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PHYSIOLOGICAL AND BIOCHEMICAL ASPECTS OF OPTIMISING THE SOWING RATE OF SPRING AND WINTER *Pisum sativum* FORMS

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ABSTRACT. The winter and spring varieties of peas (*Pisum sativum*) require careful study of the entire range of technological measures, including seeding rates, as the basis for optimal sowing density and the formation of phytocenose crops. This issue has not been resolved to date, not only in the context of agrobiological justification but also in everyday practice in Ukraine. This research was carried out in a field experiment in a three-way factorial experiment: factor "A" was the type of development - winter and spring; factor "B" was the variety - spring peas (Svit and Darunok Stepu) and winter peas (Moroz, Enduro and Baltrapp); and factor "C" was the seeding rate. According to the field studies, differences in the physiological and biochemical parameters of the *P. sativum* test culture characterised the photosynthetic activity of the plants, considering the type of development and variety. The winter varieties of *P. sativum* were characterised by a higher chlorophyll content (by 35–40%) compared to the spring varieties, which had an economic effect with an increase in the yield of dry biomass of the experimental crop and a decrease in seeding rates, with the formation and increase in grain yield by 14–18%. The intensity of chlorophyll in the process was not a determining factor in the accumulation of organic biomass. The extensive nature of the integration complex was noted (the amount of chlorophyll - the amount of biomass). At the optimal seeding rate, a certain specificity was observed in different types of *P. sativum*: for spring varieties, the sufficient rate was 0.9 million seeds/ha, and for winter varieties, it was 0.7 million seeds/ha. For varieties with a low productivity level (spring - Svit and winter - Moroz), the optimum sowing rate was around 0.7 million seeds/ha. The increase in the seeding rate was accompanied by a decrease in the content of various chlorophyll fractions from 10–12% to 20–26%.

Keywords: chlorophyll; economic effect; *Pisum sativum*; productivity; seeding rate; varieties and types of development.

INTRODUCTION

Winter forms of *Pisum sativum* require a thorough study of the entire complex of technological measures, including seeding rates, as the basis for optimal sowing density and the formation of phytocenosis crops. This issue has not been resolved today, not only in the context of agrobiological justification but also in everyday practice in Ukraine.

More than 450 varieties of *P. sativum* have been tested in Europe to identify the best varieties for winter (Vernooij *et al.*, 2017). The article describes in detail the research methodology and presents the test results. Studies have shown that among the *P. sativum* varieties tested, there are those that are highly resistant to overwintering and can produce high yields. Criteria that can be used to assess the resistance of *P. sativum* varieties to overwintering have also been established.

Rzedzicki *et al.* (2018) investigated the effect of sowing date on winter hardiness and yield of *P. sativum*. The study tested different varieties of *P. sativum* sown at different times. The sowing date has a significant impact on the winter hardiness and yield of *P. sativum*, and early sowing dates allow for more resistant and high-yielding varieties of *P. sativum*.

It was previously established that the seeding rate of *P. sativum* ranges from 0.8 to 1.4 million viable seeds/ha (Lykhochvor and Andrushko, 2019a). In arid conditions, a decrease in the seeding rate in comparison with zones of sufficient moisture provides an economic effect and a high adaptive ability to plants, which makes it possible to restore their metabolic processes under unstable climatic conditions (Kindie *et al.*, 2019).

The main properties that determine the level of adaptability of *P. sativum* include a high harvesting index, type of stem growth, simultaneous ripening, resistance to diseases and shedding, high yield potential (Telecalo, 2019), effective seed germination, and the growth and development of plants on chernozem soils of average mechanical composition without salinity (Dvoretska *et al.*, 2016).

Under various soil and climatic conditions, the sowing rate significantly affects the yield potential of *P. sativum* (Lykhochvor and Andrushko, 2019a, b; Vasylenko *et al.*, 2018). For example, Ramzan *et al.* (2016a) investigated the effect of the seeding rate on the yield of *P. sativum*. Various densities were used, ranging from 40 plants/m^2 to 120 plants/m^2. The best yields were obtained at a density of 80 plants/m^2(Ramzan *et al.*, 2016b). With an increase in the seeding rate from 0.9 million/ha to 1.4 million/ha, the number of beans per plant decreased from 4.8 to 4.5 (6.25%), the number of grains in a bean decreased from 6.9 to 6.1 (11.59%), and the number of grains per plant decreased from 33 to 27.6 (16.4%). At the same time, the individual productivity of the plant decreased by 27.3%, and the weight of 1000 grains decreased from 291.0 g to 255.8 g (11.95%). In experimental field studies on typical chernozems, the dependence of the grain productivity of *P. sativum* variety Madonna on the meteorological conditions of the year and seeding rates was revealed (Lykhochvor and Andrushko, 2019b).

Riahi *et al.* (2019) studied the effect of different sowing rates, fertilisers and their combinations on the yield of *P. sativum* in chernozem soils of the Mediterranean. As a result, an increase in the sowing rate from 20 to 60 kg/ha increased the yield by 50%, but a further increase in the rate did not have a significant effect on the yield.

It has been established that the early stage of *P. sativum* development can take place in a large temperature range (Voskoboynikov *et al.*, 2012). Winter forms of *P. sativum*, unlike winter cereals, do not require a long period of low temperatures down to 4–6°C for their development; samples of the Afghan and especially Chinese and South Asian groups are more resistant to temperature drops of up to −12°C. Sowing the crop at an early date simultaneously with early grain crops is recommended. Seeds of different *P. sativum* varieties can germinate at 1–2°C, with short-term frosts down to −5°C. Biologically, these spring forms can tolerate a decrease in temperature in the first phases of growth, commonly called winter.

Several studies (Brezhneva *et al.*, 2012; Iepel and Rudenko, 2021; Karabanov, 2018; Solomonov and Kryvenko, 2021; Voskoboynikov *et al.*, 2012) have revealed the following advantages of winter *P. sativum* in comparison with spring development:

- delays the laying of fruiting organs and reduces the intensity of growth in autumn, which makes it possible to carry out the necessary agrotechnical measures in areas with a lack of soil moisture and elevated air temperatures (Voskoboynikov *et al.*, 2012);
- the possibility of effectively using autumn-winter moisture reserves in comparison with other spring legume crops; intensive growth and development in spring is ensured by the formation of a developed root system up to 10 cm deep (Voskoboynikov *et al.*, 2012) and up to 1 m (Dvoretska *et al.*, 2016) with the possibility of growth and development during critical periods of moisture from the lower soil horizons, enabling them to endure short-term drought better than many spring crops (Dvoretska *et al.*, 2016);
- the beginning of flowering of *P. sativum* plants occurs earlier than the mass flight of beetles from the *P. sativum* caryopsis (Solomonov and Kryvenko, 2021);
- the possibility of overcoming critical phases in relation to the reserves of productive moisture in the soil in the period from seed germination (requires 100–120% of water from their mass) and the beginning of the laying of generative organs (especially from budding and flowering to the formation of beans) with the high moisture requirement of *P. sativum* plants (Dvoretska *et al.*, 2016);
- obtaining early spring high-protein forage before the onset of summer drought and more stable grain and green mass harvests (Voskoboynikov *et al.*, 2012); the yield potential of winter *P. sativum* is 2–3

times higher with the necessary use of 650–700 units of water per unit of dry biomass (Dvoretska *et al.*, 2016);

- frost resistance of *P. sativum* seedlings when the temperature drops to −23.3°C with a snow cover height of 10 cm (Brezhneva *et al.*, 2012);
- earlier harvesting of winter *P. sativum* provides the possibility of sowing and obtaining intermediate crops (*Panicum miliaceum*, *Fagopyrum esculentum*, etc.) under irrigation conditions while increasing the efficiency of irrigated area use (Iepel and Rudenko, 2021), making use of areas with stubble for green manure crops (Solomonov and Kryvenko, 2021); and
- it is possible to solve the problem of non-deficient nitrogen in crop rotations, where the cultivation of other legumes is impossible or unprofitable from an economic point of view (Solomonov and Kryvenko, 2021); soil protection from wind and water (Solomonov and Kryvenko, 2021).

Drought stress is a predictable factor that occurs in multiple environments deprived of recognisable borders and no clear warnings, thereby hindering plant biomass and quality agricultural production (Kausar *et al.*, 2023).

The important factors that influence prospective yield and competition against weeds in pea, depending on the variety type and cropping system, were found by the current sensitivity analysis of pea production and biological weed regulation of pea variety and crop management. In agroecological cropping systems, these standards are used to choose pea varieties with the goal of controlling weeds through biological interactions. We also developed guidelines to help farmers select the optimal pea variety based on the cropping system and production target, as well as to adjust crop management to a particular pea variety and production objective. Additionally, we created guidelines to assist farmers in choosing the best pea variety based on the cropping system and production goal, as well as crop management tailored to a certain pea variety and production goal (Kausar *et al.*, 2023).

Because the optimal density of *P. sativum* plants and their provision with nutrients are the most important conditions for crop productivity, further study of the effect of various seeding rates on these indicators on the processes of element formation of the agrophytocenosis yield structure is an urgent task of modern crop production. Its solution requires further deepening of general theoretical ideas about the types of development of legumes and the effectiveness of varieties in the formation of phytocenosis crops and the continuation of relevant field and desk studies.

The task of the research was to deepen the physiological and biochemical concepts and determine the optimal seeding rates for the spring and winter forms of *P. sativum*, assuming the presence of differences in the types of development and varieties of the test culture.

MATERIALS AND METHODS

Field studies were carried out for three years in the experimental field of the Odessa State Agricultural Experimental Station of the National Academy of Agrarian Sciences of

Ukraine, now the OSAES of the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine (v. Khlibodarske, Odesa district, Odessa region). The soils of the experimental field are represented by southern chernozem with a humus content of 2.9–3.1% in the 10–30 cm layer. The content of available macroelements in the soil during the years of research was: N (easily hydrolysable) - 2.60 mg/100 g of soil (the determination was made in accordance with the current DSTU 7863:2015); P_2O_5 - 6.25 mg/100 g of soil; and K_2O - 17.4 mg/100 g of soil (the determination was made in accordance with the current DSTU 4115:2002). The field study was carried out for three years (2019–2022).

The experiment used a three-way factorial design, and the three factors were as follows:

- Factor "A" was the type of development, either winter or spring;
- Factor "B" was the varieties: spring development varieties - Svit and Darunok Stepu and winter development varieties - Moroz, Enduro and Baltrapp. These varieties were chosen because they represent different ecological groups and have different characteristics. The results of different varieties will show how well winter *P. sativum* performs in the southern steppe of Ukraine.
- Factor "C" was the seeding rate. The scheme of the field experiment included the study of different seeding rates (0.7, 0.9, 1.1, and 1.3 million seeds/ha) considering different varieties of the test culture. The seeding rates were chosen because the generally accepted seeding rate for spring *P. sativum* is 1.1 million/ha. For this study, norms that made up 57% (0.7 million/ha) of the generally accepted norms (1.1 million/ha) were used. It is at such densities that the biological characteristics of the culture, such as sensitivity to competition for light, water and nutrients, are revealed.

The size of the experimental plot was 15 m^2 (10 × 1.5 m), and the width of the protective strips (inter-row corridor) was 6 m. The location of the experimental options was randomised, and there were four replicates. The yield of green mass was determined by sampling in plots from an area of 0.25 m^2 in six repetitions. The mass was weighed, and its moisture content was determined and recalculated for absolute dry matter. The grain yield was determined by direct combining (Sampo-300) from the entire area of the plot, and the actual moisture content and field weediness were determined and recalculated for the basic indicators. For both types, pre-sowing cultivation was carried out. When growing the winter and spring varieties of *P. sativum*, there are several features in field work.

For winter *P. sativum*, this is:

- Variety selection. For winter varieties, sowing is carried out in early autumn (September–October), when the soil is still warm enough for seed germination, and in winter, the plants develop at a depth of snow cover. Varieties are selected based on their resistance to low temperatures that can develop in deep snow.
- Depth of seed placement. Winter *P. sativum* seeds should be planted to a depth of 7–10 cm to ensure good growth activity.

• Seeding density. The planting density of winter *P. sativum* should be lower than that of spring *P. sativum*. The optimal planting density for overwintering *P. sativum* is 80–100 plants/m^2.

• Culture care. Overwintering *P. sativum* requires more care during the winter growing period, as the plants may suffer from frost and a lack of moisture.

For spring *P. sativum*, this is:

• Variety selection. When growing spring varieties, sowing is carried out in the spring, when the soil has warmed up to the required temperature for seed germination and, for this, varieties are selected that are best adapted to such conditions.

• Depth of seed placement. Seeds of spring *P. sativum* should be planted to a depth of 3–5 cm.

• Seeding density. The optimal planting density for spring *P. sativum* is 120–150 plants/m^2.

• Culture care. Spring *P. sativum* requires less care than winter *P. sativum*. However, you still need to ensure regular watering and fertilisation.

The order of placement of options for the experiment is presented in *Table. 1*.

The content of chlorophyll A and B was determined by the spectrophotometric method using a NanoDrop 2000 spectrophotometer. This well-known method was based on the study of absorption spectra in the ultraviolet (200–400 nm), visible (400–760 nm) and infrared (> 760 nm) spectral regions.

One gram of freshly cut, evenly mixed representative leaf samples were sampled for the measurement of chlorophyll. They were broken down into a fine slurry by adding 20 ml of cold, 80% acetone. The sediment was put into a 100 ml volumetric flask after it had been centrifuged at 5000 rpm for five minutes at 4°C. After again centrifuging the residue in 20 ml of 80% cooled acetone, the precipitated liquid was added to the same volumetric flask. Until the residue was colorless, this process was repeated. With 80% acetone, the solution and pestle were completely cleaned. The clear washes were then collected in a volumetric flask. Using 80% acetone, the volume was adjusted to 100 ml. On a spectrophotometer, absorption readings at 644 and 662 nm were recorded against a stock of 80% acetone. The spectrophotometrically determined values of the optical density of the dilute solutions ranged from 0.1 to 0.8.

In chemical analytical studies, reagents and algorithms of the well-known method of biochemical analysis of plants, according to Ermakov *et al.* (1987), were used. The content of chlorophyll a and chlorophyll b and the total chlorophyll content were calculated using the following formulas (mg chlorophyll per gram of tissue) (*Equation 1-3*):

$$Cb = 21{,}426D644 - 4{,}650D662 \quad (1)$$

$$Ca + Cb = 5{,}134D662 + 20{,}436D644 \quad (2)$$

$$C_{cap.} = 4{,}695D44062 - 0{,}268(Ca + Cb) \quad (3)$$

where C*a* is the concentration of chlorophyll a, mg/L; C*b* is the concentration of chlorophyll b, mg/L; $C_{cap.}$ is the concentration of carotenoids, mg/L.

The concentration of pigments (mg/100 g) was calculated using the following *Equation (4)*:

$$X = C \times V \times V2 \times 100 \times w \times V1 \times 1000 \quad (4)$$

where C is the concentration of carotenoids, mg/L; V is the volume of the initial extract, mL; V1 is the volume of the initial extract taken for dilution, mL; V2 is the volume of the diluted extract, mL; w is the weight of the sample.

Mathematical and statistical processing was carried out using analysis of variance (ANOVA) in Agrostat New and Anova.

RESULTS AND DISCUSSION

Previously, we substantiated the agrobiological advantages of winter *P. sativum* for the arid conditions of the southern steppe in Ukraine (Karabanov, 2018; Voskoboynikov *et al.*, 2012). We also studied how different types of plant development affect their phenotypes by changing the phytocenosis relationships between cultivated plants and weeds. Weeds inherent in crops of the spring development type of *P. sativum* belong to the group of early spring and perennial root shoots. Weeds from the winter and winter groups characterise the winter type of development of *P. sativum*. Thus, phenotypic differences between different types of development of *P. sativum* and a significant change in the components of phytocenosis have been established.

Under field conditions, the specificity of the reaction of various development types of *P. sativum* to the density of agrophytocenosis plants, which in turn is determined by different seeding rates, was revealed. For the spring development type of *P. sativum*, this element of technology has been studied quite well. Regarding the winter type of development of *P. sativum*, the seeding rate, as one of the leading elements of technology, is considered without taking into account the phenotypic characteristics of plants and simply copying the recommendations for the spring development type of *P. sativum*. It has also been established that the basis for the formation of a higher yield of winter *P. sativum* is the reduction in vegetation, and due to this, there is a mitigation of the detrimental effect of drought. Other researchers have also studied these features (Brezhneva *et al.*, 2012; Iepel and Rudenko, 2021; Solomonov and Kryvenko, 2021).

Based on the results of the field studies, we revealed differences in the physiological and biochemical parameters of the test culture, characterising the photosynthetic activity of plants, considering the type of development and variety (*Table 2*).

Comparing the obtained results on the carotenoid content, one can notice a higher indicator in spring varieties (171 and 176 mg/100 g). The presence of carotenoids in *P. sativum* depends on several factors, including the genetic characteristics of the variety and the environment.

A higher chlorophyll content was established in the leaves of *P. sativum* of the winter type (Enduro) in comparison with the spring development type, mainly due to the "a" fraction, which is the most active in photosynthesis (*Table 3*).

Based on the data in the table, for fraction "a", the winter varieties of *P. sativum* significantly exceeded the standard variety of spring *P. sativum* by +37.15% in Enduro and +15.36% in Frost. Fraction "c" showed that the

Enduro variety showed a noticeable increase of +11.19% compared to the standard, the spring variety Svit, but the Moroz variety had a negative deviation (−2.88%). The presence of chlorophyll "b" may depend on the intensity and spectrum of light and the characteristics of the variety. However, we were more interested in the dependence of chlorophyll content on sowing rates. The obtained results confirmed our hypothetical ideas about this dependence.

Table 1 – Scheme of the placement of plots in the experiment

I repetition			III repetition		
C_1H_1	C_3H_2	C_2H_4	C_1H_3	C_3H_4	C_2H_2
C_2H_1	C_1H_3	C_3H_4	C_2H_3	C_1H_1	C_3H_2
C_3H_1	C_2H_3	C_1H_1	C_3H_3	C_2H_1	C_1H_3
C_1H_2	C_3H_3	C_2H_1	C_1H_4	C_3H_1	C_2H_3
C_2H_2	C_1H_4	C_3H_1	C_2H_4	C_1H_2	C_3H_3
II repetition			**IV repetition**		
C_1H_2	C_3H_3	C_2H_1	C_1H_4	C_3H_1	C_2H_3
C_2H_2	C_1H_4	C_3H_1	C_2H_4	C_1H_2	C_3H_3
C_3H_2	C_2H_4	C_1H_2	C_3H_4	C_2H_2	C_1H_4
C_1H_3	C_3H_4	C_2H_2	C_1H_1	C_3H_2	C_2H_4
C_2H_3	C_1H_1	C_3H_2	C_2H_1	C_1H_3	C_3H_4

Note: C1 - Moroz variety; C2 - Enduro variety; C3 - Baltrapp variety; H1 - sowing rate 0.7 million seeds/ha; H2 - sowing rate 0.9 million seeds/ha; H3 - sowing rate 1.1 million seeds/ha; H4 - sowing rate 1.3 million seeds/ha.

Table 2 – The content of chlorophyll and carotenoids in the leaves of *Pisum sativum* (average for 2020–2022)

Type of development (A)	Variety (B)	Chlorophyll content, mg/100 g of biomass			Content of carotenoids, mg/100 g of biomass
		Total	B		
			fraction "a"	fraction "b"	
Winter	Enduro	650	491	159	170
	Moroz	552	413	139	150
Spring	Svit	501	358	143	171
	Darunok Stepu	486	360	126	176
Average by type of development	Winter	601	452	149	160
	Spring	493.5	359	134.5	173.5

Table 3 – Deviation of chlorophyll content by fractions from the standard

Variety	Fraction "a", mg/100 g	Deviation +/- from the standard		Fraction "b", mg/100 g	Deviation +/- from the standard	
		+/- deviation	%		+/- deviation	%
Enduro	491	+133	+37.15	159	+16	+11.19
Moroz	413	+55	+15.36	139	−4	−2.88
Svit	358	0	0	143	0	0
Darunok Stepu	360	+2	+0.56	126	−17	−13.49

In this experiment, we were most interested in the dependence of chlorophyll content on the number of seeds. The obtained results confirmed the hypothetical idea of dependence (*Table 4*).

An increase in the density of plants leads to an increase in the degree of shading, which in turn leads to a decrease in the chlorophyll content. The advantage of rare plants in terms of chlorophyll content is a trend and is not absolute. However, its regularity can be traced quite clearly. To ensure that these dependencies were non-standard, we present their graphical representation in *Figure 1*.

According to the data in Table 4, the chlorophyll content in winter *P. sativum* was noticeably higher than that in spring. In 2021, it was 502 mg/100 g of biomass in Enduro at a rate of 0.9 million seeds/ha; in Baltrapp - 477 mg/100 g at a density of 1.1 million seeds/ha; and in Moroz - 423 mg/100 g at a density of 0.9 million seeds/ha. In spring varieties, the difference was ~30–40%: in Svit - 341 mg/100 g at 0.7 million seeds/ha; Darunok Stepu - 386 mg/100 g at 0.7 million seeds/ha.

In 2022, the difference between winter and spring *P. sativum* was traced: in Enduro, it was 491 mg/100 g of biomass at a rate of 0.7 million seeds/ha; in Baltrapp - 448 mg/100 g with a density of 0.9 million seeds/ha; in Moroz - 422 mg/100g with a density of 0.9 million seeds/ha. In spring varieties, the difference was ~20–30%: in Svit – 384 mg/100 g at 0.7 million seeds/ha; Darunok Stepu - 390 mg/100 g at 0.7 million seeds/ha.

Within each year of the study, the relationship between seeding rates and chlorophyll "a" content was identical; with a decrease in the density of the stand, the content of this fraction of the green pigment increased (correlation coefficients by module ranged from 0.45 to 0.98). The most clearly given trend appeared in 2021, so the dependence graph is for the indicated period. The pigment system of the Baltrapp variety reacted to a lesser extent to the change in the seeding rate (determination coefficient 0.40), but in the Enduro variety, the seeding rates determined the chlorophyll "a" content (98%), and the winter *P. sativum* variety Moroz occupied an average position (R^2=0.65) (Riahi *et al.*, 2019).

However, the total amount of chlorophyll and even its fractional composition cannot testify to the result - the accumulation of organic biomass. Therefore, it was supposed to determine the yield of aboveground biomass, which correlates with grain productivity. The results of determining the aboveground biomass yield showed that Baltrapp had the advantage among the studied varieties (*Table 5*).

Higher levels of chlorophyll content and biomass yield indicators were established in Enduro and Baltrapp varieties compared to Moroz in 2020 and 2022. Moroz showed the best result at a density of 0.9 in 2020, 0.7 in 2021 and 0.7 in 2022; Enduro at a density of 0.7 in 2020, 0.7 in 2021 and 0.7 in 2022; Baltrapp at a density of 0.9 in 2020, 0.7 in 2021 and 0.7 in 2022.

Table 4 – Chlorophyll content (fraction "a") depending on the seeding rate (mg/100 g of biomass)

Type of development (A)	Variety (B)	Chlorophyll content (fraction "a"), mg/100 g of biomass			
		Sowing rate, million seeds/ha			
		0.7	0.9	1.1	1.3
2021 p.					
Winter Spring	Enduro	491	502	445	485
	Moroz	422	423	331	350
	Baltrapp	472	456	477	401
	Svit	341	340	324	328
	Darunok Stepu	386	362	340	332
LSD 0.5%	A	42.6			
	B	23.8			
	AB	31.3			
2022 p.					
Winter Spring	Enduro	491	489	432	458
	Moroz	403	422	320	324
	Baltrapp	421	448	441	381
	Svit	384	370	350	332
	Darunok Stepu	390	381	364	352
LSD 0.5%	A	32.0			
	B	31.3			
	AB	34.0			

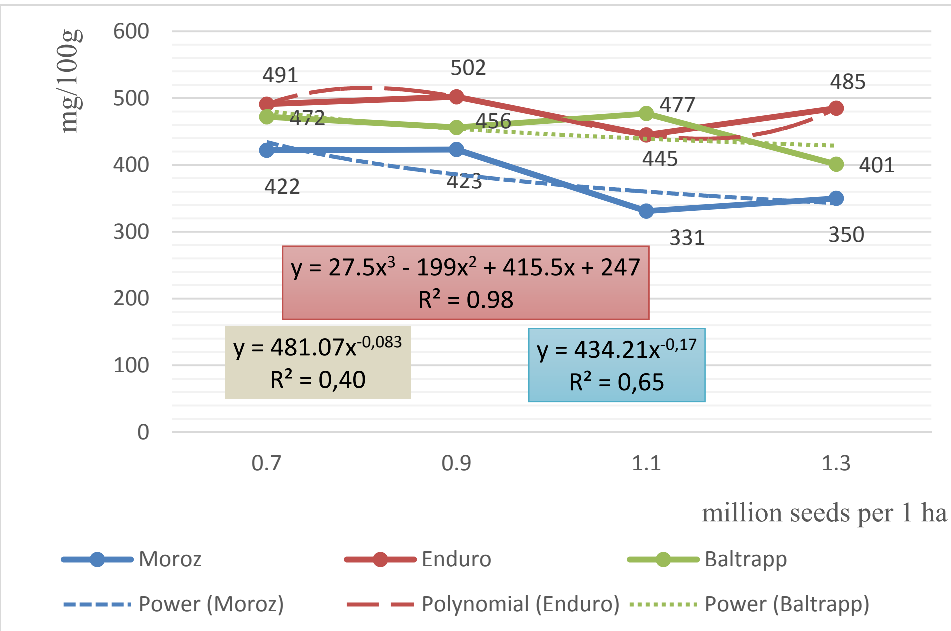

Figure 1 – Dependence of chlorophyll content (fraction "a") on seeding rates in 2021

Table 5 – Yield of dry aboveground biomass of winter *Pisum sativum* (full maturity phase), t/ha

Variety (A)	Sowing rate, million seeds/ha (B)	Year			Average indicator %	Deviation +/- from the standard	
		2020	2021	+/- deviation		+/- deviation	%
Moroz	0.7	0.81	2.05	1.95	1.60	+0.24	+15.00
	0.9	0.79	2.01	1.89	1.56	+0.20	+14.71
	1.1	0.76	1.55	1.76	1.36	0	0
	1.3	0.73	1.61	1.51	1.28	-0.08	−6.25
Enduro	0.7	0.83	3.48	3.30	2.54	+0.56	+28.28
	0.9	0.75	2.99	3.12	2.29	+0.31	+15.66
	1.1	0.73	2.43	2.79	1.98	0	0
	1.3	0.73	2.19	2.65	1.86	−0.12	−6.06
Baltrapp	0.7	1.18	3.50	3.12	2.60	+0.39	+17.65
	0.9	1.22	2.85	3.09	2.39	+0.18	+8.14
	1.1	1.20	2.60	2.84	2.21	0	0
	1.3	1.16	2.56	2.56	2.09	−0.12	−5.43
LSD 0.5 %	A B AB	0.07	0.15	0.16	-	-	-

The tendency to decrease the yield of dry biomass in winter *P. sativum* was most clearly observed when comparing the deviation - the higher the density of sowing, the stronger the deviation into the negative indicator. The increased seeding rate led to competition for nutrients and moisture and, ultimately, to a lower yield compared to the standard (1.1 million seeds/ha).

As a result, the productivity of *P. sativum* in most cases correlated with the chlorophyll content, especially fraction “a” (r=0.68–0.75) (*Table 6*).

As shown in *Table 6*, the average yields of spring and winter *P. sativum* for all sowing rates were 1.31 and 1.62 t/ha, respectively. Among the varieties in the winter group, the Enduro (1.78 t/ha) and Baltrapp (1.88 t/ha) varieties provided similar yields. The Moroz variety was significantly inferior to the leaders in yield (1.10 t/ha) and showed a lower result, even compared to the spring Darunok Stepu variety (0.39 t/ha less). At the optimal rate of seeding in different types of development, a certain specificity was observed: spring varieties formed the maximum yield at a rate of 0.9 and winter varieties - at a rate of 0.7 million/ha of seeds. It should be especially noted that for varieties with a low level of yield (spring - Svit and winter - Moroz), the optimum seeding rate was 0.7–0.9 million seeds/ha. In intensive high-yielding varieties, specific rates were optimal: for the spring variety Darunok Stepu - 0.9 million seeds/ha, and for winter Enduro and Baltrapp - 0.7 million seeds/ha.

The change in the sowing rate was ultimately related to the level of total production costs because 0.2 million seeds (50 kg/ha) cost euro 15 for spring *P. sativum* and euro 20 for the winter varieties. Therefore, the obtained results should be evaluated not only from a business perspective but also from an economic perspective. We present the calculation of the size of the net profit of spring and winter *P. sativum*, depending on the sowing rate (*Table 7*). The exchange rate was presented in accordance with the year of purchase of the seed material and the additional costs incurred (MINFIN, 2020–2022).

Table 6 – Yield of *Pisum sativum* varieties depending on sowing rate, t/ha

Type of development (A)	Variety (B)	Sowing rate (C)	Year			On average for three years	Deviation +/- from the standard	
			2020	2021	2022		+/- deviation	%
Spring	Svit	0.7	0.28	1.48	1.50	1.09	+0.08	+7.92
		0.9	0.29	1.58	1.62	1.16	+0.15	+14.85
		1.1	0.26	1.40	1.36	1.01	0	0
		1.3	0.21	1.14	1.18	0.84	−0.17	−16.83
	Darunok Stepu	0.7	0.33	2.11	2.36	1.59	+0.14	+9.66
		0.9	0.38	2.72	2.58	1.89	+0.44	+30.34
		1.1	0.31	1.88	2.16	1.45	0	0
		1.3	0.29	1.69	1.75	1.04	−0.41	−28.28
Winter	Moroz	0.7	0.69	1.79	1.70	1.21	+0.19	+18.63
		0.9	0.69	1.78	1.69	1.19	+0.17	+16.67
		1.1	0.68	1.35	1.52	1.02	0	0
		1.3	0.67	1.40	1.32	0.97	−0.05	−5.15
	Enduro	0.7	0.73	3.03	2.90	2.22	+0.48	+27.59
		0.9	0.69	2.60	2.78	2.20	+0.46	+26.44
		1.1	0.68	2.12	2.43	1.74	0	0
		1.3	0.67	1.91	2.31	1.63	−0.11	−6.75
	Baltrapp	0.7	0.74	3.10	2.88	2.24	+0.50	+28.74
		0.9	0.67	2.48	2.69	1.94	+0.20	+11.49
		1.1	0.66	2.11	2.47	1.74	0	0
		1.3	0.56	1.88	2.23	1.55	−0.19	−10.92
LSD 0.5 %	A	-	80.07	28.37	31.44	-	-	-
	B		8.32	24.69	28.37			
	C		0.75	7.55	3.81			
	ABC		0.47	1.43	0.55			

Table 7 – Net profit when growing spring and winter *Pisum sativum* at different sowing rates (average for 2020–2022)

Type of develop-ment	Variety	Sowing rate, million seeds /ha	Standard produc-tion costs, euro/ha	Additional expenses, euro/ha		General produc-tion costs, euro/ha	Cost of gross production, euro/ha	Net profit, euro/ha
				Seeds	For the collection of additional harvest			
Spring	Darunok Stepu	0.7	232	-	-	232	342	110
		0.9	232	+15	2	249	407	158
Winter	Baltrapp	0.7	248	-	3	251	482	231
		0.9	248	+20	-	268	420	152

Our results showed that only strict compliance with technological requirements provides a positive economic effect. For example, sowing of winter *P. sativum* at a rate of 0.9 million seeds/ha not only reduced yield but also, together with the growth of production costs, reduced the net profit to the level of the spring Darunok Stepu variety. A seeding rate of 0.7 million/ha increased the net income to more than euro 70/ha.

CONCLUSIONS

1. Winter forms of *P. sativum* had 35–40% more chlorophyll than spring forms.
2. Lower seeding rates improved the chlorophyll content, but the process was complex and variable.
3. Chlorophyll intensity did not determine organic biomass accumulation; integration complexity did.
4. Optimal seeding rates varied: 0.9 million seeds/ha for spring varieties and 0.7 million seeds/ha for winter varieties.
5. Strictly following the optimal seeding rate was crucial for maximising the net profit from winter varieties.

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REFERENCES

Brezhneva, V.I.; Myroshnychenko, A.N.; Brezhnev, A.V. Achievements in the breeding of winter peas. *Scientific Journal Kub GAU*. **2012**, 78, 665-674.

Dvoretska, S.P.; Ryabokin, T.M.; Karazhbey, T.V. The influence of agrometeorological conditions on the formation of productivity of pea varieties. *Collection of scientific works of the National Science Center, Institute of Agriculture of the National Academy of Sciences*. **2016**, 1, 36-45.

Ermakov, A.I.; Arasimovich, V.V.; Yarosh, N.P.; Peruvian, Yu.V.; Lukovnikova, G.A.; Ikonnikova, M.I. Methods of biochemical research of plants. *Leningrad: Agropromizda.* **1987**, 107-108.

Iepel, A.V.; Rudenko A.V. The influence of sowing dates on the yield of winter peas in the irrigated conditions of the southern steppe of Ukraine. *Modern science: state and prospects of development*. **2021**, 72.

Karabanov, I. Subtleties of growing winter peas (in *Ukrainian*). *Agronom.* **2018** https://www.agronom.com.ua/igor-karabanov-vlasnyk-tov-nvk-rostok-kiv/.

Kausar, A.; Zahra, N.; Zahra, H.; Hafeez, M.B.; Zafer, S.; Shahzadi, A.; Raza, A.; Djalovic, I.; Prasad, P.V.V. Alleviation of drought stress through foliar application of thiamine in two varieties of pea (*Pisum sativum* L.). *Plant Signaling and Behavior*. **2023**, 18. https://doi.org/10.1080/15592324.2023.2186045

Kindie, Y.; Bezabih, A.; Beshir, W.; Nigusie, Z.; Asemamaw, Z.; Adem, A.; Tebabele, B.; Kebede, G.; Alemayehu, T.; Assres, F. Field Pea (*Pisum sativum* L.) Variety Development for Moisture Deficit Areas of Eastern Amhara, Ethiopia.

Advances in Agriculture. **2019**, 2019. https://doi.org/10.1155/2019/1398612.

Lykhochvor, V.V.; Andrushko, M.O. Influence of pea sowing rates on structural elements and grain yields (in *Ukrainian*). *Bulletin of Poltava State Agrarian Academy*. **2019a**, 4, 51-57. https://doi.org/10.31210/visnyk2019.04.06.

Lykhochvor, V., Andrushk, M. Yield of pea of Madonna variety depending on sowing rates (in *Ukrainian*). *Scientific Horizons*. **2019b**, 12, 53-59. https://doi.org/10.33249/2663-2144-2019-85-12-53-59.

MINFIN. Current information on finance in Ukraine. Available online: https://minfin.com.ua/ (accesed on 2020 and 2022).

Ramzan, M.; Ali, M.A.; Ali, A.; Ghaffar, A.; Hussain, A. Effect of planting density on yield and yield components of pea (*Pisum sativum* L.) varieties. *Journal of Animal and Plant Sciences*. **2016a**, 26, 953-959.

Ramzan, M.; Ali, M.A.; Ali, A.; Ghaffar, A.; Hussain, A. Effect of planting density on yield and yield components of pea (Pisum *sativum* L.) varieties. *Journal of Animal and Plant Sciences*. **2016b**, 26, 1295-1299.

Riahi, M.; Souri, M. K.; Khormali, F.; Koocheki, A. Yield of Pisum *sativum* L. as influenced by sowing rates, nitrogen and phosphorus fertilization in soils of the Mediterranean region. *Archives of Agronomy and Soil Science*. **2019**, 65, 930-944. https://doi.org/10.1080/03650340.2018.1532187.

Rzedzicki, M.; Mikos-Bielak, M.; Bielak, K. Influence of sowing date on winter survival and yield of pea cultivars. *Journal of Elementology*. **2018**, 23, 249-260.

Solomonov, R.V.; Kryvenko, A.I. The technology of growing winter peas in the conditions of Southern Ukraine (in *Ukrainian*). Strategy of integration of agricultural education, science, production: global challenges of food security and climate change: reports of participants of the international scientific and practical conference of the International Forum, 27- May 28, 2021, Mykolaiv, 151-153.

Telecalo, N.V. Influence of the complex of technological administrations on the growth of the pigs of general (in *Ukrainian*). *Agriculture and Forestry*. **2019**, 13, 84-93.

Vasylenko, A.O.; Bezuglyi, I.M.; Shevchenko, L.M.; Shtelma, A.M.; Glyantsev, A.V.; Ilchenko, N.K. Effects of abiotic factors on fulfillment of the potential of pea cultivars (in *Ukrainian*). *Plant Breedingand Seed Production*. **2018**, 113, 35-44. https://doi.org/10.30835/2413-7510.2018.134356.

Vernooij, C.J. *et al.* Winter survival in field pea: evaluation of 450 cultivars grown in Europe and recommendations for improvement. *Plant Breeding*. **2017**, 136, 172-179.

Voskoboynikov, A.V.; Lysenko, I.O.; Ageev, V.V. Productivity of winter peas depending on mineral fertilizers on leached chernozem (in *Ukrainian*). *Agrochemical Vestnik*. **2012**, 2, 32-33.

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