions during the year (factor A) in the range from 15 to 22% with the highest level of impact on the formation of leaf length indicator (L). Graphically, this dependence (Fig. 6, position 4) has a complex power nature.

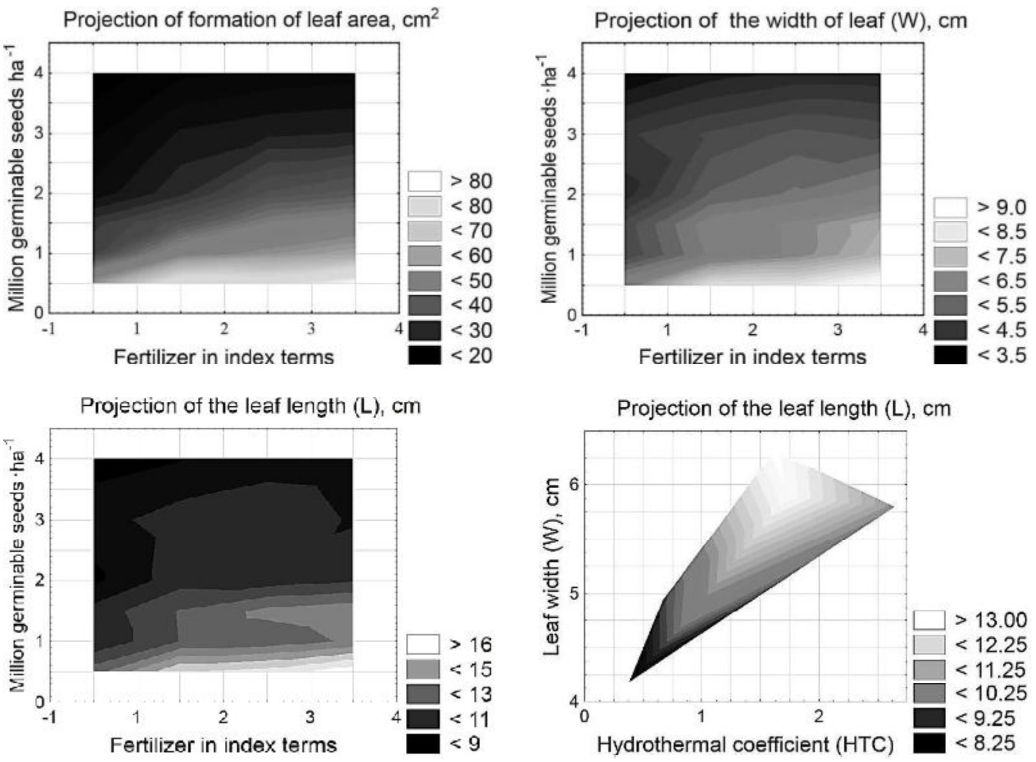


Figure 6. The reaction surface (projection (axis z)) of the formation of area depending on the sowing rate (stand density) of plants and fertilization in the index expression linear parameters of the leaf (width (W) and length (L)). The graphical dependence between the hydrothermal coefficient of the seedling–flowering period and the linear sizes of the leaf during the flowering period (position 4 (the relationship between the parameters: $z = -3.1375-0.7967x+3.5622y-1.5772x^2+1.0431xy-0.2929y^2$)) for the average value of varieties and years of study over the period 2013–2018.

Although, the growth of leaf length is associated with the growth of leaf width, but hydrothermal conditions during the period of leaf formation up to the flowering phase at their growth according to the hydrothermal coefficient (HTC) contribute to the overall growth of morphological parameters of the leaf with peak growth up to the HTC level of 1.6–1.8 with subsequent reduction of the overall length of the leaf blade at the HTC growth to the level of 1.8–2.6. The angular inclination of the reaction curve indicates the already determined advance effect of elongation of the leaf in comparison with the increase in its width. The determined features point to the fact that the increase in the intensity of growth processes due to excessive hydrothermal resources leads to intensive disproportional growth in above-ground biomass, including intensive leaf-making. The general shading and the increase of the coenotic tension contribute to the reduction of the average values for the plant of leaf morphological indicators and provide, as an option, the formation of a larger number of leaves with their significantly smaller average area. This distinguishes the average HTC level of 1.7 as the threshold for oilseed radish varieties from the perspective of combination of optimal growth rates and formation rates of individual leaf parameters. The results obtained correspond to the biological components of cruciferous crops growth processes and their reaction to stress factors (Paul, 1980; Nanda et al., 1995; Kumar et al., 1997; Kirkegaard et al., 2012), particularly positive reaction to the improvement of hydrothermal conditions in combination with sufficient humidity and moderate temperatures, guarantees the growth of HTC to 1.2–1.5 1.2–1.5.

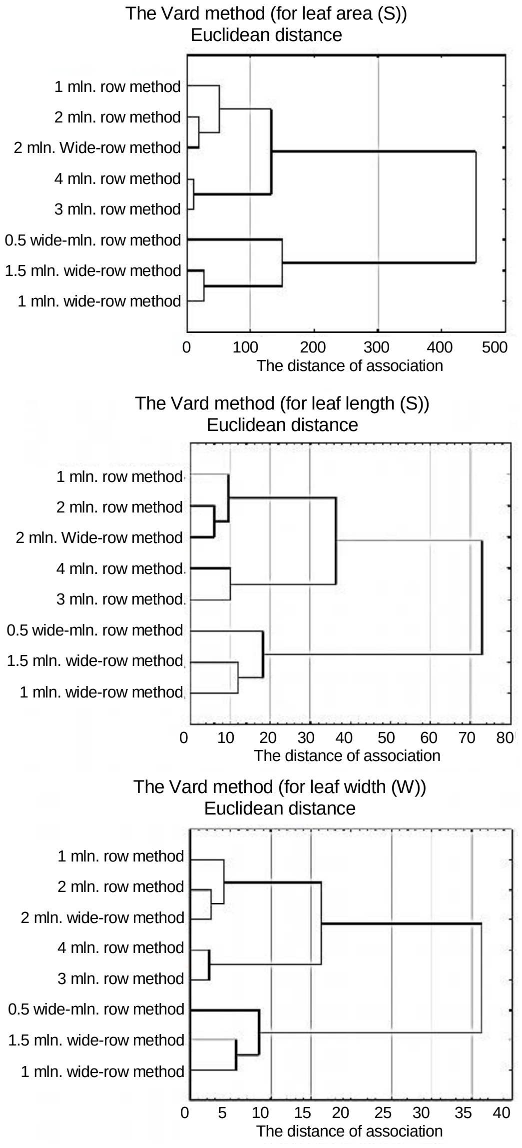


Figure 7. Cluster dendrograms of formation of the leaf average individual area and leaf linear sizes at various technological variations of the oil radish agrophytocenosis construction at the flowering phase (BBCH 59-61) on the average by the fertilizer options, 2013–2018.

The conclusions about the formation of average linear sizes of the leaf and its area depending on the range of applied technological solutions for growing oilseed radish varieties are also confirmed by the results of cluster analysis (Vard method) (Fig. 7), the index of Euclidean distances the system of row sowing according to which by and wide-row sowing have significant differences in the size of morphological features of the leaf on the plant, starting with the sowing rate of 1.5 million pcs. ha^{-1} of germinable seeds due to the classification of the variation of 2.0 million pcs. ha^{-1} of germinable seeds at wide-row sowing to one cluster group with row sowing variations. The morphological parameters of the leaf are significantly higher in the variation of 0.5 million pcs. ha^{-1} of germinable seeds. Close in terms of formation of both length and width of the leaf were variations of 4.0 and 3.0 million pcs. ha^{-1} of germinable seeds with row sowing and 1.0 and 1.5 million pcs. ha^{-1} of germinable seeds with wide row sowing. Generally speaking, in terms of the association distances indicator, as it has been noted, the variability range of the leaf width within the oilseed radish plant is significantly less variable than its length in terms of the ratio of the specified distances as 1:2 in favor of the leaf width indicator (W).

Thus, the analysis and the intermediate generalizations that have been done confirm that it is possible to determine the leaf area using a non–destructive method of calculating it by selecting the appropriate functional connection between the initial parameters S, L and W. Possibility of such methodical approach is caused by the established features of uniformity of value formation of both width, and length of a leaf at various technological variations and certain proximity of determining factors in system of conditions year–variety–sowing method–sowing rate–fertilizer.

This is also confirmed by the conducted correlation analysis for the totality of the examined leaves between the formation of its main morphological features, their combinations and the leaf area (Table 4, Fig 8).

Table 4. Correlation coefficients between the area (S), length (L) and width (W) of individual leaves of oilseed radish and some its combination (in the cumulative total of accounted plant leaves for all varieties, technological variations and years of research)

Parameters	S, cm^2	L, cm	W, cm	L+W, cm	W^2, cm^2	L^2, cm^2	L^2+W^2, m^2	L W, cm^2
S, cm^2	1.000	0.880	0.885	0.903	0.914	0.809	0.926	0.928
L, cm	0.880	1.000	0.896	0.989	0.952	0.729	0.937	0.894
W, cm	0.885	0.896	1.000	0.953	0.847	0.885	0.892	0.927
L+W, cm	0.903	0.989	0.953	1.000	0.939	0.799	0.944	0.927
W^2, cm^2	0.914	0.952	0.847	0.939	1.000	0.782	0.988	0.943
L^2, cm^2	0.809	0.729	0.885	0.799	0.782	1.000	0.868	0.939
L^2+W^2, cm^2	0.926	0.937	0.892	0.944	0.988	0.868	1.000	0.981
L W, cm^2	0.926	0.937	0.892	0.944	0.988	0.868	1.000	0.981

* – all correlations are significant at the level $p < 0.001$.

The provided data show that there is a direct close relation between the leaf area and its linear parameters. At the same time, the closeness of relation with the parameter of its width is higher by 4.4%.

This confirms our conclusions on different rates of linear and latitudinal increase of the oilseed radish leaf blade and the significantly higher reaction of the leaf length parameter on changing the agrophytocenosis density against the background of increasing fertilizer rates. Due to this difference, the reaction plane between the length, width of the leaf and the hydrothermal coefficient has an angular inclination with respect to the Z axis (see Fig. 6, position 4). Thus, the established closeness of the relation enabled us to search for an appropriate regression equation of the relation between the leaf area and the variants of attracting to the equation its length (L) and width (W), or their respective combinations (Table 5). The results obtained on 29 models of different combinations of leaf parameters in the consolidated totality proved the complexity of dependencies between the leaf area and its basic dimensions.

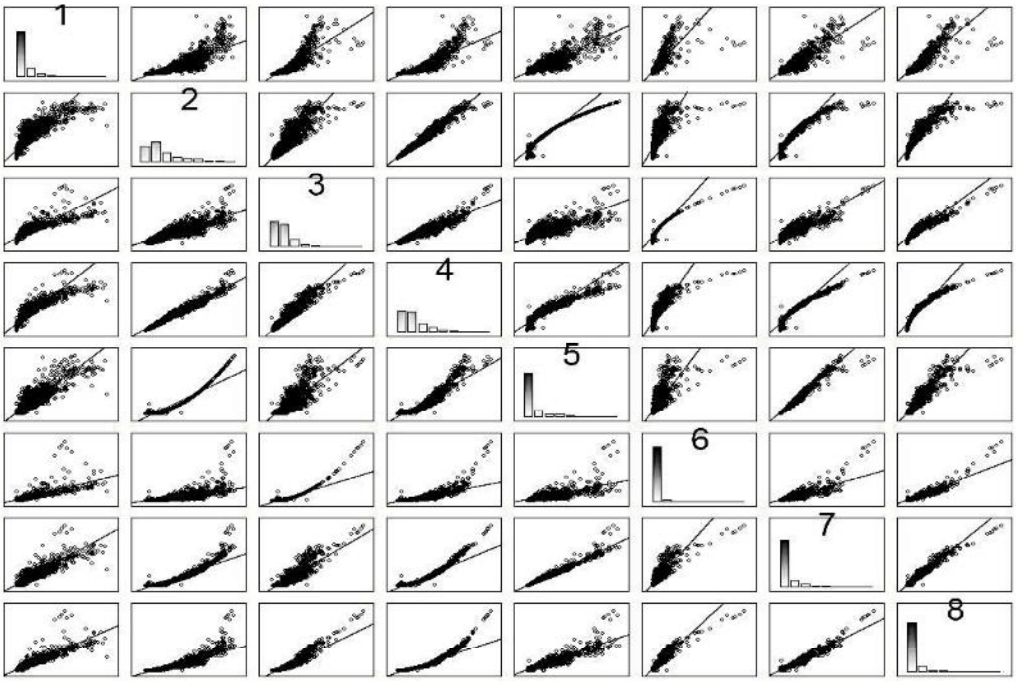


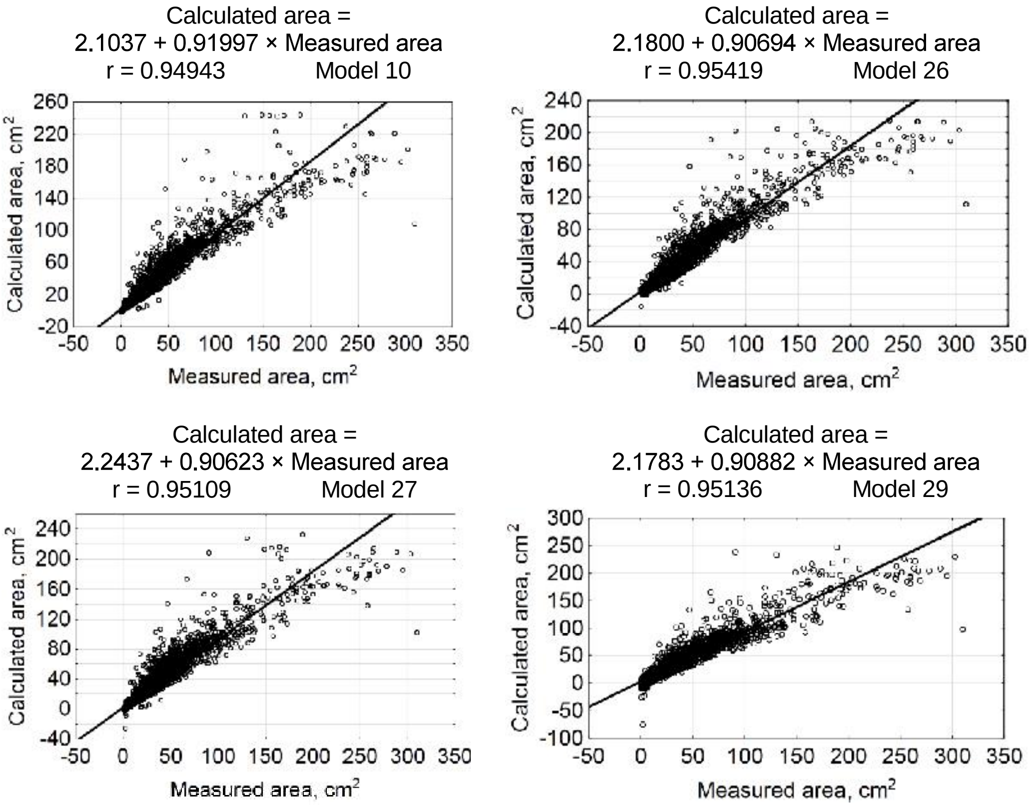
Figure 8. Correlation matrix of dependencies between leaf area (S, cm^2) its length (L, cm) and width (W, cm) for oil radish varieties in the totality of data for the period between 2013 and 2018 (matrix diagonal from left to right; 1 – S (cm^2); 2 – L (cm); 3 – W (cm); 4 – L+W (cm); 5 – W^2 (cm^2); 6 – L^2 (cm^2); 7 – (L+W)^2 (cm^2); 8 – LW (cm^2)).

In comparison with similar researches on rapeseed (Chavarria et al., 2011; Cargnelutti Filho et al., 2015; Tartaglia et al., 2016) and radish (Salerno et al., 2005; Aminifard et al., 2019), where models of correlation of leaf area with its morphological parameters were determined, which provide the level of approximation (R^2) 0.972–0.984 with the *RMSE* value 6.19–11.28, in our case, the approximation level of the examined models in the maximum value was 0.9106 (model 26) with a spread of *RMSE* values 9.75–21.19.

Table 5. Regression models for the estimation of canola leaf area (S, cm^2) with the respective coefficients of determination (R^2) of their generation and the Akaike information criterion (*AIC*), root–mean–square error (*RMSE*), Willmott's index (Willmott et al., 1985 and 2012) of agreement (*d*) and *BIAS* index of their test, as a function of length (L), width (W) and the product of length versus width (L.W) (in the cumulative total of accounted plant leaves for all varieties, technological variations for the period between 2013 and 2018)

Model	Form of model tested	Fitted coefficients and costant					R^2	Test of the models			
no.		a	b	c	d	e		*AIC*$_C$	*RMSE*	*d*	*BIAS*
1	$S = a + bL$	–17.9815	5.0238				0.7751	41268.9	15.45	0.885	–0.0005
2	$S = a + bW$	–20.0172	10.1400				0.7835	41335.7	15.16	0.888	0.0001
3	$S = a + b\,LW$	3.1566	0.4090				0.8605	41913.2	12.17	0.927	–0.0099
4	$S = a + b(L + W)$	–20.7099	3.5219				0.8156	41583.5	13.99	0.908	0.0014
5	$S = a + b(L^2 + W^2)$	2.9473	0.1623				0.8579	41892.6	12.28	0.928	–0.0061
6	$S = a + bL^2$	3.3383	0.2012				0.8353	41728.6	13.22	0.915	0.0202
7	$S = a + bW^2$	8.3645	0.5772				0.6539	40222.9	19.17	0.773	0.0013
8	$S = a + bL + cL^2$	0.9069	0.5280	0.1819			0.8374	41744.2	13.18	0.916	–0.0189
9	$S = a + bW + cW^2$	–17.1133	8.9509	0.0835			0.7865	41358.6	15.05	0.889	–0.0042
10	$S = a + bLW + c\,(LW)^2$	–0.9993	0.5428	–0.0003			0.9018	42201.5	10.25	0.953	0.8305
11	$S = a + b\,(L + W) + c\,(L + W)^2$	–3.6447	0.9003	0.0700			0.8737	42006.8	11.58	0.937	–0.0337
12	$S = aL^b$	0.3712	1.8147				0.8349	41726.0	13.24	0.917	–2.6743
13	$S = aW^b$	2.7911	1.4442				0.7760	41276.1	15.42	0.867	9.2928
14	$S = a(LW)^b$	0.9075	0.8623				0.8773	42032.2	11.41	0.937	3.5065
15	$S = a(L + W)^b$	0.2078	1.7745				0.8751	42017.1	11.51	0.937	1.3669
16	$S = a(W^2)^b$	2.7897	0.7220				0.7729	41255.5	15.52	0.865	9.1994
17	$S = a(L^2)^b$	0.3687	0.9084				0.8334	41718.6	13.29	0.917	–2.7293
18	$S = a(L^2 + W^2)^b$	0.3211	0.8990				0.8609	41916.2	12.15	0.930	–0.3281
19	$S = a + bL + cW$	–21.3902	2.5252	5.5975			0.8222	41633.2	13.74	0.912	0.0001
20	$S = a + bL^2 + cW^2$	2.9555	0.1724	0.1596			0.8580	41895.1	12.41	0.930	4.0421
21	$S = a + bL + c(LW)$	–3.8599	1.4526	0.3087			0.8735	42005.4	11.59	0.937	0.0034
22	$S = a + bW + c(LW)$	–2.0309	2.0582	0.3356			0.8650	41945.5	11.97	0.931	0.0008
23	$S = a + bL + c(L + W)$	–21.3902	–3.0722	5.5975			0.8222	41633.2	13.74	0.912	0.0036
24	$S = a + bW + c(L + W)$	–21.3902	–3.0722	5.5975			0.8222	41633.2	21.19	0.852	51.5648
25	$S = a + bL + cW + dL^2 + eW^2$	–2.1694	–4.2264	9.4815	0.2470	-0.1859	0.8959	42165.5	10.52	0.948	0.0214
26	$S = a + bL + c\,(LW) + dL^2 + e\,(LW)^2$	7.9316	–2.3613	0.6897	0.0458	-0.0005	0.9106	42265.1	9.75	0.956	–0.1523
27	$S = a + bW + c\,(LW) + dW^2 + e\,(LW)^2$	–1.2284	0.5111	0.5902	-0.2003	-0.0002	0.9048	42226.1	10.07	0.954	0.0443
28	$S = a + bL + c\,(L + W) + dL^2 + e\,(L + W)^2$	–2.1808	–11.4602	8.0457	0.2831	-0.0400	0.8911	42132.3	10.85	0.945	0.0501
29	$S = a + bW + c\,(L + W) + dW^2 + e\,(L + W)^2$	–0.6683	13.1036	-4.2612	-0.6174	0.1666	0.9073	42242.8	10.04	0.953	0.0285

According to the criteria of correlation of the model evaluation parameters, four models have been distinguished, which ensure the combination of the above criteria with the possibility of meeting the requirements of the regression model between the defined and calculated value of the individual leaf area (Fig. 9).



Calculated area = 2.1037 + 0.91997 × Measured area
r = 0.94943 Model 10

Calculated area = 2.1800 + 0.90694 × Measured area
r = 0.95419 Model 26

Calculated area = 2.2437 + 0.90623 × Measured area
r = 0.95109 Model 27

Calculated area = 2.1783 + 0.90882 × Measured area
r = 0.95136 Model 29

Figure 9. The dependence between the individual area of the oilseed radish leaf defined using appropriate mathematical models that include the appropriate morphological parameters of the leaf and the same area defined by scanning the entire leaf. The solid line represents the linear regression line; the line represents the 1:1 relationship.

Assessing the accuracy of the prediction in the system of non-destructive determination of individual leaf area, we can distinguish the model 26 with the highest level of approximation (R^2), the d criterion and the lowest *RMSE* value. Although there are general cautions concerning the application of this model and similar to it among 29 analyzed oilseed radish plants. Particularly, the high variability of the leaf area within the plant and the complexity of its morphotypes, defined by us in the first part of the paper, caused certain difficulty in observing the regular correlations between the length (L) and width (W) of an oilseed radish leaf. As a result, direct dependencies of both non–power and direct power linear nature do not provide sufficient level of regression ratio significance. The effectiveness of predictive models based on a combination of power and linear dependencies is higher, especially when using the leaf length criterion (L) in equations. Thus, the L criterion is parametrically more informative for determining the area of an oilseed radish leaf (R^2 level was 0.823 on average for models using the L criterion and 0.755 for using the leaf width criterion (W)), than the width criterion (W), which is consistent with the results of researches Chavarria et al. (2011) on the use of leaf length in the variations of determining the leaf area by indirect methods of its measurement. Relatively high values of the *BIAS* criterion for models with the highest level of approximation R^2 indicate, according to the properties of this indicator (Leite et al., 2002), an increase in the regression dependence bias for leaves with an intensively developed leaf blade of large sizes, which, as we have already noted, may have the nature of a mutual overlap of the divided lobes, and often a complex corrugated surface (see Fig. 5, position 7). As a result, the overall variability predetermines the expansion of the deviation from the desired regression dependence for leaves with an area of more than 150 cm^2. Thus, regression dependence nature for prognostic and actual leaf area value has a sectoral nature with an extension from the minimum point of regression values to the maximum point, which attributes the dependence model to a multi–component in which linear and power variations can be combined (Sheskin, 2007). This nature is confirmed by the value of the *AICS* indicator, which according to the obtained parameters of values attributes morphological parameters of oilseed radish leaves within the plant to the highly variable ones (Motulsky & Christopoulos, 2003; Floriano et al., 2006). The nature of morphological misbalance between L and W parameters also confirms the nature of approximation of a certain model of oilseed radish leaf formation according to a height gradient (see Fig. 4), where approximation expression of the leaf area is lower than its linear parameters, that, according to the determination of the area of geometrical parts of plants (Klingenberg, 2015), attributes oilseed radish leaf to the body of complex morphologic configuration (Efroni et al., 2010).

CONCLUSIONS

1. The leaves of oilseed radish differ both in morphological features, and in the regularities of formation within the plant from other representatives of the cruciferous family, with the possibility of distinguishing a number of its morphotypes typical for three tiers of plants, of which the most variable is the upper tier, which forms their pre–generative and generative part.
2. The analysis of a variation range of leaf morphotypes allowed us to distinguish a longline type in the nature of leaf formation by a height gradient of oilseed radish plants, respectively, of the lower, middle and upper tier with maximum expressions of such nature of leaf formation at the phase of the beginning of flowering.
3. The peculiarities of leaf placement along the high gradient from the lower tier to the upper one are described by the Richards model with the approximation value (R^2) 99.01 (at *RMSE* 1,605) for leaf area, 99.19 (at *RMSE* 1.605) for leaf length (L) and 99.31 (at *RMSE* 0.70122) for leaf width (W).
4. It has been determined that the reduction of the feeding area of one plant with fertilization increase under favorable hydrothermal conditions in the period of seedling and beginning of flowering with the threshold optimal HTC for this period of 1,7 ensures the growth of both the variation of morphological parameters of the leaf and its average sizes in all linear parameters with the impact on the formation of the annual conditions 15.91–21.64%, sowing rate 28.18–32.78%, fertilization rate 9.82–17.38%.

5. The cluster analysis, including leaf morphology indicators for the examined technological groups of options for oilseed radish agrophytocenosis construction, determined a smaller scale interval of leaf width variability in comparison with its length in relation to the Euclidean distances as 1:2 in favor of leaf width indicator (W).

6. The individual area of the oilseed radish leaves can be determined without their selection, by measuring their length and width using the S model = 7.9316-2.3613L+0.6897 (LW)+0.0458L^2-0.0005 $(LW)^2$ (under the following test parameters of the model: R^2 0.9106; *RMSE* 9.75; *d* 0.956; *BIAS* 0.1523).

7. Further researches on the non–destructive way of determining the individual area of oilseed radish leaf should focus on approaches to exploring models for area determination for its different morphotypes, considering the tier of their placement along a height gradient on the stem.

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