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Peculiarities of Photosynthetic Activity of Winter Pea Plants Depending on the Sowing Rates

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Abstract. Peas are a crop that is quite picky about weather conditions, therefore, against the backdrop of worsening climatic conditions, it is necessary to pay attention to the wintering form. The main advantage of overwintering peas is that it uses the moisture of the winter period and thanks to this forms above-ground and underground biomass of plants even before the onset of summer drought. At the beginning of the recovery of spring vegetation, plants have a well-developed root system that penetrates deep into the soil up to 10 cm, while spring peas at this time are just beginning to sow. As a result, the potential yield of winter peas is 2-3 times higher than that of spring peas. The purpose of the research was to determine the influence of varietal features of plants, seed sowing rates on the photosynthetic activity of crops and grain yield of winter peas in the conditions of southern Ukraine. Research methods: field, laboratory, computational, statistical. As a result of the research, the peculiarities of the growth of the above-ground mass of plants, the photosynthetic activity of crops and the formation of grain yield of winter pea varieties were studied. The optimal rate of winter pea seed sowing, at which the genetic potential of varieties is fully realized, has been revealed. The norm of seed sowing was established, at which winter pea plants formed the maximum area of the leaf surface. Research has established that in most cases the maximum level of biomass harvest is formed at the minimum density of plants in the budding phase. As the density increases, the biomass gradually decreases, which is a reliable sign of the significant advantage of crops with lower sowing rates in terms of photosynthesis productivity.It was determined that the highest winter pea grain yield, on average over the years of research and according to the studied sowing rates, was formed by the Enduro variety. Research has established that wintering peas form a small area of the leaf surface, which is characterized by a high level of difference in productivity at a reduced seeding rate. The practical aspects and conclusions reflected in the article are aimed at improving the processes of wintering pea productivity in the conditions of southern Ukraine, in particular, at significantly more efficient use of moisture during the growing season of plants for the formation of a unit of harvest

Keywords: photosynthetic activity, leaf surface, above-ground biomass of plants, chlorophyll, density, grain yield

INTRODUCTION

The main task of modern agriculture in Ukraine is to increase the productivity of grain crops, which will contribute to the formation of plant resources, providing livestock with complete feed, and the population with food products. An important place in solving this task is occupied by peas. Its grain contains protein, carbohydrates, saturated with essential amino acids, minerals and vitamins, therefore it is widely used in the production of balanced concentrated feeds. A short growing season and the ability to fix atmospheric nitrogen characterize peas as the best predecessor for agricultural crops, in particular winter forms [1].

Peas are characterized by great genetic diversity, according to the morphological composition there are varieties with leaves (ordinary) and leafless (with tendrils of the so-called aphylla type), indeterminate and determinate growth of the stem and very early and late ripening. There are winter and spring varieties. Seeds vary in color, shape and size. Some varieties of peas are used as a vegetable crop; field peas are used

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for the production of dry grain for the food industry, and forage pea varieties are also widely used [2].

Peas are grown in most countries of the world. North America has increased its share of seed pea and lentil production in recent years. Europe, once the largest producer of seed peas, is seeing a sharp decline in total legume production. At the same time, Asian countries remain the main producer of many leguminous crops, including field peas [3].

According to V.V. Kolosovska [4], peas are widely distributed in Ukraine due to their high productivity and feed value. Peas are a potential crop that, under optimal growing conditions, can provide a high yield of green above-ground mass, as well as grain. Significant fluctuations in the yield of peas depend on the influence of weather conditions on the productivity of plant photosynthesis. The yield of peas depends on many factors, in particular, agricultural technology, weather and climate conditions during the growing season of plants, varietal characteristics, etc. [5; 6; 8]. In recent years, small areas of sowing and low yields of pea grain are due to unfavorable weather conditions and the lack of stable demand in the domestic market, as well as the difficult economic situation of agricultural enterprises. All this, as well as the imperfect technology of growing peas, gives preference to agricultural crops whose cultivation costs are lower, and their production volumes are larger [4; 7; 9].

Systematic droughts in the second half of May and in June suppress the pea so much that it grows 15-20 cm tall, forms no more than 2 beans per plant with 1-2 seeds, and thus provides a yield of 0.4-0.6 t/ha, which is a catastrophic phenomenon against the background of other cultures. Therefore, producers, despite the importance of peas in animal diets, refuse this crop and exclude it from their crop rotations.

But in the last 15-20 years, a new form of peas has appeared – winter peas, which are sown in autumn and spring. He manages to form a generative apparatus earlier than during droughts.Such peas under normal conditions provide a yield of 2.0-2.5 t/ha of seeds, and under favorable conditions – 3.5-4.0 t/ha. Currently, breeders are creating wintering varieties, and agricultural technicians are developing a technological model that would correspond to the biology of this pea. It should be noted that the development of winter pea agrotechnology has not yet been completed, and many issues need to be clarified. In particular, the optimal parameters of sowing rates and plant stand density have not been definitively determined. This element of technology was mechanically transferred from spring peas, so the goal of our research was to determine the optimal rate of sowing seeds for modern varieties of winter peas for growing it in the conditions of southern Ukraine.

One of the main elements of the pea growing technology is the rate of sowing seeds, which ensures optimal sowing density. The pea sowing rate ranges from 0.8 to 1.4 million similar seeds per hectare [5]. In conditions of sufficient moisture supply, more seeds should be sown than in dry conditions [6].

N.V. Telekalo [7] in his experiments came to the conclusion that it is the correctly selected sowing rates that provide a high adaptive capacity, which allows metabolic processes to be restored to an optimal level after exposure to stress factors, which is especially important in conditions of climate change. The main characteristics that determine the adaptation of peas include a high harvesting index, the type of stem growth, friendly ripening of grain, resistance to pests and diseases, shedding of grain, high potential yield.

Optimum plant density and nutrient supply are the most important conditions that affect the productivity of agricultural crops. Therefore, studying the impact of different sowing rates on plant density and yield is of great importance for the process of forming the structural elements of the crop. The density of plants before harvesting is an indicator that shows the correct choice of seed sowing rate during sowing. The rate of sowing can significantly affect the realization of the potential yield of peas under different soil and climatic conditions of its cultivation [8]. Thus, the studies of V.V. Lykhochvor and V.M. Andrushko [9] determined that the structural elements and yield of peas were significantly influenced by the norms of seed sowing. Thus, increasing the rate of sowing seeds to 1.4 million/ha contributed to a decrease in the number of beans per plant to 4.5 pcs., the number of grains in a bean – to 6.1 pcs., the number of grains per plant – to 27.6 pcs. Then, at the sowing rate of 0.9 million/ha, the specified indicators amounted to 4.8, respectively; 6.9; 33 pcs. It has been proven that, in addition to the investigated norms of seed sowing, the yield of Madonna pea grains was also influenced by the agrometeorological conditions of the research years.

At the same time, the dependence of the photosynthetic activity of plants on the density of agrophytocenosis is an important and little-studied issue. Absorption of light and its direct effect on the growth of agricultural plants is an important factor in the life of plants [10]. As for many agricultural plants, the amount of incoming photosynthetically active radiation and the efficiency of use of solar radiation by the plant cover are important indicators during the cultivation of leguminous crops [11].

It has been confirmed that the intensity of photosynthesis of cultivated plants is a rather labile feature, prone to significant exogenous influence of environmental factors. Agrometeorological conditions during the growing season of agricultural crops affect the indicators of photosynthesis. In addition, the photosynthetic activity of crops depends on the area of the leaf surface of plants, the area of their nutrition, the content of nutrients in plant leaves, etc. [12; 13]. The leaf surface area of plants is one of the main factors that determines the amount of absorbed solar energy and its use for biomass accumulation, and also affects the indicators of net photosynthetic productivity. In turn, the amount of biomass accumulated by plants and the activity of photosynthetic processes are decisive in the formation of the yield of agricultural crops [14-16].

The increase in the area of the leaf surface of plants is an indicator that characterizes the general growth rate of any agricultural crop, which leads to a significant absorption of solar radiation and, as a result, contributes to the formation of higher productivity [17].

Thus, further deepening of research in this direction is an urgent task of modern plant breeding.

MATERIALS AND METHODS

For the study, the winter pea varieties Moroz, Enduro and Baltrapp were used, which were sown on the experimental field of the Odesa State Agricultural Research Station of the National Academy of Agrarian Sciences of Ukraine for 3 years. The scheme of the experiment provided for the study of the following sowing rates: 0.7; 0.9; 1.1; 1.3 million seeds/ha. The size of the plots and placement: in the massif, the plot is 15 m^2 (10×1.5 m), randomized. Inter-level corridor: 6 m. Number of repetitions: four.

The experimental field is located in the village of Khlibodarske, Bilyaiv district, Odesa region. The soils are represented by northern chernozem with a humus content of 2.0% in a layer of 10-30 cm. The content of macroelements in the soil during the years of research was P_2O – 6.25; N – 2.60; K_2O – 17.4 mg/100 g of soil.

The main experiment had the following arrangement of plots (Table 1).

Table 1. *Scheme of the location of the 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: *C_1 – Moroz variety; C_2 – Enduro variety; C_3 – Baltrapp variety; H_1 – sowing rate 0.7 million plants/ha; H_2 – sowing rate 0.9 million plants/ha; H_3 – sowing rate 1.1 million people/ha; H_4 – seeding rate of 1.3 million people/ha*

The area of the sheet surface was measured by the weight method with the preparation of standard cutouts with an area of 1 cm^2. 20 cuttings were weighed and all leaves from a sample of plants were weighed. The area of the leaves in the samples was calculated according to the proportion:

20 cm^2–m_{1T}
X cm^2–m_{2T}

$$x = \frac{20 \times m_2}{m_1}; \quad (1)$$

The size of the photosynthetic potential was calculated according to formula 2:

$$PP = \frac{S_1 + S_2}{2} \times T \quad (2)$$

S_1 – leaf area at the beginning of the calculation period, thousand m^2/ha; S_2 – leaf area at the end of the calculation period, thousand m /ha; T – calculation period, days.

The size of the net productivity of photosynthesis was calculated according to formula 3:

$$NPP = \frac{\mathrm{FP}}{U_2 - U_1} \quad (3)$$

FP – photosynthetic potential thousand m^2/ha × days; U_2 – dry biomass harvest at the end of the period; U_1 – dry biomass yield at the beginning of the period, g/ha

RESULTS AND DISCUSSION

The conducted studies showed that winter peas form a rather low level of the leaf surface (Table 2).

Table 2. Leaf surface area of peas under different sowing rates, 2021 (thousand m^2/ha)

Sowing rate. million seeds per hectare	Moroz		Enduro		Baltrapp	
	2-3 leaves	Budonization	2-3 leaves	Budonization	2-3 leaves	Budonization
0.7	1.3	13.5	1.1	11.4	0.8	13.4
0.9	2.2	16.5	0.9	16.0	1.3	16.2
1.1	2.7	18.40	1.2	19.1	1.5	19.1
1.3	3.0	23.9	1.9	22.5	1.5	22.7
HIP_{05}, thousand m^2	–	0.8	–	1.1	–	0.7

Varieties had no significant differences in leaf area. A direct dependence of the size of the leaf area on the sowing rate was found. As you can see, in all cases, crops with the highest seeding rate had the maximum leaf area. This indicates that the result of photosynthetic activity (accumulation of organic phytomass) is primarily determined not by a quantitative indicator (the size of the leaf area), but by a qualitative one (the productivity of the leaves). Such a conclusion can be drawn already from the analysis of data on the harvest of above-ground biomass (Table 3).

Table 3. *Crop of above-ground pea biomass under different sowing rates, t/ha (2021)*

Sowing rate of million seeds per hectare	Moroz		Enduro		Baltrapp	
	2-3 leaves	Budonization	2-3 leaves	Budonization	2-3 leaves	Budonization
0.7	1.2/0.24	6.6/1.65	1.0/0.21	7.9/1.97	1.3/0.26	6.9/1.79
0.9	1.6/0.32	6.7/1.61	1.2/0.24	6.9/1.72	1.6/0.31	6.1/1.59
1.1	1.9/0.40	6.2/1.55	1.4/0.27	6.5/1.63	1.8/0.36	5.9/1.53
1.3	2.0/0.43	6.5/1.62	1.7/0.33	6.4/1.60	2.1/0.40	5.6/1.51
HIP_{05}, thousand m^2	–	0.03/0.02	–	0.02/0.02	–	0.04/0.03

Note*: green mass is shown in the numerator, and absolute dry mass in the denominator*

As you can see, in most cases, the maximum level of biomass harvest is formed at the minimum density of plants in the budding phase. As the density increases, the biomass gradually decreases, which is a reliable sign of the significant advantage of crops with lower sowing rates in terms of photosynthesis productivity (Table 4).

Table 4. *Net productivity of photosynthesis for the period of 2-3 leaves to the budding phase depending on the pea sowing rate, 2021 (Moroz variety)*

Sowing rate, million seeds per 1 ha	Average leaf area, m^2/ha	Increase in dry biomass per period, t/ha	Duration of the period, days	Photosynthetic potential, thousand m^2/ha *days	Net photosynthetic productivity, g/m^2 per day
0.7	2400	1410000	36	266.4	5.29
0.9	9400	1290000	36	338.4	3.81
1.1	10500	1050000	36	378.0	2.78
1.3	13400	1190000	36	482.0	2.47

Thus, the decisive role in the formation of the phytomass crop belongs to the productivity of photosynthesis, and not to the size of the apparatus. The difference between the extreme options, as we can see, reaches 200%. Such a difference led us to the idea of determining the chlorophyll content in pea leaves. We obtained the following results (Table 5).

Table 5. Chlorophyll content in pea leaves in the budding phase, 2021 (Moroz variety)

Sowing rate, million/ha	Total chlorophyll, mg/100g		
	Total	Including	
		"a"	"c"
0.7	5.9	4.3	1.6
0.9	4.9	3.5	1.4
1.1	3.3	2.4	0.9
1.3	2.7	2.0	0.7

Indeed, the difference in options was very high (more than 2 times). Comparing the fractional composition, it is necessary to note the lack of specificity in this respect. In all cases, the "c" fraction was equal to 35-40% of the "a" fraction, which is a typical ratio for plants with the C4 type of photosynthesis. The main indicator that characterizes the expediency of one or another sowing rate is the yield of the main products. In our experiment, the Baltrapp variety with a sowing rate of 0.7 million seeds/ha was the most productive (Table 6).

Table 6. *Yield of winter peas depending on the sowing rate, t/ha*

Sowing rates million/ha	Moroz			Enduro			Baltrapp		
	2020	2021	Avarage	2020	2021	Avarage	2020	2021	Avarage
0.7 (в)	0.69	1.79	1.20	0.73	3.03	1.88	0.74	3.10	1.92
0.9	0.69	1.78	1.21	0.69	2.60	1.65	0.67	2.48	1.58
1.1	0.68	1.35	1.02	0.68	2.12	1.40	0.66	2.11	1.39
1.3	0.67	1.40	1.04	0.67	1.91	1.30	0.56	1.88	1.22
$HIP_{0.5}$, t/ha	A-0.06 B-0.04 AB-0.08	A-0.11 B-0.13 AB-0.18	–	–	–	–	–	–	–

Other varieties also formed the maximum productivity at the sowing rate of 0.7 million seeds/ha. Only the Moroz variety provided the same level of productivity at the norms of 0.7 and 0.9 million/ha.

Of course, the results of the 2020 crop, when the drought nullified all the efforts of the producers, and the wild pea did not form any crop at all, could negatively affect the final conclusions. But the data of 2021 very convincingly testifies to the expediency of sowing peas at the rate of 0.7 million units/ha.

Research by V.V. Lykhochvor and V.M. Andrushko [18; 19] established that the yield of pea grain also changed under the influence of seed sowing rates. A somewhat lower yield was noted on the variant with a seed sowing rate of 0.9 million/ha – 6.34 t/ha. The highest yield of peas, on average over the years of research, was noted on the variants of the experiment with a seeding rate of 1.0 and 1.1 million/ha – 6.52 and 6.55 t/ha, respectively, which is more by 0.18-0.21 t/ha for the option of seeding rate of 0.9 million/ha. On the variants of the experiment 1.2; 1.3 and 1.4 million/ha observed a natural decrease in the yield of pea grain in all years of research. It should be noted that, regardless of the investigated rate of seed sowing, higher grain yield was formed by plants of the Madonna variety.

CONCLUSIONS

On the basis of two-year data, it can be concluded that wintering peas form a small area of the leaf surface, which is marked by a high level of difference in productivity. Thus, the leaf surface area of winter pea plants at the rate of seed sowing of 0.7 million/ha was the smallest and, depending on the phase of growth and development of the plants, was 1.3-13.5 thousand m^2/ha in the Moroz variety, 1.1-11.4 thousand m^2/ha in the Enduro variety and 0.8-13.4 thousand m^2/ha in the Baltrapp variety. At the same time, the largest leaf surface area was formed by pea plants at the sowing rate of 1.3 million/ha, regardless of the studied variety. Varieties had no significant differences in leaf area. The decisive importance in the formation of the crop belongs to the productivity of photosynthesis. Thus, according to the results of the research, the highest indicators of net productivity of photosynthesis were characterized by the variant of the experiment with the seed sowing rate of 0.7 million/ha.

It was established that the highest winter pea grain yield, on average over the years of research and according to the studied sowing rates, was formed by the Enduro variety – 1.56 t/ha, which exceeded the indicators of the Baltrapp variety by 0.03 t/ha or 1.9%. and for the Moroz variety – by 0.38 t/ha or 24.4%. It should be noted that, regardless of the studied variety, the highest grain yield was obtained for seed sowing norms of 0.7 million/ha – 1.67 t/ha on average for the studied varieties, which exceeded the indicators of other variants of seed sowing norms by 0.19-0.48 t/ha or 11.4-28.7%. It should be noted that an increase in the sowing rate of winter pea seeds to 1.3 million/ha ensured the lowest grain yield regardless of the studied variety in all years of research.The practical aspects and conclusions of our research are aimed at improving the conditions of growth and development of winter pea plants during the growing season, which directly affect the yield of the crop in the conditions of southern Ukraine, in particular, the introduction of the researched elements of crop cultivation technology will ensure a much more efficient use of moisture during the growing season of plants and, as a result, their formation of a higher grain yield.

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Особливості фотосинтетичної діяльності рослин гороху зимуючого залежно від норм висіву

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Анотація. Горох – досить вибаглива до погодних умов культура, тому на тлі погіршення кліматичної ситуації треба звернути увагу на зимуючу форму. Основною перевагою гороху зимуючого є те, що він використовує вологу зимового періоду і завдяки цьому формує надземну і підземну біомасу рослин ще раніше, ніж настає літня посуха. На початку відновлення процесів весняної вегетації рослини мають добре розвинену кореневу систему, яка проникає вглиб ґрунту до 10 см, тоді як горох ярий в цей час тільки починає висівати. Як наслідок, потенційна урожайність гороху зимуючого в 2–3 рази вища, ніж у ярого. Метою досліджень було визначення впливу сортових особливостей рослин, норм висіву насіння на фотосинтетичну діяльність посівів та урожайність зерна гороху зимуючого в умовах півдня України. Методи досліджень: польовий, лабораторний, розрахунковий, статистичний. У результаті досліджень було вивчено особливості наростання надземної маси рослин, фотосинтетичної діяльності посівів та формування урожайності зерна сортів гороху зимуючого. Виявлено оптимальну норму висіву насіння гороху зимуючого, за якої повною мірою реалізується генетичний потенціал сортів. Встановлено норму висіву насіння, за якої рослини гороху зимуючого формували максимальну площу листкової поверхні. Дослідженнями встановлено, що у більшості випадків максимальний рівень урожаю біомаси сформовано за мінімальної густоти рослин у фазі бутонізації. Зі зростанням густоти поступово зменшується біомаса, що є надійною ознакою суттєвої переваги посівів з меншими нормами висіву за показниками продуктивності фотосинтезу. Визначено, що найвищу врожайність зерна гороху зимуючого, в середньому за роки досліджень і за досліджуваними нормам висіву, сформував сорт Ендуро. Дослідженнями встановлено, що зимуючий горох формує невелику площу листової поверхні, яка відзначається високим рівнем відмінності за продуктивності при пониженій нормі висіву. Відображені в статті практичні аспекти та висновки спрямовані на вдосконалення процесів формування продуктивності гороху зимуючого в умовах півдня України, зокрема за значно ефективнішого використання вологи в період вегетації рослин на формування одиниці врожаю

Ключові слова: фотосинтетична активність, листкова поверхня, надземна біомаса рослин, хлорофіл, густота, урожайність зерна