JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(11), 17–30
https://doi.org/10.12911/22998993/207409
ISSN 2299–8993, License CC-BY 4.0

Received: 2025.05.28
Accepted: 2025.08.01
Published: 2025.08.15

Development and application of *Secale cereale* L. cultivation technology based on optimal physiological parameters for arid conditions

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ABSTRACT

Currently, the disruption of the ecological balance and water scarcity are becoming one of the serious environmental problems facing all of humanity. Drought became the main limiting factor in the development of agricultural production. Therefore, currently, the study of drought resistance of plants, especially grain crops, is one of the most important issues. Drought resistance is the ability of a plant to maintain physiological properties without significant changes under drought conditions. The drought resistance of rye is related to its physiological conditions. Because its root system has the ability to absorb water well. However, drought affects almost all physiological indicators of rye. First of all, drought leads to a shortening of the plant's vegetation period. Rye (*Secale cereale* L.) is one of the most beneficial grain crops. Rye has many benefits for the national economy. In agriculture, rye flour is used as bread, and grain as animal feed. Therefore, this research work, aimed at assessing the physiological indicators of *Secale cereale* in drought conditions, is one of the important studies. The information presented in this article *Secale cereale* L. of varieties serves to explain the impact of drought on some physiological indicators. The achieved scientific results provide an opportunity to develop and apply in practice a technology for growing *Secale cereale* L. based on optimal physiological parameters for arid conditions.

Keywords: *Secale cereale* L., phenological phases, varieties, drought, transpiration, pigments, photosynthetic.

INTRODUCTION

The global climate change observed around the world has a negative impact on the environment, including food production (Olufemi et al., 2014). One of the main causes of global climate change is a sharp increase in the amount of CO_2 in the atmosphere. This is currently causing drought, which threatens the entire living world (Abigail et al., 2018; Akramov et al., 2025).

Drought is an ecological and global factor that limits agricultural production, causes serious damage to the ecosystem and the human world, and sharply reduces economic growth, causes soil erosion, and leads to desertification of large areas of land. In addition (Hao et al., 2015; Fang et al., 2015). The occurrence of drought is directly related to the lack of water in the amount necessary for the normal growth and development of plants. Insufficient water negatively affects the main physiological indicators of plants. Therefore, preventing water shortages, eliminating drought, or selecting or creating drought-resistant crop varieties is one of the most important issues today (Serraj et al., 2009; Khojakulov et al., 2024).

When plants are exposed to unfavorable factors, they develop responses to these stresses.

For example, the mechanism of drought resistance in plants is the process of preventing dehydration. This process is the plant's ability to retain hydration (Blum et al., 2011). Drought in plants is one of the most widespread stresses, which leads to changes in the morphological characteristics of plants, ranging from the molecular level. The mechanism of drought resistance is not equally developed in all plants. Some plants have the ability to maintain cell homeostasis even in arid environments. Such plants are considered drought-resistant (Salehi et al., 2016; Mukhtorova et al., 2024).

Drought leads to a decrease in the yield of agricultural crops, including grain crops. Among cereal crops, rye (*Secale cereale* L.) is distinguished by its drought resistance compared to other grain crops. Rye is grown mainly in European countries, including Russia, Belarus, Germany, Ukraine, and Poland. Rye is mainly used in the production of black bread, as fodder, in the production of ethanol and biomethane. According to the data, rye is an ancient plant, and its cultivation began in the countries of the Eastern Baltic, while in Europe it has been cultivated for more than 1000 years. It is closely related to wheat (*Triticum aestivum*) and is more adaptable to environmental factors than other grain crops (Geiger et al., 2009; Grippėdis et al., 2016; Ikram et al., 2023).

Rye although it belongs to *the tribe triticeae* and has well-developed drought resistance, water scarcity leads to negative changes in its physiological, morphological, and biochemical indicators. As a result, it leads to a decrease in rye yields (Czyczyło-Mysza et al., 2017). Therefore, water scarcity is one of the abiotic factors limiting plant yields. In studies conducted over several years by specialists such as Lorenz Kotman and Peer Wilde, Siegfried Schittenhelm, a decrease in rye yield from 14% to 57% was observed as a result of drought (Kottman et al., 2016).

Rye is distinguished by several beneficial properties. Rye bread has a positive effect on glucose levels by reducing insulin production compared to wheat bread. In addition, it surpasses other grain crops in its high antioxidant properties. Taking into account such beneficial properties of rye, the demand for its cultivation is growing. If rye production in the world averaged 14.2 million tons from 2009 to 2018, then in subsequent years this indicator has relatively decreased. The main reason for this is the decrease in rye yields due to frequent droughts. Therefore, in recent years, the selection of drought-resistant rye varieties or the creation of hybrid rye varieties has become one of the important issues (Dziki et al., 2022; Korzun et al., 2021).

According to the data analyzed above, drought negatively affects the physiological properties of grain crops, including rye, which is an important plant for agriculture. Therefore, it is important to study the influence of drought on different varieties of rye. The purpose of the research is to assess the influence of drought on the physiological indicators of annual rye varieties.

MATERIALS AND METHODS

Research object and experimental site

Seeds of rye varieties "Vakhsh-116," "Shalola," and "Savo" were used as the object of research. Seeds were taken from the seed collection of the Institute of Biochemistry of Samarkand State University. Field experiments were conducted in the laboratory of the Department of Plant Physiology and Microbiology of the Institute of Biochemistry of Samarkand State University at the "Ulug' Baraka yerlari" farm in the Jomboy district of the Samarkand region.

Determination of leaf water deficit

The water deficit in the leaves relative to full saturation was determined by the Chatsky method (Abdullaev et al., 2004) and the following calculations were performed based on the Stocker formula:

$$x = \frac{U \times 100}{S} \quad (1)$$

where: X – degree of leaf dehydration, in %;
U – the amount of additional water absorbed by the leaves, in g;
S – total water content in the leaves.

Leaf transpiration rate

The intensity of transpiration was determined by the Ivanov method on an analytical electronic balance of the KERN ABJ-NM/ABS-N brand (Kuznetsov et al., 2005). The transpiration intensity of rye varieties was calculated using the following equation.

$$x = \frac{U \times 100}{S} \qquad (2)$$

where: U – transpiration intensity, g/m^2/s;
a – the amount of water evaporated for 3 minutes, in g;
b – leaf area, sm^2;
10000 sm^2 – conversion factor to m^2.

Determination of plastid pigments

The content of pigments in the leaves was determined by calculating the content of chlorophylls and carotenoids in a 96% alcohol solution of Wettstein (1957) using the method of Gavrilenko et al. (2000).

Determination of net photosynthetic productivity

The net productivity of photosynthesis was calculated by the method of Nichiporovich using the following formula (Khuzhaev et al., 2019):

$$F = \frac{B_2 - B_1}{\frac{1}{2}(L_1 + L_2)T} \qquad (3)$$

where: B_1 and B_2 – the amount of dry matter (g) formed in the plant at the beginning and end of the experiment,
L_1 and L_2 – leaf area at the beginning and end of the experiment (m^2),
T – number of days during the experiment,
F – amount of accumulated organic matter (g /m^2, day).

Determination of dry matter content

The amount of dry matter was determined by drying in a drying cabinet to a constant mass according to the method by Tretyakov et al., (1990).

Statistical analysis

Statistical processing of the results collected during the scientific research was carried out according to the recommendations of Dospekhov (Dospekhov 1985). For the average comparison of the experimental results, the protective LSD test (P ≤ 0.05) was used. Mathematical and statistical analysis was carried out according to the method of calculating the mean values and deviations of indicators, as well as probabilities (Lakin 1990; Rayimova et al., 2024).

RESULTS AND DISCUSSION

Water deficit in leaves in drought conditions *S. cereale*

We know that high air temperature and a decrease in relative humidity lead to a decrease in soil moisture, and these factors negatively affect agricultural crops. As a result, all physiological and biochemical processes occurring in plants are disrupted. Disruption of water balance is one of the factors leading to water deficiency in plant leaves. Any plant growing in natural conditions experiences water deficiency. Water deficit in rye varieties is a process that demonstrates the resistance of varieties to soil and atmospheric drought, characterized by a low amount of water deficit in drought-resistant plants. In reality, water scarcity occurs as a result of rising daytime air temperatures. The reason for this is a change in the relative equilibrium due to the acceleration of water evaporation in the leaves of the plant and the inability of the received water to replace the consumed water. When cultivating rye, it is advisable to study water deficit when adapting varieties to new soil and climatic conditions.

Therefore, in our research work, it is important to study the water deficit in the leaves of rye varieties in temperate and arid conditions. As can be seen from the data presented in Figure 1, the water deficit in rye varieties increased from morning until 14:00, and then decreased until evening. This pattern was repeated in all varieties and phases. It was established that the time of high water deficit in the leaves occurred at 14:00. In conditions of sufficient water availability, the water deficit in the tillering phase was observed in the morning from 3.3% to 4.2%. By the warmest time of day, the water deficit increased, i.e., from 7.9% to 10.4%, and by evening from 5.1% to 7.4%, which was confirmed in our experiment. In this phase, the average daily water deficit was from 5.6% to 7.7%, and the range of daily changes was from 4.6 to 6.2. In the tubing phase, the water deficit was slightly higher than in the accumulation phase. Water deficit in the morning period ranges from 4.0% to 5.3%.

By the warmest time of day, the water deficit increased, i.e., from 9.7% to 13.1%, and by evening from 6.3% to 7.9%. In this phase, the average daily water deficit was from 7.2% to 9.9%, and the range of daily changes was from 5.7% to 7.8%. In this phase, the lowest water deficit was

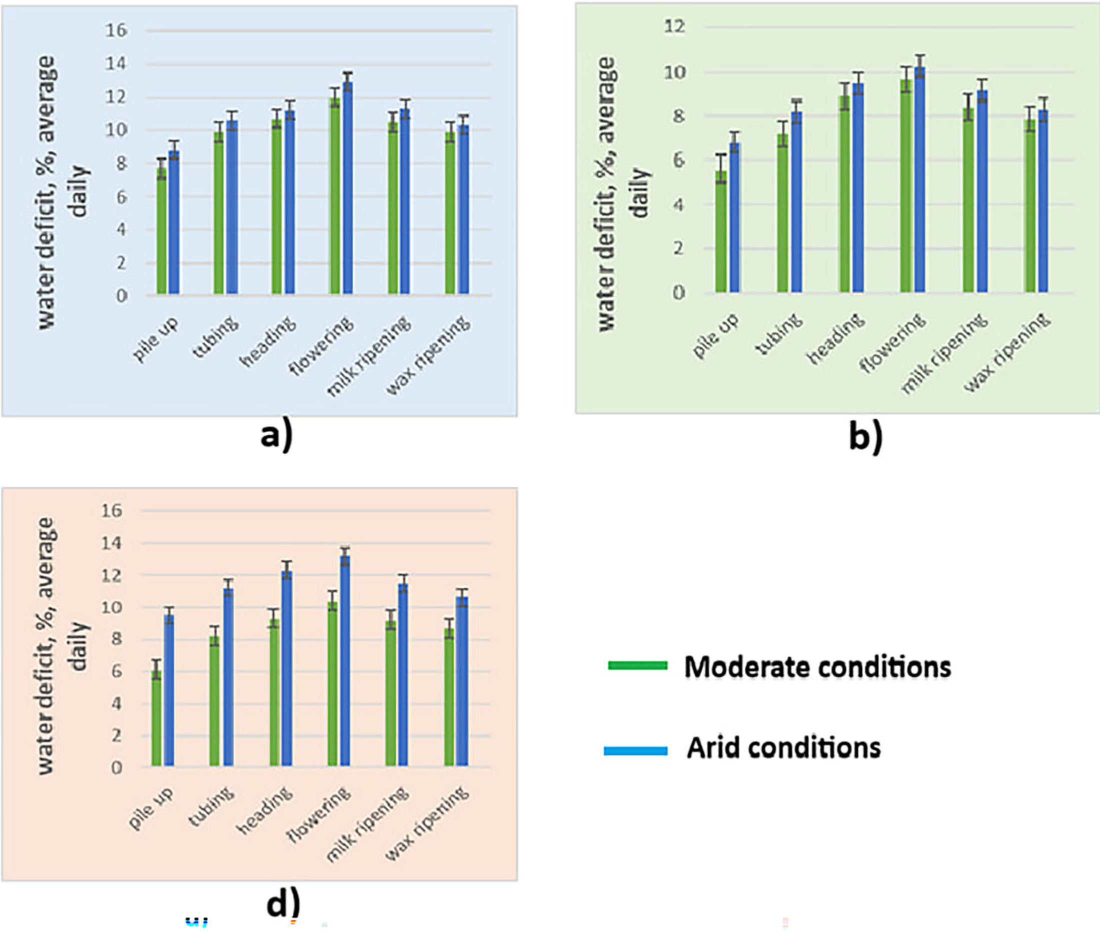


Figure 1. Average daily water deficit of rye varieties, (%): (a) Vakhsh-116, (b) Shalola, (d) Savo

observed in the Shalola variety, while the highest water deficit was observed in the Vakhsh-116 variety, and the Savo variety took an intermediate position. Under the influence of increasing temperature in the heading phase, the water deficit increased in all varieties. Water deficit was observed in the morning from 5.1% to 5.9%. By the warmest time of day, the water deficit increased, i.e., from 12.6% to 13.7%, and by evening from 7.1% to 9.1%. In this phase, the average daily water deficit was from 8.9% to 10.7%, and the range of daily changes was from 5.7 to 7.8. It was found that the water deficit is highest during the flowering phase. Water deficit was observed in the morning from 5.8% to 7.8%. By the warmest time of day, the water deficit increased, i.e., from 12.3% to 14.8%, and by evening from 7.1% to 10.6%. In this phase, the average daily water deficit was from 9.7% to 12.0%, and the range of daily fluctuations was from 6.5 to 8.0. The lowest water deficit was observed in the Shalola variety, the highest water deficit in this phase was also in the Vakhsh-116 variety, the remaining variety occupied an intermediate position. Arriving in the grain ripening phase, the water deficit decreased somewhat. Water deficit was observed in the morning from 4.1% to 5.7%. By the warmest time of day, the water deficit increased, i.e., from 10.9% to 12.8%, and by evening from 5.2% to 7.2%. In this phase, the average daily water deficit was from 7.9% to 9.9%, and the range of daily fluctuations was from 6.7 to 7.1. When analyzing the water deficit in the leaves of rye varieties grown in arid conditions, it was observed that the water deficit in plants growing in arid conditions is somewhat higher. In arid conditions, water deficit in the tillering phase ranges from 3.8% to 5.4% in the morning. By the warmest time of day, the water deficit increased, i.e., from 10.2% to 13.2%, and by evening from 5.5% to 7.2%, which was confirmed in our experiment. In this phase, the average daily water deficit was from 6.8% to 8.8%, and the range of daily changes was from 6.4 to 7.8. In this phase, resistance to water deficit was observed in the Shalola variety, and high water deficit in the Savo variety. A high water deficit was observed in all varieties due to the increase in temperature in the tubing phase. In the morning hours, the deficit was from 5.1% to 7.0%, the maximum deficit was from 11.5% to 14.1% at 14:00, and by 18:00 it was from 6.4% to 9.0%. The average daily water deficit was from 8.2% to 11.2%, the range of daily changes was from 6.4 to 7.1. In the heading phase, the water deficit also increased in all varieties. Water deficit was observed in the morning from 6.0% to 7.5%. By the warm time of day, the water deficit was from 12% to 14.3%, and by evening – from 7.2% to 10.2%. In this phase, the average daily water deficit was from 9.5% to 12.3%, and the range of daily fluctuations was from 6 to 6.8. It was established that in arid conditions, the water deficit is highest during the flowering phase. The water deficit was from 6.4% to 9.1% in the morning, the maximum deficit was from 13.0% to 16.4% at 14:00, and by 18:00 in the evening it was from 7.5% to 10.3%. The average daily water deficit was from 10.3% to 13.2%, and the range of daily fluctuations was from 6.6 to 7.3. The lowest water deficit was observed in the Shalola variety, and the highest water deficit in this phase was also in the Savo variety. In the flowering phase, the Shalola variety experienced an average daily deficit of 0.8% more in arid conditions compared to moderate conditions, while the Savo variety showed an increase of 2.8%. Arriving in the grain ripening phase, the water deficit decreased somewhat. Water deficit was observed in the morning from 4.4% to 5.9%. By the warm time of day, the water deficit increased, i.e., from 11.0% to 13.5%, and by evening from 5.6% to 8.2%. In this phase, the average daily water deficit was from 8.5% to 11.2%, and the range of daily changes was from 6.4 to 7.8. In this study, when analyzing the water deficit in the leaves, the results showed that the Shalola variety of rye grown in arid conditions is less water-deficient and drought-resistant compared to other varieties in all phases of development and at all times of the day. In general, the lowest water deficit in rye varieties was observed in the tillering phase, the highest deficit was observed in the flowering phase, and a decrease was observed in the grain ripening phase. The increase in water demand during the flowering phase is associated with a high air temperature and a decrease in relative humidity. Our experiments have proven that plants growing in arid conditions have a higher deficit compared to temperate conditions.

Transpiration intensity in *S. cereale* under drought conditions

The next stages of our research are aimed at determining the intensity of transpiration of rye varieties. Usually, the intensity of transpiration of all plants varies depending on their geographical location, soil and climatic conditions, and plant species. In cereal crops, it occurs from the stem elongation phase to flowering (Figure 2).

Because plants need the most moisture during this period. In moderate conditions, due to the lower air temperature in the tillering phase of rye varieties, the transpiration intensity is not high, and the time of intensive transpiration in the tillering phase is from 67.5 g/m^2 hours to 74.7 g/m^2 hours at 14:00. In the tillering phase, the average daily transpiration rate ranged from 48.8 g/m^2 hours to 58.1 g/m^2 hours. In this phase, a relatively high transpiration intensity was noted in the Vakhsh-116 variety, and a low transpiration intensity was noted in the Shalola variety. In this phase, the time of intensive transpiration at 14:00 is from 88.2 g/m$^{2\cdot}$ hours to 102.3 g/m^2. hours. The low indicator of transpiration intensity in the tubal phase is 41.2 g/m in the morning $^{2\cdot}$ hour to 48.9 g/m^2 hour. In the tubal phase, the average daily transpiration rate ranged from 64.3 g/m$^{2\cdot}$ hours to 76.8 g/m^2 hours. In the heading phase, the intensity of transpiration intensified due to the increase in air temperature. In this phase, the time of intensive transpiration at 14:00 was from 125.6 g/m^{2}hours to 153.2 g/m^{2}hours. In the heading phase, the low transpiration rate was observed in the morning hours from 68.6 g/m^2 hours to 75.4 g/m^2 hours. In the heading phase, the average daily transpiration rate ranged from 89.8 g/m^2 hours to 105.8 g/m^2 hours. In our research, it was established that the greatest transpiration in rye varieties occurs in the flowering phase.

In the flowering phase of rye varieties, the most intense transpiration was observed at 14:00. Accordingly, the transpiration rate ranged from 196.9 g/m^{2}hours to 223.6 g/m^{2}hours. In the flowering phase, a relative decrease in transpiration was observed in the mornings, ranging from 76.5 g/m^2 hours to 88.9 g/m^2 hours. The average daily transpiration rate ranged from 136.9 g/m^2 hours to 153.8 g/m^2 hours. In the flowering phase, the highest transpiration intensity was observed in the Vakhsh-116 variety, and the lowest transpiration intensity was observed in the Shalola variety. From our research, it became known that under

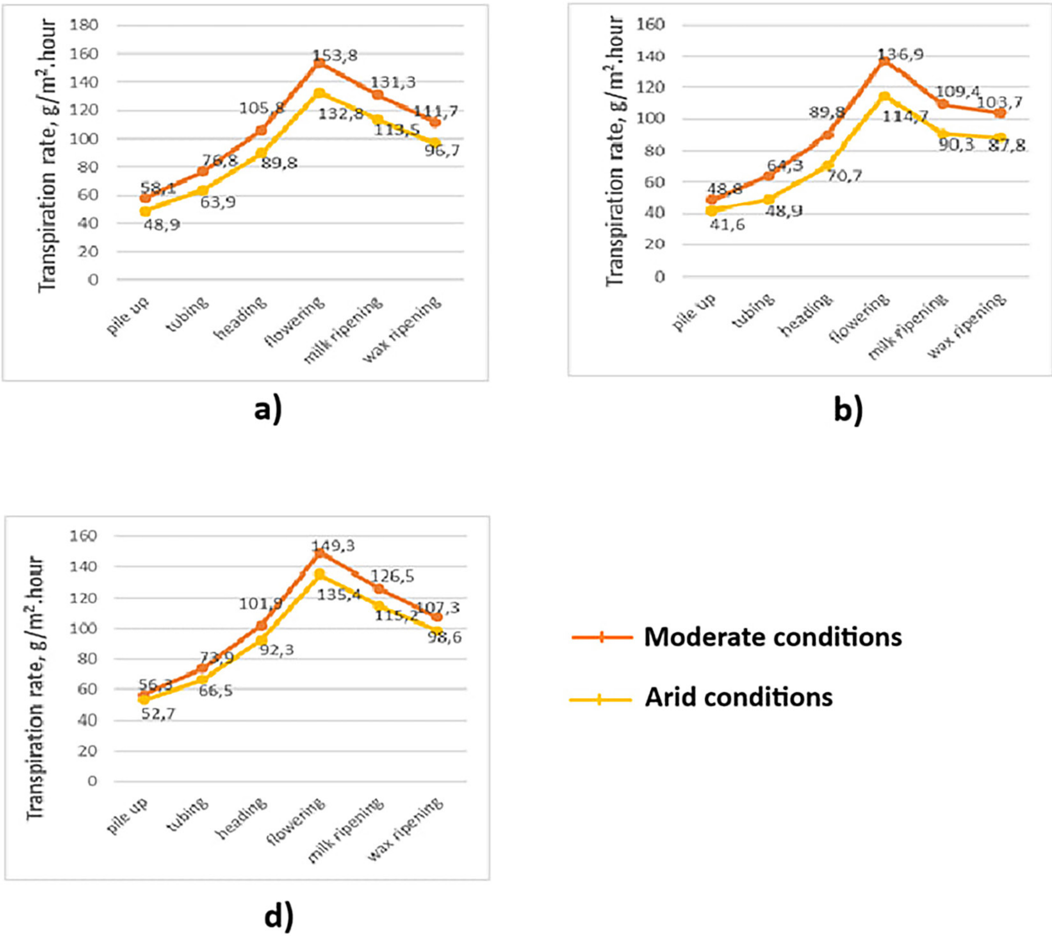


Figure 2. Daily average transpiration rate of rye varieties (g/m^2. hours): (a) Vakhsh-116, (b) Shalola, (d) Savo

conditions of sufficient humidity, the intensity of transpiration in the Shalola variety of rye was slightly lower in all phases and throughout the day. In the Vakhsh-116 variety, transpiration was found to be slightly more intensive.

In arid conditions, a significant decrease in the intensity of transpiration was observed in rye varieties. This pattern was repeated in all phases of development. Due to the low temperature in the tillering phase, no significant difference was observed in temperate and arid conditions. In the tillering phase, the time of intensive transpiration at 14:00 was from 51.6 g/m^2 hours to 68.8 g/m^2 hours. In the tillering phase, the low indicator of transpiration intensity was observed in the morning hours from 31.2 g/m^2 hours to 36.3 g/m^2 hours. In the tillering phase, the average daily transpiration rate ranged from 41.6 g/m^2 hours to 52.7 g/m^2 hours. It was established that the time of intensive transpiration in the tubal phase is from 66.5 g/m^2 hours to 91.3 g/m^2 hours at 14:00. In the tubal phase, the average daily transpiration rate ranged from 48.9 g/m^2 hours to 66.5 g/m^2 hours. In the heading phase, the time of intensive transpiration was observed at 14:00. In this phase, the average daily transpiration rate ranged from 70.7 g/m^2 hours to 92.3 g/m^2 hours. The highest transpiration intensity occurred during the flowering phase. During the grain ripening phase, transpiration decreased slightly. It has been scientifically substantiated that the intensity of transpiration in arid conditions is lower than in normal conditions. Under these conditions, a relatively low transpiration rate was observed in the Shalola variety at all stages of development, while a high indicator was noted in the Savo variety.

In drought conditions *S. cereale* plastid pigment content in leaves

As we know, photosynthesis occurs mainly in the green leaves of plants and partially in young shoots and unripe fruits, the main reason for this is the presence of chloroplasts. These pigments, found in the bodies of plants, play a very important role in the process of photosynthesis.

Chlorophyll pigments are directly involved in carrying out all primary reactions of the photosynthesis process. Chloroplast pigments are one of the most important indicators that determine the intensity of photosynthesis, growth and development of plants, as well as productivity indicators and yield. Chlorophyll pigments “a” and “b” are most actively involved in the process of photosynthesis. The remaining yellow, orange, and red carotenoid pigments participate in several physiological processes. The function of carotenoids mainly consists of protecting plants from harmful factors and delivering short-wavelength rays to chloroplasts (Xujaev et al., 2004).

In our studies, the dynamics of plastid pigment formation in rye varieties growing in temperate and arid environments changed throughout the development phases depending on the biological characteristics of the varieties. The content of plastid pigments in the wet leaves of rye varieties changed at different stages of development. In this case, the total number of chlorophylls increased from the tillering phase to the flowering phase, and by the grain ripening phase, a decrease in the total number of chlorophylls was observed. In accordance with the law, it was established that the amount of chlorophyll “a” in rye varieties is higher than the amount of chlorophyll “b.” The amount of carotenoid pigments was initially lower than the amount of chlorophyll “a” and “b” and increased during the growing season. When analyzing pigments in the tillering phase under moderate conditions, the total amount of chlorophyll ranged from 4.53 mg/g to 4.89 mg/g, respectively, and the amount of chlorophyll “a” in this phase ranged from 2.71 mg/g to 2.94 mg/g, respectively. It was noted that the amount of chlorophyll “b” in rye varieties ranged from 1.82 mg/g to 1.95 mg/g, and when analyzing the amount of carotenoids, it ranged from 1.51 mg/g to 1.59 mg/g, respectively. The ratio of chlorophyll “a” to chlorophyll “b” varied from 1.49 to 1.51, respectively.

When analyzing pigments in the tubing phase under normal conditions, the total amount of chlorophyll ranged from 4.84 mg/g to 5.14 mg/g, the amount of chlorophyll “a” varied from 2.95 mg/g to 3.16 mg/g, and the amount of chlorophyll “b” varied from 1.89 mg/g to 1.98 mg/g. When analyzing the content of carotenoids, it was noted that it ranged from 1.62 mg/g to 1.69 mg/g, with the highest content in the Shalola variety and the lowest in the Vakhsh-116 variety (Table 1).

During the analysis of pigments in the heading phase, the total amount of chlorophyll increased in all varieties. In this phase, the total amount of chlorophyll in the Vakhsh-116 variety was 5.56 mg/g, which is 0.5 mg/g more compared to the tubing phase, in the Shalola variety it was 5.63 mg/g, which is 0.49 mg/g more compared to the tubing phase, in the Savo variety it was 5.34 mg/g, which is 0.5 mg/g more compared to the tubing phase. It was noted that the amount of chlorophyll “a” in this phase varied from 3.21 mg/g to 3.39 mg/g, corresponding to the varieties. In the heading phase, the amount of chlorophyll “b” in rye varieties ranged from 2.14 mg/g to 2.24 mg/g. When analyzing the carotenoid content in the varieties, it was found that it varied from 1.79 mg/g to 1.85 mg/g. The ratio of chlorophyll “a” to chlorophyll “b” was found to be from 1.50 to 1.51.

It was established that in arid conditions, the content of chlorophyll “a” and “b” is slightly lower than in moderate conditions, but the content of carotenoids is higher than in varieties growing in moderate conditions. In drought conditions, in the tillering phase, the total amount of chlorophyll in rye varieties ranged from 4.44 mg/g to 4.79 mg/g, the amount of chlorophyll “a” varied from 2.66 mg/g to 2.88 mg/g, and the amount of chlorophyll “b” varied from 1.78 mg/g to 1.91 mg/g. When analyzing the content of carotenoids, it was found that it ranged from 1.54 mg/g to 1.62 mg/g, which is slightly higher than under normal conditions. The ratio of chlorophyll “a” to chlorophyll “b” ranged from 1.49 to 1.52.

When analyzing pigments in the tubing phase under dry conditions, the total amount of chlorophyll ranged from 4.68 mg/g to 4.92 mg/g, and the amount of chlorophyll “a” varied from 2.87 mg/g to 2.99 mg/g, respectively. It was noted that the amount of chlorophyll “b” ranged from 1.81 mg/g to 1.93 mg/g. When analyzing the carotenoid content, it was found that it varied from 1.66 mg/g to 1.73 mg/g, depending on the variety. In the heading phase, the total amount of chlorophyll in the plants ranged from 5.17 mg/g to 5.46 mg/g. The amount of chlorophyll “a” in the Vakhsh-116 variety was 3.11 mg/g, which is 0.24 mg/g less than under normal conditions, in the Shalola variety it was 3.29 mg/g, which is 0.1 mg/g less than under normal conditions, in the Savo variety it was 3.15 mg/g, which is 0.6 mg/g less than under normal conditions.

In the flowering phase, the total amount of chlorophyll in the varieties ranged from 5.28 mg/g to 5.50 mg/g, the amount of chlorophyll “a” in this

Table 1. The content of plastid pigments in the developmental phases of rye varieties under moderate conditions (mg/g)

Varieties	Developmental phases	Chlorophylls		Carotenoids	Xl,,a " +Xl,,b "	Xl,,a " / Xl,,b "
		a	b			
Vakhsh-116	Pile up	2.81 ±0.12	1.86 ±0.09	1.56 ±0.17	4.67	1.51
Shalola		2.94 ±0.14	1.95 ±0.11	1.59 ±0.19	4.89	1.51
Savo		2.71 ±0.11	1.82±0.13	1.51 ±0.11	4.53	1.49
Vakhsh-116	Tubing	3.11 ±0.19	1.94 ±0.08	1.67 ±0.16	5.07	1.60
Shalola		3.16 ±0.11	1.98 ±0.11	1.69 ±0.07	5.14	1.59
Savo		2.95 ±0.07	1.89 ±0.17	1.62 ±0.18	4.84	1.59
Vakhsh-116	Heading	3.35 ±0.18	2.21 ±0.12	1.83 ±0.15	5.56	1.51
Shalola		3.39 ±0.17	2.24 ±0.11	1.85 ±0.17	5.63	1.51
Savo		3.21 ±0.11	2.14 ±0.15	1.79 ±0.14	5.34	1.50
Vakhsh-116	Flowering	3.29 ±0.18	2.23 ±0.13	1.87 ±0.17	5.52	1.48
Shalola		3.43 ±0.17	2.29 ±0.17	1.89 ±0.15	5.72	1.49
Savo		3.25 ±0.11	2.21 ±0.15	1.86 ±0.08	5.44	1.47
Vakhsh-116	Milk ripening	2.98 ±0.15	2.01 ±0.09	1.91 ±0.11	4.99	1.48
Shalola		3.04 ±0.20	2.06 ±0.08	1.93 ±0.16	5.10	1.47
Savo		2.91 ±0.07	1.98 ±0.12	1.88 ±0.13	4.89	1.47
Vakhsh-116	Wax ripening	2.94 ±0.14	1.96 ±0.07	1.94 ±0.07	4.92	1.50
Shalola		2.99 ±0.15	2.01 ±0.16	1.97 ±0.18	5.10	1.49
Savo		2.85 ±0.13	1.91 ±0.07	1.93 ±0.16	4.76	1.49

phase ranged from 3.18 mg/g to 3.34 mg/g. It was noted that the amount of chlorophyll "b" in plants ranged from 2.10 mg/g to 2.21 mg/g (Table 2).

When analyzing the content of carotenoids, it was established that during the flowering phase, the amount of pigment in the Vakhsh-116 variety was 1.98 mg/g, which is 1.2 mg/g higher than normal conditions, in the Shalola variety it was 2.11 mg/g, which is 0.22 mg/g higher than normal conditions, and in the Savo variety it was 2.03 mg/g, which is 0.16 mg/g higher than normal conditions. The content of plastid pigments decreased in all varieties by the grain ripening phase. In this phase, the total amount of chlorophyll ranged from 4.60 mg/g (in the Vakhsh-116 variety) to 4.56 mg/g (in the Savo variety). The amount of chlorophyll "a" varied from 2.77 mg/g to 2.86 mg/g, respectively. In this phase, the amount of chlorophyll "b" ranged from 1.79 mg/g to 1.92 mg/g. When analyzing the content of carotenoids, it was established that the amount of pigment increased from 2.24 mg/g to 2.29 mg/g, which is higher compared to varieties growing in moderate conditions.

In general, it was established that the amount of chlorophyll "a" in rye varieties is higher than chlorophyll "b," and the amount of carotenoids is lower than chlorophyll "a". From the initial stages of rye development to the flowering phase, the total amount of chlorophyll increases, but by the grain ripening phase, a slight decrease in the amount of pigments is observed. It was found that the amount of carotenoids in rye varieties is relatively low in the initial stages of development and increases at the end of the growing season. A slightly higher content of carotenoids was observed in plants growing in arid conditions. In moderate and arid conditions, the total amount of chlorophyll in the Shalola variety was higher than in other varieties.

Net photosynthetic productivity in *S. cereale* under drought conditions

The process of photosynthesis is an important process that determines the productivity of plants. Usually, in the process of cultivating cultivated plants, the level of net productivity of photosynthesis is of great importance. The amount of organic matter formed as a result of photosynthesis depends on a number of factors, for example, external abiotic factors, the biological characteristics of varieties, and the results of agrotechnological measures.

In our studies, the net productivity of photosynthesis of rye varieties in a moderate and arid

Table 2. The content of plastid pigments in the developmental phases of rye varieties in arid conditions (mg/g)

Varieties	Developmental phases	Chlorophylls		Carotenoids	Xl,,a ” +Xl,,b ”	Xl,,a “ / Xl,,b ”
		a	b			
Vakhsh-116	Pile up	2.66 ±0.13	1.78 ±0.16	1.54 ±0.12	4.44	1.49
Shalola		2.88 ±0.09	1.91 ±0.09	1.62 ±0.15	4.79	1.50
Savo		2.76 ±0.14	1.82 ±0.17	1.59 ±0.14	4.58	1.52
Vakhsh-116	Tubing	2.87 ±0.10	1.81 ±0.15	1.66 ±0.11	4.68	1.58
Shalola		2.99 ± 0.15	1.93 ±0.11	1.73 ±0.18	4.92	1.55
Savo		2.93 ±0.13	1.88 ±0.13	1.70 ±0.08	4.81	1.56
Vakhsh-116	Heading	3.11 ±0.22	2.06 ±0.19	1.79 ±0.16	5.17	1.51
Shalola		3.29 ±0.18	2.17 ±0.15	1.88 ±0.15	5.46	1.52
Savo		3.15 ±0.09	2.11 ±0.16	1.84 ±0.07	5.26	1.49
Vakhsh-116	Flowering	3.18 ±0.16	2.10 ±0.18	1.98 ±0.13	5.28	1.51
Shalola		3.34 ±0.18	2.21 ±0.15	2.11 ±0.17	5.55	1.51
Savo		3.17 ±0.09	2.13 ±0.11	2.03 ±0.15	5.30	1.49
Vakhsh-116	Milk ripening	2.91 ±0.13	1.92 ±0.07	2.13 ±0.19	4.83	1.51
Shalola		2.99 ±0.15	2.02 ±0.09	2.21 ±0.20	5.01	1.48
Savo		2.89 ±0.17	1.92 ±0.18	2.15 ±0.17	4.81	1.50
Vakhsh-116	Wax ripening	2.79 ±0.14	1.81 ±0.15	2.24 ±0.15	4.60	1.54
Shalola		2.86 ±0.18	1.92 ±0.11	2.29 ±0.11	4.78	1.49
Savo		2.77 ±0.15	1.79 ±0.09	2.26 ±0.09	4.56	1.55

environment was determined. In this case, the net productivity of photosynthesis varied depending on the biological characteristics of the varieties. The obtained data are presented in Table 3.

According to the data presented in Table 3, the net productivity of photosynthesis in rye varieties varied throughout the development phases, depending on the biological characteristics of the varieties. In all rye varieties, from the tillering phase to the flowering phase, net photosynthetic productivity increased, and by the grain ripening phase, a decrease in net photosynthetic productivity was observed. Under moderate conditions, the net photosynthetic productivity in the tillering phase was 5.83 g/m^{2}day in the Vakhsh-116 variety, 5.72 g/m^{2}day in the Shalola variety, and 5.65 g/m^{2}day in the Savo variety.

In the tubing phase under moderate conditions, it was 6.19 g/m^{2}day for the Vakhsh-116 variety, 6.11 g/m^{2}day for the Shalola variety, and 5.96 g/m^{2}day for the Savo variety.

In the heading phase, depending on the biological characteristics of the varieties, the net productivity of photosynthesis increased, averaging from 6.49 g/m^{2}day to 6.73 g/m^{2}das. In this phase, the highest net productivity was observed in the Vakhsh-116 variety, and the lowest productivity in the Savo variety. In rye varieties, the net productivity of photosynthesis was highest in the flowering phase. In this phase, in the Vakhsh-116 variety it was 7.23 g/m^{2}day, and in the Shalola variety it was 7.45 g/m^{2}day. A decrease in net photosynthesis productivity was observed in the grain ripening phase, which averaged 6.21 g/m^{2}day for the Vakhsh-116 variety. In the Shalola variety, it was 6.33 g/m^{2}day. According to the research results, the net productivity of photosynthesis in the heading and flowering phases of rye varieties was higher than in other phases. Among the varieties, it was during the flowering and grain ripening phases that the Shalola variety showed high net photosynthetic productivity. In these phases, relatively low net productivity of photosynthesis was observed in the Savo variety. In arid conditions, a slight decrease in the net productivity of photosynthesis was observed in rye varieties compared to normal conditions. It was established that the net productivity of photosynthesis in plants during the tillering phase averaged from 5.09 g/m^{2}day to 5.14 g/m^{2}day. In the tubal phase, an increase in net photosynthesis productivity was observed, averaging from 6.01 g/m^{2}day to 6.09 g/m^{2}day. In the heading phase, a decrease in net photosynthetic productivity was observed in arid conditions compared to moderate conditions; the lowest productivity was also

Table 3. Net photosynthetic productivity of rye varieties (g/m^{2}day)

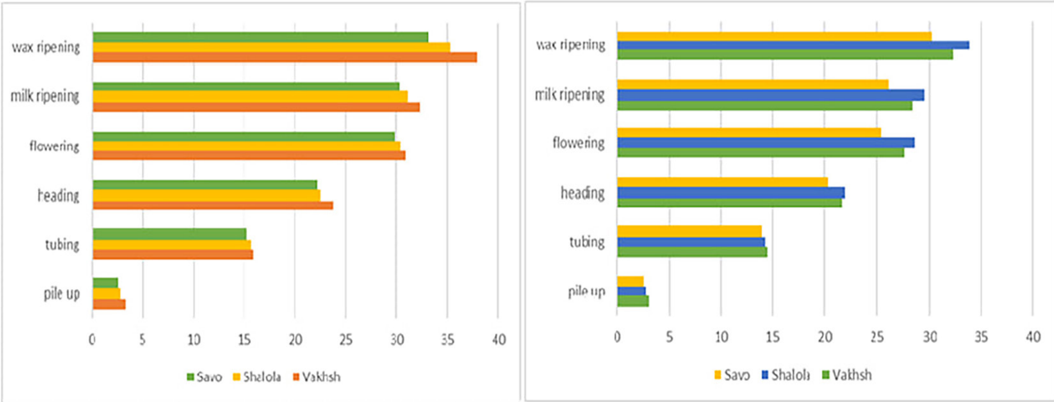
No	Varieties	Pile up	Tubing	Heading	Flowering	Milk ripening	Wax ripening
Moderate conditions							
1.	Vakhsh-116	5.83 ±0.35	6.19 ±0.43	6.73 ±0.33	7.23 ±0.32	7.10 ±0.21	6.21 ±0.45
2.	Shalola	5.72 ±0.40	6.11 ±0.44	6.61 ±0.45	7.45 ±0.36	7.21 ±0.34	6.33 ±0.43
3.	Savo	5.65 ±0.45	5.96 ±0.38	6.49 ±0.54	7.12 ±0.22	6.95 ±0.40	6.11 ±0.28
Drought conditions							
1.	Vakhsh-116	5.14 ±0.33	6.03 ±0.41	6.32 ±0.38	6.72 ±0.33	6.54 ±0.32	5.75 ±0.21
2.	Shalola	5.11 ±0.27	6.09 ±0.45	6.48 ±0.32	7.19 ±0.21	6.83 ±0.45	5.98 ±0.45
3.	Savo	5.09 ±0.21	6.01 ±0.38	6.35 ±0.42	6.88 ±0.25	6.59 ±0.29	5.82 ±0.40

noted in the Vakhsh-116 variety (6.32 g/m^{2}day). The highest net photosynthetic productivity was observed in the Shalola variety (6.48 g/m^{2}day). When comparing 2 conditions, the variety with the greatest difference in productivity was the Savo variety. Even in the flowering phase, a decrease in net photosynthetic productivity was observed in arid conditions compared to moderate conditions. The relatively low net productivity of photosynthesis in the Savo variety was 6.88 g/m^{2}day, while among the varieties, the highest indicator was 7.19 g/m^{2}days in the Shalola variety. A decrease in net photosynthesis productivity was observed during the grain ripening phase. A relatively low net productivity of photosynthesis was observed in the Vakhsh-116 variety, which amounted to 5.75 g/m^{2}day, while among the varieties, a relatively high indicator was observed in the Shalola variety, which amounted to 5.98 g/m^{2}day. In general, there is an inextricable link between the net productivity of photosynthesis and the biological yield, and in our experiments, it was established that a low water content in the soil leads to a decrease in the value of net productivity of photosynthesis in varieties. In our experiments, it was established that the highest net productivity of photosynthesis was observed in the flowering phase, and under both conditions, the Shalola variety had higher indicators compared to other varieties.

Dry matter content in the biomass of *S. cereale* under drought conditions

In plants, organic substances are formed from inorganic substances during photosynthesis. The resulting organic substances are used for the growth, development, and reproduction of the plant. One of the important results of the photosynthesis process is the indicator of dry matter formation. According to the research results, it was established that in rye varieties growing in moderate conditions, the amount of dry matter in the tillering phase ranged from 2.9 g/plant to 3.3 g/plant. In arid conditions, it was found that from 2.6 g/plant to 3.1 g/plant dry matter is formed. In both conditions, the amount of dry matter was relatively higher in the Vakhsh-116 variety, and the amount of dry matter was lower in the Savo variety. The formation of dry matter in rye varieties was observed most intensively in the tubing phase. Under moderate conditions, the dry matter content in the tubing phase varied from 15.3 g/plant to 15.9 g/plant, depending on the variety. In the tubing phase, the rate of dry matter increase was 15.9 g/tup in the Vakhsh-116 variety, 15.7 g/tup in the Shalola variety, and 15.3 g/tup in the Savo variety. In drought conditions, in the tubing phase, the total dry matter content in the varieties ranged from 14.0 g/plant to 14.5 g/plant, and the growth rate of dry matter was 14.5 g/plant in the Vakhsh-116 variety, 14.3 g/plant in the Shalola variety, and 14.0 g/plant in the Savo variety. In the heading phase, the total dry matter content in the varieties increased, and under moderate conditions, the total dry matter content in rye varieties ranged from 22.2 g/plant to 23.8 g/plant (Figure 3).

Under arid conditions, the total dry matter content in the varieties ranged from 20.3 g/plant to 21.9 g/plant. During the heading phase under moderate conditions, the dry matter content in rye varieties during the flowering phase under moderate conditions ranged from 29.8 g/plant to 30.9 g/plant. In arid conditions, the total dry matter content in the varieties ranged from 25.4 g/plant to 28.6 g/plant. A high content of total dry matter in the flowering phase was noted in the Vakhsh-116 variety under moderate conditions (30.9 g/plant), and in the Shalola variety under arid conditions



a) b)

Figure 3. Accumulation of dry matter in the phases of development of rye varieties, g/plant, (a) moderate conditions, (b) arid conditions

(28.6 g/plant). In the grain ripening phase, the total dry matter content in moderate conditions ranged from 33.2 g/plant to 37.9 g/plant, and in arid conditions from 30.2 g/plant to 33.9 g/plant. It was established that in the grain ripening phase, the rate of dry matter formation decreases due to a decrease in the leaf surface area of plants and the drying and falling of leaves.

In conclusion, in our studies, it was established that the level of water content in the soil affects the formation of total organic matter in rye varieties. At the end of the growing season, the greatest accumulation of organic matter was observed in the Vakhsh-116 variety under moderate conditions (37.9 g/plant), and in the Shalola variety under dry conditions (33.9 g/plant). In both conditions, relatively low accumulation of organic matter was observed in the Savo variety.

Cultivation of grain crops for agriculture based on the most optimal agrotechnological methods is the key to a high yield. Initially, high-quality sowing of field crops, that is, the distribution of seeds to the required depth in agricultural plots, forms the basis for ensuring uniform distribution of plants throughout the plant area and also affects the state of physiological indicators of plants. In studies conducted in Northern Kosovo, good results were obtained when sowing winter rye seeds with a row spacing of 5 cm and a sowing depth of 3.5 cm to 4 cm (on average 3.75 cm) (Barach et al., 2016).

According to experts The biological reaction of the rye plant to water deficit is one of the most complex processes, sometimes this process leads to the elimination of drought by accelerating the aging process in plants. As a result, the vegetative growth period of plants is usually shortened by drought. This process is unfavorable for plants, as it leads to a decrease in plant yields (Kottman et al., 2016). Although rye yields better than other cultivated plants on low-fertility soils, under the influence of severe drought, its physiological indicators change negatively, which leads to a sharp decrease in yield. As a result of the conducted research, the drought affected the complex of genes that determine the yield of rye. As a result, rye yields decreased by up to 41% compared to the control variant (Hübner et al., 2013).

Polish researchers conducted a series of experiments to assess the drought resistance of rye. In the experiments, to assess the plant's reaction to the effects of water, physiological, biochemical, and morphological parameters of the plant were used, chlorophyll fluorescence tests were conducted, allowing for the registration of changes occurring in the photosynthetic apparatus, and based on this, the physiological state of the plant was determined. The study was mainly aimed at assessing the influence of drought stress on the effectiveness of the photosynthetic apparatus of the rye line, and was assessed based on the measurement of chlorophyll fluorescence and gas exchange parameters, water balance, assimilation pigments, and morphological features, and the relationship between these parameters. According to the results obtained, in rye lines tested under drought conditions, dental permeability decreased by 17% compared to the control. Significant differences were revealed between the tested control rye lines and those exposed to stressful conditions in the level of relative water content and water saturation and deficit. On the 18th day of the drought, a decrease in the amount of water in the tissues by 31.7% compared to the control was observed. When studying the content of chlorophyll pigments in rye lines grown in arid conditions, the content of chlorophyll “a” and “b” and carotenoids was significantly lower (Malinowska et al., 2018).

Veny Yang and other researchers conducted research on the evolution of rye and its adaptation mechanisms to abiotic stresses. According to researchers, the adaptability of rye to different environments is primarily due to its rich genetic diversity, which provides a wide reservoir of alleles that can be selected for different environmental conditions. The main mechanisms include gene replication, polyploidy, and introgression of wild relatives, which introduce new genetic material that may be useful under certain ecological stresses. Another important adaptive feature is drought resistance. The deep root system of rye and efficient water use are the main physiological adaptations, which are genetically coded by selecting special traits associated with drought resistance. Studies identify genomic regions controlling properties such as dental permeability, root architecture, and osmotic adaptation, all of which contribute to rye’s ability to survive in a water-limited environment (Yang et al., 2024).

CONCULUSIONS

The results of the above-mentioned studies show that the water deficit, transpiration intensity, net productivity of photosynthesis, dry matter formation, and the amount of plastid pigments of various rye varieties grown in the soil and climatic conditions of the Samarkand region are higher in plants grown in moderate conditions compared to arid conditions.

Drought is one of the most common stress factors for a plant organism, altering many of its physiological processes. Including during our experiments, this factor led to a decrease in the physiological indicators of rye varieties.

In general, moisture plays an important role in the life of organisms. Determining the physiological characteristics that determine the resistance of plants to water deficit is the most important task, the solution of which has great theoretical and practical significance. Dehydration changes such important parameters as the viscosity and permeability of the protoplasm, the degree of hydration of its colloids, and the pH level of the system. This inevitably leads to fundamental changes in the state and function of the cell’s enzyme systems.

Acknowledgements

The authors express their deep gratitude to the Department of Plant Physiology and Microbiology of the Institute of Biochemistry of Samarkand State University named after Sharof Rashidov for providing all the necessary equipment for the research.

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