A new greenhouse: an attempt to reduce the cost of growing plants

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Abstract. Growing plants in extremely cold environmental conditions is a difficult and expensive process. The required microclimate is usually created for plants artificially on the protected ground. For this purpose, we have developed an industrial prototype of a mini greenhouse, which allows to grow single plants. Laboratory tests have confirmed that the mini greenhouse provides optimal internal environment conditions due to the design features. This leads to a significant reduction in the cost of plants growing.

1 Introduction

Growing plants in extremely low temperatures is a time consuming and expensive process. The necessary conditions of the microclimate are provided for plants artificially on the protected ground. Up to 40% of all financial costs are usually spent on maintaining the required temperatures in the greenhouse. This factor leads to higher cost of the grown crop. However, the use of natural processes of lighting, ventilation and heating of the inside of the greenhouse can significantly reduce the costs of growing plants.

As for greenhouse complexes of large sizes, they are generally produced at a production site using conventional technologies and factory facilities. However, majority of mini greenhouses are mostly handmade nowadays. Thus, the problem of mini greenhouses production on industrial scale is of considerable interest. And the development of a mini greenhouse prototype, using the natural recourses for internal environment sustain, is an important task.

2 Problem formulation

While growing plants, it is necessary to control the three factors: lighting, ventilation and temperature [1-3]. Lighting and ventilation can be artificial (forced) or natural [4]. A mini greenhouse can use only natural processes. Lighting is provided by insolation. Ventilation is supported by holes in the walls of the mini greenhouse. The most difficult task is to keep a stable temperature. For plants resistant to low temperatures, daytime temperatures should be +13...+ 18°C, while night temperatures should vary from +6 to + 10°C. For thermophilic plants, the temperature should not fall below + 18 °C [5]. Temperature can be

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controlled using various heating systems and technical solutions. A heat accumulator, built into the wall of the mini greenhouse, heats the inside of the mini greenhouse [6-11].

Thus, the mini greenhouse provides all the factors necessary for start under cover: light, ventilation, the required level of temperature.

Next, we are describing the stages of the mini greenhouse development. First, we determine the height of the mini greenhouse taking into account the previous experience of using mini greenhouses. The height of the mini greenhouse is supposed to be 15 cm, as it allows a single seedling to reach 10 cm in height. Then, the mini greenhouse is removed and the plant grows independently. As a result, the death rate of young plants is considerably reduced.

The next step, we choose the shape of the mini greenhouse. We have developed several regular pyramidal mini greenhouses with triangular and square bases. The length of each side of the base is 15 cm. In addition, for fixing the greenhouses to the ground, there was designed a wide edge on the base. It has two holes for the insertion of special locks into the soil.

Third, special attention is paid to the design of the walls of the mini greenhouse. One of the walls is chosen as a heat accumulator, all the rest are made of transparent material. The wall-heat accumulator is a five-layer structure. The outer and inner layers are made of the material of black color. As a result, the material quickly heats up and transfers heat to the intermediate layer. The intermediate layer is a plate made of a high heat capacity material, for example, aluminum or copper, and between the materials there is an insulating layer that prevents damage to the outer and inner layers as a result of high heating of the intermediate layer. So, the heat is accumulated and the mini greenhouse inside is heated without a light source.

Besides, we pay particular attention to the requirement for easy assembly, transportation and installation of the mini greenhouse. For this purpose, PVC is used as the main material. This material has sufficient wear resistance, high light transmittance of transparent walls (0.87), thermal connection ability, and low cost. In addition, a PVC mini greenhouse can be easily folded [12-13]. On the other hand, the impact of wind load on the mini greenhouse should not reduce its stability [14-15]. So, the stiffeners are added.

Further on, we describe the process of the mini greenhouse designing and manufacturing.

The minimum dimensions of the greenhouse determined the peculiarities of its design and manufacturing process. First, we chose three prototypes to produce a regular pyramidal mini greenhouse. One of them was the mini greenhouse with a triangular base and the side length of 10 cm with an aluminum plate.

The second one was a mini greenhouse with a triangular base and the side length of 15 cm with a copper plate. The third one was a mini greenhouse made with a square base, the side length of the edges of 15 cm with a copper plate.

Next, we produced prototypes of a mini greenhouse from paper. The prototypes were used to try out the details of the connection of the parts and the method of installing the mini greenhouse onto the ground. As a result, a set of patterns was developed to manufacture individual parts for various mini greenhouse prototypes. Transparent parts were made of light-transmitting material. Several patterns were used to make the wall-heat accumulator. Several patterns were used to produce the wall-heat accumulator. All patterns were made taking into account the over-measure for seams.

We started manufacturing with fixing grommets and making air holes with the diameter of 3 mm. Next, the cut out parts were connected one by one using a sealing machine. The hermiticity of the seams is the main condition for the mini greenhouse effectiveness. Many experiments were carried out with the materials used. Structural changes were made in the sealing machine to ensure the hermiticity of the seams. As a result, we came to the

conclusion, that the parts should be manufactured with increased space for seams allowances. In addition, a special technology of joining parts was developed. Thus, in the places of the allowances, stiffening ribs were formed.

Figure 1 shows bench laboratory testing. The bench consists of a computer, an instrument for measuring the density of heat flux, four temperature sensors, two humidity sensors, and a thermohygrometer. The results of the experiment were automatically processed on the computer using a special program.

Fig. 1. Laboratory unit for mini greenhouse microclimate research.

A 500W halogen lamp was fixed above the mini greenhouse. The temperature sensors were located on the ground surface and three of them were covered with the mini greenhouses. The fourth temperature sensor made it possible to record the surrounding medium indicators. The heat flow sensor and the thermohygrometer were placed in the center of the laboratory bench above the light source. The wall-heat accumulator was pointed to the light source. This contributed to the maximum rapid heating of the inside medium of the mini greenhouse.

The experiment was carried out under the following initial conditions: the ambient temperature was 19 °C, the soil temperature was 21 °C, the air humidity was 41%. Twenty minutes later, the following environmental parameters were established: the ambient temperature was 24 °C, the soil temperature was 25 °C, the air humidity was 27%. The average heat flux from the light source was 66.72 W / m². With minor deviations, these environmental parameters were maintained for fifteen hours, during which the experiment was conducted.

The experiment was aimed at studying the state of the internal climate of the greenhouse after turning on the light source from the moment of heating to the moment of complete cooling. The data from all the sensors were collected every minute. They were automatically downloaded into the computer program. The distribution of temperature fields in accordance with the prototype of the mini greenhouse allowed to make the following conclusions.

First, the developed design of the mini green house provides fast heating of the interior of the structure due to the design features and high lightweight transmittance of the transparent walls of the structure. The graphs in Figure 2 show the findings.

Fig. 2. Graphs of temperature fields of the internal environment of different prototypes of the mini greenhouse during the heating period.

Figure 3 shows that the design provides constant temperature parameters and compensates for abrupt changes in heat flow, which are necessary for the cultivation of plants, provided there is a constant source of illumination.

Fig. 3. Graphs of temperature fields of the internal environment of different prototypes of the mini greenhouse during the period of temperature normalization.

The inside medium is cooled down within an hour after turning off the light source, as can be seen in Figure 4. At the same time, air vents help avoid condensation.

Fig. 4. Graphs of temperature fields of the internal environment of different prototypes of the mini greenhouse after turning off the light source.

The second conclusion refers to the base form. The square shape provides greater coverage of the heated area than the triangular shape. Consequently, more favorable conditions are created for the germination of plants. In addition, the selected height of the greenhouse is optimal for forming the angle of inclination of the wall-battery. This arrangement allows to accumulate more heat.

The temperature of the internal environment of a regular square greenhouse increased by 10°C during the experiment compared to the air temperature. The graphs in Figure 5 show the findings.

Fig. 5. Graphs of temperature fields of the internal environment of different prototypes of the mini greenhouse.

According to the results of a full-scale experiment, the prototype meets the following requirements: a proper pyramidal mini greenhouse has a square base; the height of the mini greenhouse is 15 cm; a copper plate works as the heat accumulator; the vents are 1 mm. The developed technology of joining parts of the walls ensures the hermeticity of the mini greenhouse design as a whole.

In conclusion, we carry out a calculation of the designed mini greenhouse cost in the Russian Federation. The materials for the production of each mini greenhouse prototype cost about 30 rubles (0.4 Euro). In case of mass production, the materials will be purchased in large quantities, the production process will receive additional automation. In addition, an innovative enterprise can count on tax breaks.

All this will reduce the cost of one mini greenhouse to 22 rubles (0.4 Euro).

3 Analytical solution

Thus, we have developed an industrial prototype of the mini greenhouse, which allows to maintain the microclimate parameters from natural sources. Also, this design is a protection against wind for young plants. Relatively simple production technology allows you to create individual technical solutions depending on the climate of use, by changing the design of the heat accumulator and plant variety, by changing the size of the product. In addition, the prototype has a low cost and is easy in use.

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