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Influence of protective structures on the development and productivity of tomatoes

Influencia de las estructuras protectoras en el desarrollo y productividad del tomate

Anna Pastukhova, Andrey Petrov*, Ksenia Makarova, Matvey Yakovlev, Olga Kolbina, Pavel Potapov

Novosibirsk State Agrarian University. Novosibirsk, Russia.
*Corresponding author E-mail: i.a.korotkiy@mail.ru

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ABSTRACT

The need to obtain consistently high yields of agricultural plants in the Siberian Federal District is sufficiently high. Therefore, this work aimed to study the influence of protective structures on the growth, development, and productivity of tomatoes in the Novosibirsk region. The data obtained allow concluding that the use of protective structures protects plants from recurrent frosts, gusts of northern winds, and a sharp drop in temperature. Plants grown in standard protective structures, in the first periods after planting at a permanent place of growth, were subjected to stressful situations, which led to a decrease in the immunity of the plant and, as a result, damage by fungi and bacteria.

Keywords: agriculture technique, cultivation technology, cellular polycarbonate, protective stationary shelter.

RESUMEN

La necesidad de obtener rendimientos consistentemente altos de plantas agrícolas en el Distrito Federal de Siberia es suficientemente alta. Por lo tanto, este trabajo tuvo como objetivo estudiar la influencia de las estructuras protectoras en el crecimiento, desarrollo y productividad de los tomates en la región de Novosibirsk. Los datos obtenidos permiten concluir que el uso de estructuras protectoras protege a las plantas de heladas recurrentes, rachas de viento del norte y fuerte descenso de la temperatura. Las plantas cultivadas en estructuras de protección estándar, en los primeros períodos después de la siembra en un lugar de crecimiento permanente, fueron sometidas a situaciones de estrés, lo que provocó una disminución de la inmunidad de la planta y, como resultado, daños por hongos y bacterias.

Palabras claves: técnica agrícola, tecnología de cultivo, policarbonato celular, refugio estacionario de protección.

1. INTRODUCTION

According to the research of the agribusiness expert and analytical center in 2019, the structures of tomato acreage in Russia by Federal Districts amounted to 17.78 thousand hectares, of which the area in the Siberian Federal District (SFD) occupied 0.4% (0.08 thousand hectares) (Fig. 1) (ABtsentr, 2020). In 2021, the acreage of tomatoes in farms of all categories amounted to 78.9 thousand hectares, and the acreage of tomatoes in households of the population equaled 62.8 thousand hectares, which amounted to 80.0% of the total volume (ABtsentr, 2022b).

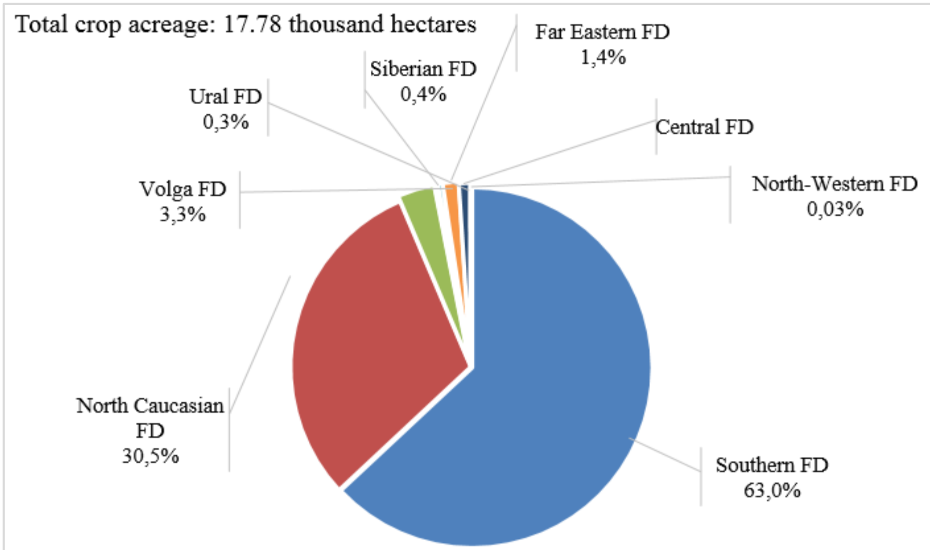

Figure 1. Structure of acreage of tomatoes of open ground in Russia by federal districts, in 2019, %.

The most favorable soil and climatic conditions in the SFD for tomato cultivation in the open ground are in the Altai Territory, where the harvest amounted to 0.1% of the total gross amount of tomatoes in Russia, which equaled 942.43 kg (ABtsentr, 2020).

In 2021, the volume of tomato imports was reduced by 4.4%, which amounted to 21.1 thousand tons compared to 2020 (ABtsentr, 2022a). These indicators were achieved thanks to the intensive construction of greenhouse plants in various regions. However, the indicators of tomato production in the SFD have not changed significantly (ABtsentr, 2022b).

Tomato cultivation in Western Siberia is accompanied by risks, such as partial or complete death of the plant from recurrent frosts or the loss of up to 40% of the expected harvest from a lack of positive temperatures during the growing season (Pastukhova & Ksenzova, 2019). Therefore, the preservation of tomato planting material planted in a permanent place is one of the main goals. The general assumption stating that a variety of protective structures (shelters) allow plants to be preserved by creating a stable internal background (temperature, humidity) for the growth and development of tomatoes, as well as allowing expanding the growing season, letting the plant form a larger number of fruits or increase the weight of the fruit, is not confirmed in practice in all aspects.

Modern protective structures and covering materials are presented on the market with a wide range of assortment, and sometimes the choice is determined by the advertising presentation of products, without going into the technical characteristics of the protective structure.

Due to the intensive increase in tomato acreage by small farms in the region (ABtsentr, 2022b), and the active demand for the purchase of protective structures, the staff of the Agrarian University decided to conduct a study to evaluate the development of the tomato plant in the most frequently purchased and used protective structure in farms.

Tomato fruits are one of the simplest and most accessible sources of vitamins, the importance of which is difficult to overestimate. [Due to] "The presence of sugars, proteins, nitrogenous substances, organic acids, fiber and minerals in them, a large number of vitamins: carotene (provitamin A), C, B, B2, P and many others. In terms of the content of vitamins C, P, and provitamin A, tomatoes almost do not differ from oranges and lemons" (Pastukhova & Ksenzova, 2020, p. 213). The presence of lycopene, which has the highest rate of interaction with singlet oxygen among antioxidants, makes it significant for human health that the entire product line obtained can meet the need for all lycopene up to 85% coming from food.

"Over the past 10 years, as a result of the painstaking work of Siberian breeders (agronomists), more than 100 varieties and hybrids of tomato have been created that are fully adapted to the harsh weather conditions of the Siberian region" (Pastukhova *et al*., 2021, p. 31). However, tomato farming is a rather laborious process. Varieties and hybrids with high plasticity and yield can give 40...50% of the potential yield during the growing season.

This is since tomato is a thermophilic culture. For example, maturation to "red fruits of early-ripening tomato varieties is possible in agro-climatic areas with a sum of positive temperatures >1,800°C" (Ivakin, 2016, p. 15).

Temperature is important not only for the formation of red fruits but also in general for the growth and development of the plant.

The best temperature for the growth and development of tomatoes is 22...28°C during the day and 17...20°C at night. According to the Pryanishnikov Institute, a decrease in daytime temperature to 20 degrees and night temperature to 14 degrees leads to an increase in the growing season from 75 to 115 days (Ludilov, 1978; Pastukhova *et al*., 2021).

At temperatures below 15°C, plants do not bloom, and at temperatures below 10°C, they stop growing. Frosts with an intensity of -0.5 ... -1° are dangerous for tomato seedlings while freezing to -2°C practically does not damage the leaves, but the yield is reduced by 25%. At -3°C, the leaves are largely damaged, and the yield is reduced by 60%. Freezing up to -4°C destroys the leaves of plants completely. A high temperature of 30 ... 35°C at low relative humidity leads to a massive fall of flowers or the appearance of cracks in the fruit (Ivakin, 2016; Usmanov & Khokhlov, 2020; Kotov *et al*., 2022).

"Water is one of the necessary elements for the vital activity of plants, as it is part of the plant itself, it participates in the movement of soluble nutrients and regulates temperature by evaporation. The flow of water into the plant depends on its content in the soil, the growth rate of the root system, and the intensity of root respiration. According to the requirements for the water regime, tomatoes occupy an intermediate position, since they have a sufficiently powerful root system capable of extracting water from lower soil layers. Early-ripening varieties need water more than late-ripening ones. Lack of water leads to the suspension of growth and loss of early production and also blossom-end rot. The alternation of dry and wet periods leads to the appearance of cracks on the fruits" (Ivakin, 2016, p. 23).

The optimal soil moisture for tomatoes is 70-75% of the total field moisture capacity, while the optimal air humidity is 45-55%. Excessive soil and air humidity negatively affect the growth and development of plants: they become frail, get fungal diseases, and flowers pollinate poorly and do not form ovaries. Good humidification conditions for tomatoes are characterized by the hydrothermal index (HTI) = 1.2, with HTI from 0.8 to 1 the humidity is considered satisfactory, and with HTI <0.8 it is considered poor (Ludilov, 1978; Ivakin, 2016).

One of the conditions for increasing yields is the use of shelters with the use of regular irrigation or the establishment of a drip irrigation system for plants to create favorable conditions in the open ground.

The scientific hypothesis consists of the assumption that the temperature background inside the protective structure is distributed unevenly, which leads to overheating in the upper levels of the protective structure, where the death of the main number of inflorescences of the third and fourth truss of the determinant plant occurs.

The work aimed to study the influence of protective structures on the growth, development, and productivity of tomatoes in the Novosibirsk region.

The main objectives for achieving the purpose of the study were the following:

- collection and processing of information from metering devices;
- conducting phenological and morphological observations.
- accounting of tomato yield when growing tomatoes in the open ground, greenhouse, and in the "screen".

The obtained data will allow optimizing the costs of obtaining tomato products in a longer period of the spring-summer-autumn period by identifying additional structural elements.

2. MATERIALS AND METHODS

The studies were carried out from 2019 to 2021 in protected structures and open ground, with the structures most commonly used in private plots and farms (greenhouses) and experimental facilities (screens).

The study was carried out on the territory of the experimental field of the Siberian Institute of Mechanization and Electrification of the Siberian Federal Scientific Center for Agrobiotechnologies, Russian Academy of Sciences (SibIME SFNTsA RAN) laboratory, where the greenhouse complex and the experimental field (village Krasnoobsk) and the Sad Michurintsev Educational and Production Farm of the Novosibirsk State Agrarian University were located.

Objects of the study:

- A frame greenhouse with a coating of cellular polycarbonate, with two end doors and four vents with a hydraulic thermal drive installed (Figs. 2, 3);

Figure 2. Greenhouse with a coating of cellular polycarbonate

Figure 3. Protective screen made of cellular polycarbonate

- A complex protective shelter of the SibIME design: a "protective screen" with two end technological structural elements for the passage and care of plants, with the sides covered with sheets of cellular polycarbonate (Fig. 4);

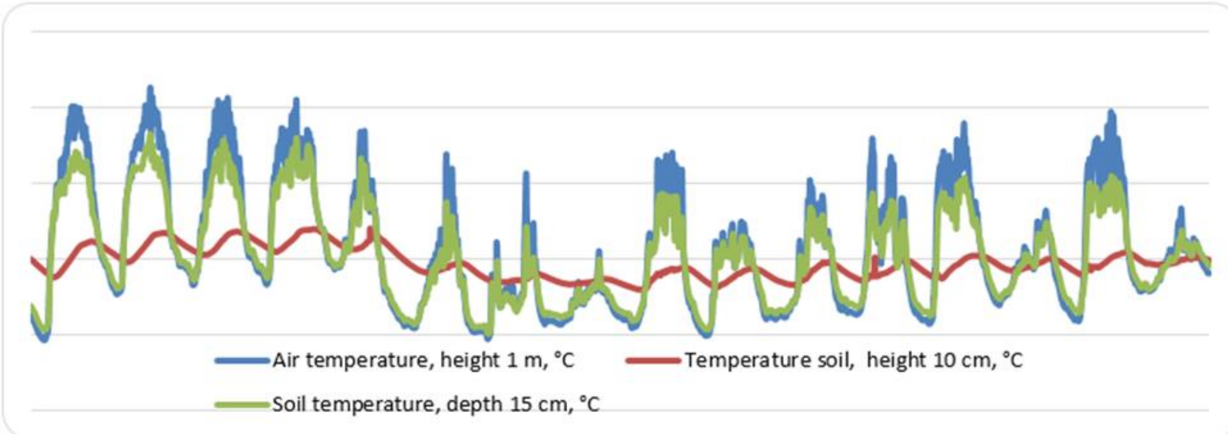

Figure 4. Temperature distribution in the greenhouse

- tomato plants are determinant, semi-determinant, and indeterminate by habit type.

Protective structures were located on the territory of the experimental site across the prevailing winds.

Considered indicators: soil temperature, relative humidity of the soil, air temperature, and relative air humidity. For these purposes, the following equipment was installed: aspiration sensor of air temperature and humidity, pharometer: RTN-2z; sensor of moisture content, electrical conductivity, and soil temperature: SMTE-3z; phytomonitor: PM-11z; meter-recorder: Relsib EClerk-M-RHT. Data processing was carried out using the EClerk-2.0 software and during the data transfer, they were processed by phyto-monitoring to an FTP server using a built-in GPRS modem. All the data obtained were converted into Excel tables and processed using the statistical programming language "R".

Following the tasks set, the following experiments were carried out:

- Plants of semi-determinant tomato variety (Bychie Serdtse) were planted in protective screens;

- Tomato plants of determinant varieties (Zyryanka, Avantyurist); and indeterminate varieties (Spock) were planted in greenhouses with polycarbonate coating;

- For the control variant, tomato plants of a determinant type were planted in the open ground (Zyryanka, Avantyurist, Buyan), as well as semi-determinant variety (Bychie Serdtse).

Methods of the study:

informational, analytical, theoretical methods, and field experiments. The studied processes of growing vegetable crops (the example of tomatoes) under the conditions of the negative impact of open ground are methodologically considered an integral biotechnological system.

When observing plants, we used the "Methods of conducting field experiments developed by an academician of the Russian Academy for Agricultural Studies (RASKhN), Doctor of Agricultural Sciences, Professor S.S. Litvinov (Usmanov & Khokhlov, 2020; Kotov *et al*., 2022).

The study takes into account: phenological observations (marking the beginning of the phase of plant growth and development (10%) and the full phase (75%)) and morphological observations, yield, ripening rate, the number of fruits in the truss, fruit quality, resistance to diseases and pests, etc. (Kotov *et al*., 2022).

Yield accounting was carried out as the full ripeness of the fruits occurred. At the last harvest, a general fruit collection was carried out, which took into account: the total number of fruits, including ripe, brown, at the milk ripeness stage, standard and non-standard according to State Standard (GOST) 34298-2017 "Fresh tomatoes", where the basic requirements for tomato fruits are imposed. Thus, in Article 5 "Technical specifications", paragraph 5.2 indicates the main quality indicators of fresh tomato products: "Appearance: the fruits shall be fresh, whole, healthy, clean, dense, of a typical botanical variety shape, with or without a peduncle, undamaged by agricultural pests, without excessive external humidity, without cracks. Fruit condition: dense, able to withstand transportation, loading, unloading, and delivery to the destination. Smell and taste: characteristic of this botanical variety, without foreign smell and (or) taste", etc. (Federal Agency for Technical Regulation and Metrology, 2017). The yield was recalculated by m^2.

The data obtained from the metering devices were statistically processed and analyzed.

3. RESULTS

The planting material was planted in protective structures (screens) on May 25 at the age of 60 days (semi-determinant varieties) and 45 days (determinant varieties). Previously, the soil had been treated with organic (humus, 2 kg per well) and mineral (nitrogen-phosphorus-potassium fertilizer, 20 g per well) fertilizers. Planting was carried out in the greenhouse on May 26, in the screens on May 25, and for the control variant in the open ground on May 31.

Planting was carried out manually, based on the calculation of the feeding area: 40×40 cm (indeterminate and semi-determinant), 30 ×30 cm (determinant varieties).

The plant care in the summer consisted of watering, fertilizing, row-to-row treatment, loosening as the soil crust was formed, and weeding. Similarly, plants of indeterminate varieties were subjected to the formation of one stem with further periodic side-shoot removal. The semi-determinant varieties were formed in two stems.

The beginning of flowering was observed 15-20 days after planting, and mass flowering was observed after 25-30 days (mid to late June). The temperature background during this period in the greenhouse was the following (Fig. 4).

As can be seen in Fig. (4), the temperature decreases from top to bottom, with a difference of 6 ... 7°C. The maximum values reach 40°C at a height of 1 m, therefore, during these periods the plant growth is inhibited, development is suspended, and twisting of leaves is observed to save moisture. More comfortable conditions are formed at a height of 60-80 cm. In this interval, tomatoes of determinant varieties feel good.

When considering the temperature background in the screen (Fig. 5), there is no significant overheating, in general, this is due to design features (full ventilation), but it is also a disadvantage; it is visible in direct dependence of the internal temperature background in the screen on the outside atmospheric background.

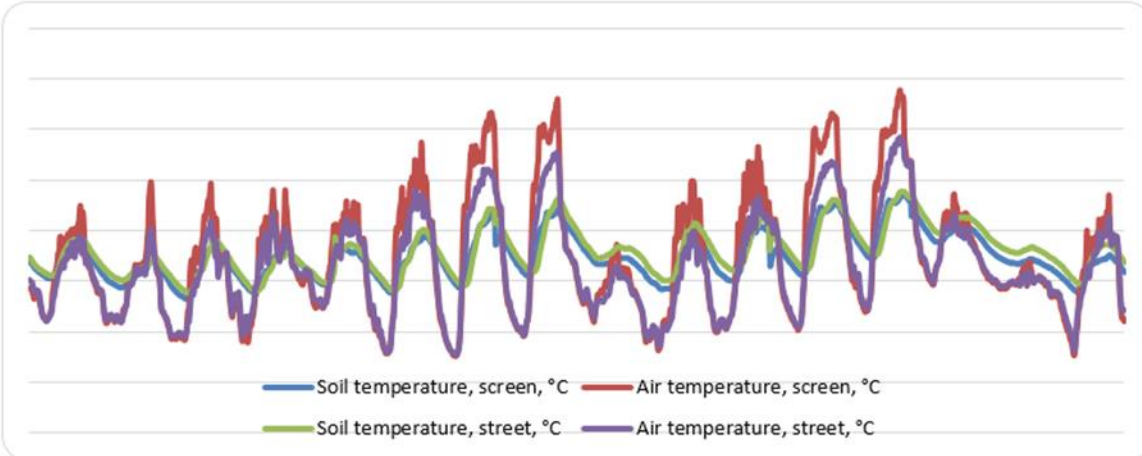

Figure 5. The temperature within the screen and in the open ground

Soil moisture, like air humidity, is a very important indicator for the full development of the plant (Fig. 6).

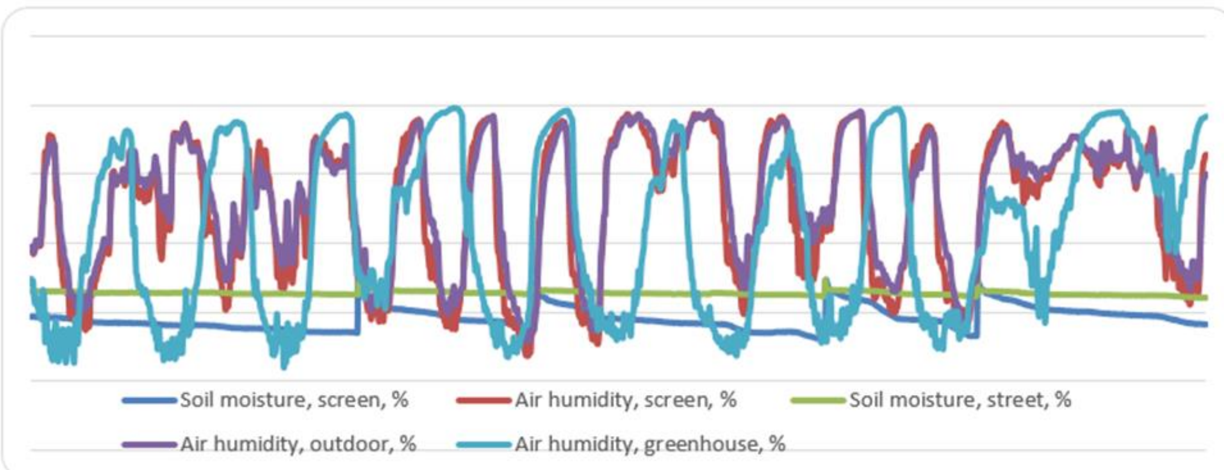

Figure 6. Data on the humidity in protective structures and open ground in the second quarter of June

When considering the data collected, Fig. (6) shows the periods of irrigation and precipitation in the form of rain, represented on the graphs in the form of peaks reaching 100%. Soil moisture in the screen and the greenhouse is close to the optimal requirements for the normal growth and development of plants in 40-45%. Therefore, favorable water-gas conditions are created for the roots of the plant. In general, the humidity of the air is not stable, periodically the optimal values are exceeded by 1 to 10% (non-critical exceeding).

Until July 20, the average daily temperature indicators were 17 ... 24°C, which allowed the plants to form the optimal number of ovaries, but at the time of intensive filling of fruits of indeterminate varieties in the greenhouse at a plant height of 1 m where the temperature reached 35°C and above, and air humidity indicators were from 29...32%, there was a fall of inflorescences, and the fruits that had started forming earlier were much smaller in mass (Figs. 7-9).

Figure 7. Fruits Figure 8. Fruits

Figure 9. Tomato fruits (greenhouse tomatoes, Bychie Serdtse variety). Buyan variety: screen — screen

As a result of the next phenological observation, the period of mass maturation was determined (August 20) During this period, the first fruit harvest would be carried out in protective structures at a height of up to 1 m (Figs. 10, 11).

Figure 10. Screen. Bychie Serdtse variety Figure 11. Greenhouse. Zyryanka variety

Thus, 71 fruits were collected in the greenhouse from the plot of the Zyryanka variety with a total weight of 8.430 kg and with an average fruit weight of 118.7 g. In the open ground, 15 fruits with a mass of 1.957 kg were collected from the Zyryanka variety, where the average fruit weight was 130 g. In the screen, the Buyan variety yielded 24 pcs. with a total weight of 9.450 kg, where the average weight per fruit was 393 g, and 35 fruits with a total weight of 7.100 kg were obtained in the open ground, where the average weight of the fruit was 203 g. The Bychie Serdtse variety collected in the screen gave 52 fruits with a total weight of 15.410 kg, the average weight of the fruit was 296 g, and 21 fruits with a total weight of 7.230 kg were collected at the control variant, where the average weight of the fruit was 344 g. When collecting the Avantyurist variety, 81 fruits with a total weight of 7.500 kg were collected in the greenhouse, the average weight of the fruit was 93 g, and the control variant collected in the open ground gave 11 fruits with a total weight of 1.026 kg where the average weight of the fruit was 93.3 g.

During harvesting, it was noted that at a height of up to 1 m in the greenhouse and screen, a tomato plant with a determinant and semi-determinant plant type formed the largest number of fruits, with similar fruit weight indicators according to the characteristics of the variety. Indeterminate tomato varieties with the attachment of a truss after the fifth leaf could form a full-fledged truss, but on subsequent trusses, at a height of 1 m, we noted thinness of the flower and ovaries on the truss (Fig. 12).

Figure 12. Greenhouse tomato variety Spock, truss attachment height: 1 m 22 cm

Fig. (12) shows a highly productive indeterminate tomato variety Spock, with the yield declared by the originator equaling 9.7 kg/m2 (Fotev et al., 2021), under favorable conditions. In this experiment, the plant was subjected to stressful situations and as a result, 114 fruits with a total weight of 1.762 kg were obtained from 1 m2.

With further observations and fruit harvesting in protective structures, damage to the leaf surfaces of plants by fungal diseases was noted.

For example, since the beginning of September, there had been a decrease in temperature at night to 5-10°C, on September 10 and 13 at night, the temperature reached +0°C (Fig. 13). Therefore, it is not advisable to further extend the growing season of tomato plants within the screen and in the open ground, since at such temperatures, the plant stops the activity of the root and vegetative parts, the immune system does not work, and the plant is intensively damaged by bacteria and fungi.

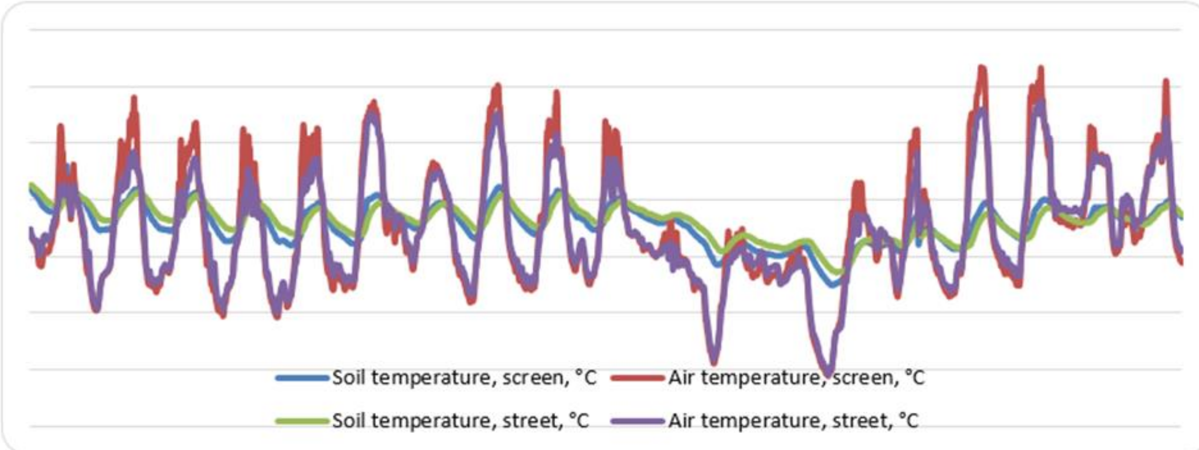

Figure 13. The temperature within the screen and in the open ground, September

When considering the obtained temperature data in the greenhouse (Fig. 14), a stable temperature background in the greenhouse is visible. Plants continued to vegetate and form single fruits, but we observed a stretching of shoots, the sparseness of inflorescences, and a decrease in photosynthetic activity, i. e. the consequences of a reduction in the daily light period.

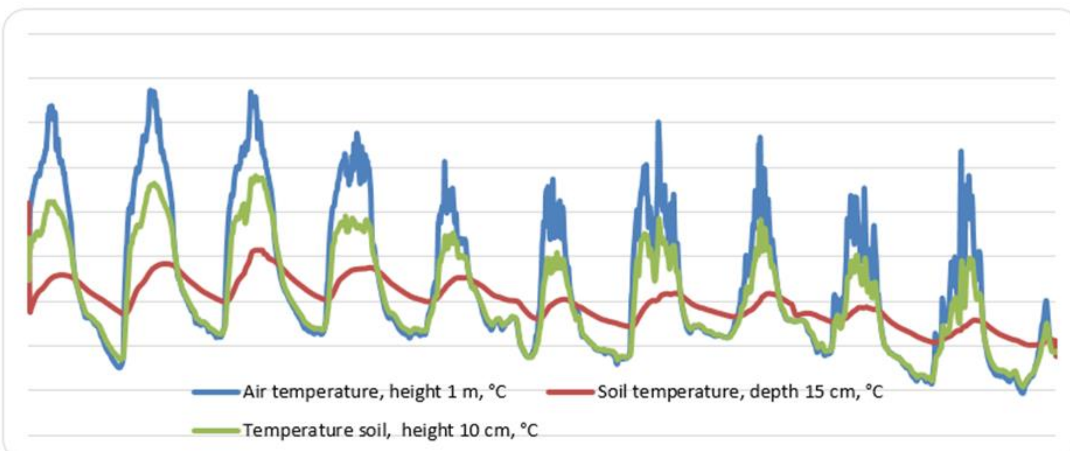

Figure 14. Temperature distribution in the greenhouse, September

The last harvest in the screens was made on September 15, on the control variant in the open ground on September 7, and in the greenhouse on September 17.

Thus, the growing season was 114 days in the greenhouse, 113 days in the screen, and 100 days in the open ground. Therefore, the use of protective structures allowed for extending the growing season by 13-14 days. In the greenhouse, the growing season can be further extended, which depends on the density and thickness (micron) of the installed covering material and the period of the onset of subzero temperatures.

As a result of the study, it was also found that at different heights of the shelter structure, there were significant differences in the temperature background of the airspace and the soil, for example, the air temperature on May 29 in a greenhouse coated with cellular polycarbonate (hereinafter referred to as the greenhouse) the daytime maximum temperature was: 34.06°C at a height of 1 m, while the air temperature at a height of 10 cm was 29.82°C, the soil temperature at a depth of 15 cm was 19.08°C with an air humidity of 55.78% (the air temperature in the open space (outside) was 16.0°C, on sunny days with variable clouds, with a humidity of 35%); at night, the minimum temperature was 7.37°C at an altitude of 1 m, while the air temperature at a height of 10 cm was 8.17°C, soil temperature at a depth of 15 cm was 17.28°C with an air humidity of 95.2% (air temperature in open space (outside) was 8.0°C, in cloudy weather, with a humidity of 70%). A similar situation developed at night in the protective screen.

4. DISCUSSION

The influence of the indoor climate in the greenhouse on the productivity of tomatoes has been considered in detail in many works. Thus, when Fidel Maureira *et al*. (2022) evaluated the production of tomatoes in the open ground and high-tech greenhouse systems in the Netherlands, they noted optimal conditions with a decrease in the consumption of attracted resources to obtain products. In their work, Zhihao He *et al*. (2022) note the importance of temperature and humidity stability even during the tomato seedling period and create a model of environmental regulation. The spatial distribution of greenhouse temperature is also mentioned in some research. Thus, Ke Xu *et al*. (2022) mentions overheating in the upper part of the greenhouse and its negative impact on plant development in the results of their study. The importance of the use of protective structures has also been noted in numerous works. Thus, M.S. Subina *et al*. (2020) are studying various materials for covering greenhouses, proving the economic benefits of using such structures. It is worth noting that many works focus on identifying the dependence of growing conditions on the chemical composition both in the fruits of the Solanaceae family (tomato, eggplant, pepper) (Kumari *et al*., 2022) and such crops as strawberries (Khammayom *et al*., 2022).

5. CONCLUSION

As a result of the conducted study of protective structures, the scientific hypothesis put before the researchers has been proved.

After the study, it was found that plants grown in protective structures at a height of 1 m from the ground surface were subject to overheating and their inflorescences fell off, which resulted in a significant loss of yield.

Therefore, we determined and recommended the optimal parameters for the tomato plants (of determinant and semi-determinant varieties), and this showed excellent results in productivity when the plants were grown in protective structures.

Based on the results obtained, methodological recommendations will be prepared for gardeners and managers of small farms, on the selection of varieties and technologies for cultivating tomatoes in protective structures, considering modern design capabilities.

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