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Trends and prospects of soil heating under conditions of protected ground

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Trends and prospects of soil heating under conditions of protected ground

I P Voiku

Pskov State University, Lenin Square 2, Pskov, 180000, Russia

E-mail: voiku-ivan@yandex.ru

Abstract. Such vital processes in vegetable plants, like absorption of carbon dioxide (photosynthesis), water intake, absorption of nutrients from the soil, respiration, evaporation of water (transpiration), nutrients transfer from roots to leaves and fruits, as well as macronutrients transfer from leaves to roots, depend on the temperature regime. The research of technical and economic parameters of popular de-vices for heating of greenhouses allowed to define quite a number of operational disadvantages. A device for air heating of the soil in protected ground conditions, designed to increase yield and reduce the energy intensity of vegetable growing in the protected ground, is developed by the fellow workers of the FSBEI of Higher Education Pskov State University. The device consists of assembled segments, combined in a system, and a special fan heater with a low temperature range. The proposed device allows to ensure an intensive development of the root system of vegetable crops; to hasten the planting time of seeds or seedlings, and, consequently, to increase a fruiting period; to prevent death of plants associated with frost and diseases, caused by temperature changes; and to reduce the cost of heating of the protected ground.

1. Introduction

Vegetable growing in the protected ground is the most important branch of agriculture, competitive advantages of which are determined by a combination of indicators such as the amount of the gross yield, crop yields, and cost effectiveness of agricultural technologies [1]. Unlike vegetable growing in the open ground, largely influenced by climatic factors, activities of greenhouse businesses are largely autonomous, and, therefore, innovation-sensitive [2].

One of the ways to ensure competitive advantages in vegetable growing in the protected ground is the introduction of innovative technical and technological solutions, including cost-effective heating technologies [3].

2. Methods

Such vital processes in vegetable plants, like absorption of carbon dioxide (photosynthesis), water intake, absorption of nutrients from the soil, respiration, evaporation of water (transpiration), nutrients transfer from roots to leaves and fruits, as well as macronutrients transfer from leaves to roots, depend on the temperature regime [4].

Table 1. Optimum and critical temperatures for protected-ground vegetables [5].

Vegetable	Optimum temperature	Critical temperature
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crops	For swelling of seeds	For seed germination n	For fruit formatio n	For seedlings	For adult plants
Eggplant	+14-16	+25-30	+25-30	+5-6	-1
Cucumber	+14-16	+25-30	+22-28	+6-8	+2-3
Pepper	+14-16	+25-30	+25-30	+5-6	-1
Tomato	+10-12	+25-30	+20-27	+3-5	-1

Table 2. Optimal soil temperature for protected-ground vegetables.

Vegetable crops	Soil temperature	
	Before fruiting	During fruiting period
Cucumber (winter-spring cycle)	+20-24	+20-24
Cucumber (autumn cycle)	+22-24	+20-22
Tomato (winter-spring cycle)	+18-20	+18-20
Tomato (autumn cycle)	+18-19	+17-18

Electric air heaters, infrared heaters, electric heating devices for soil from different manufacturers are widely represented in the markets of heating equipment [6]. Most of the presented models are designed to maintain the temperature regime in the enclosed space of the greenhouse, involve significant cash and time costs for installation, significant operating costs.

In the course of patent information retrieval, the following Russian developments, which provide a heating of the protected ground, are revealed:

1. Portable heating device for protected ground (Osinskij G I (RU), Osinskij N G (RU), Osinskaya G G (RU), Osinskaya T I (RU)) [7]. A heating element in the form of a pipe filled with conducting liquid (water), a compensator for the accumulation of the excess of the conductive liquid formed during heating, and a heat exchanger are in the body of the device. The device operates in the mode of heating the soil and air while passing the electric current of safe voltage through the conductive liquid. When the power is turned off, the device can operate in the pump mode, pumping the excess heat from the air into the ground during the day, preventing an overheating and plant damage under the plastic cover. In case of an unexpected power outage the device can also work in the mode of heat recuperation from ground to air during night frosts preventing plant damage.

2. Soil heating device (Lipovka YU L (RU), Kudryavcev N A (RU)) [8]. The device contains a solar collector, a ground heat exchanger connected to the collector by pipes, and a heat carrier circulation system. The principle of operation of the soil heating device is based on the distribution of air flow in two modes: recirculation and direct-flow. When operating in recirculation mode, the air in the system is heated by solar energy and enters the ground heat exchanger through the air duct to transfer the heat into the ground. When operating in direct-flow mode the external air supply to both sections of the solar collector and the heated air supply to the greenhouse through the exhaust air ducts are provided. Fans can be installed in the air ducts for more efficient air removal.

The research of the parameters of above-mentioned and similar devices for heating of greenhouses allowed to define quite a number of operational disadvantages.

3. Results and discussion

A device for air heating of the soil in protected ground conditions is developed by the fellow workers of the FSBEI of Higher Education Pskov State University (figures 1 and 2).

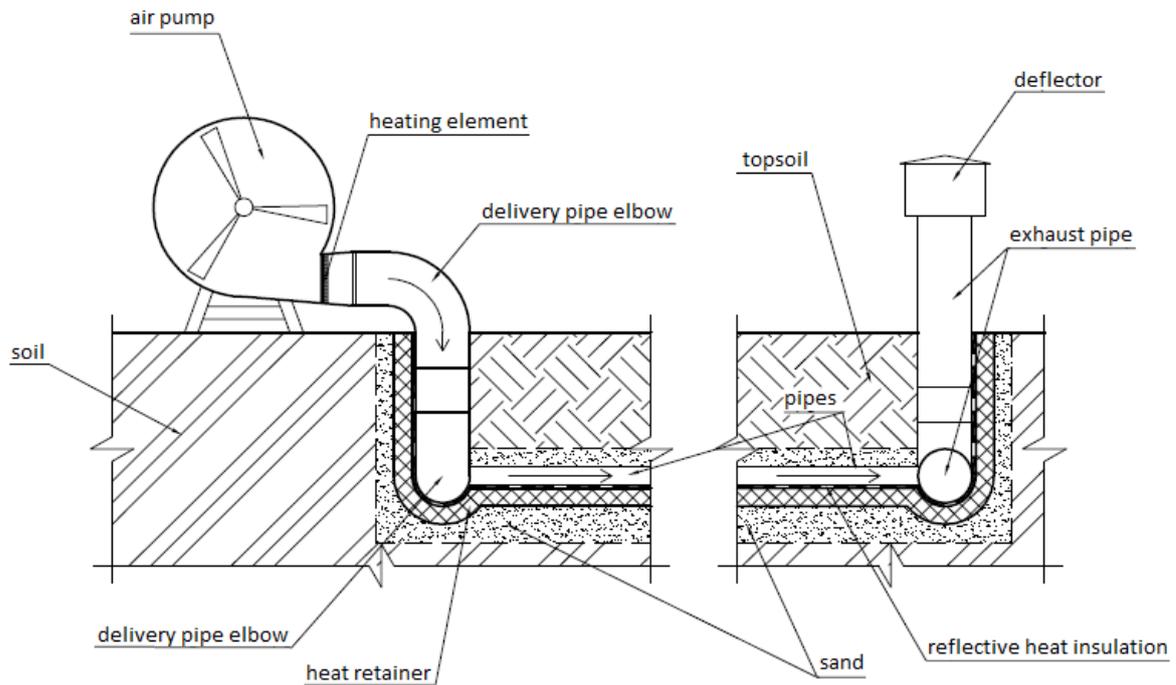


Figure 1. Device for air heating of the soil in protected ground conditions.

The device consists of corrugated pipes with holes, combined in a system, and a special fan heater with a low temperature range and fan speed controller.

The length and number of corrugated pipes and couplings, combining these pipes in the system, is determined by the acreage of the protected ground. Specially designed fan heater, consisting of an air pump and a heating element, is designed to operate in an aggressive environment (high humidity) and has a low temperature range of operation.

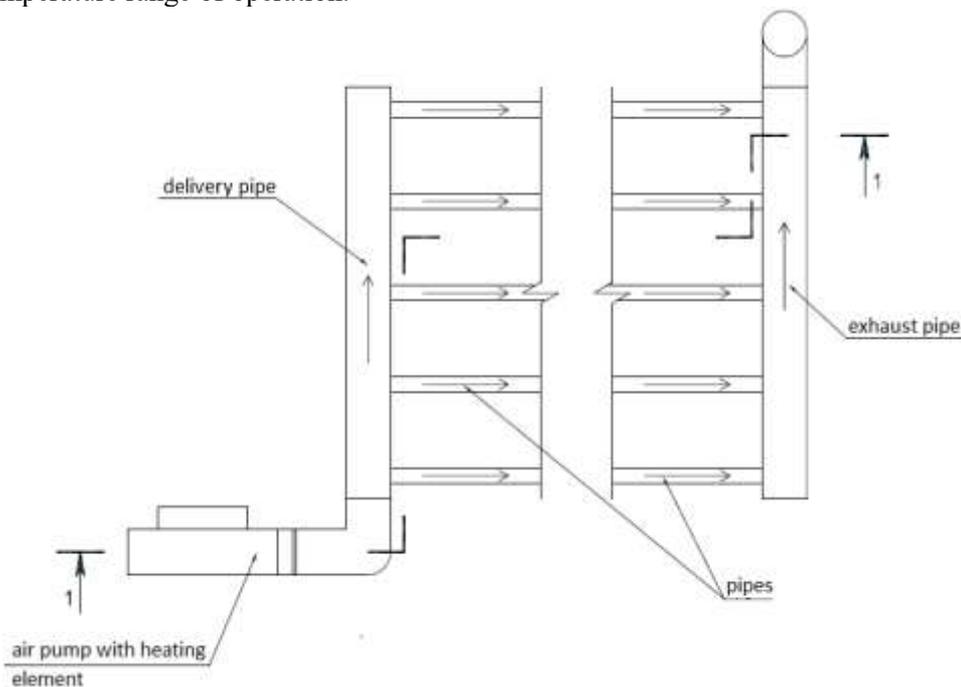


Figure 2. Device for air heating of the soil in protected ground conditions (top view).

In the assembled condition the air pipes of the device are placed to a depth from 20 to 30 cm from the ground level, depending on the cultivated vegetable crop and the characteristics of its root system. Vegetable crops can be classified into: a group with a deep root system (more than 1 m) and a group with a shallow root system (up to 50-80 cm) (Table 3). A special fan heater supplies the device with warm air. Low temperature ranges and high rotation speeds of the air pump blades ensure its long-term operation without overheating. When moving through the pipes warm air penetrates through the holes of the delivery, exhaust and connecting pipes into the ground, heating the soil and the roots of vegetable crops to the desired temperature.

Table 3. Rooting depth of vegetable crops.

Vegetable crops	Deep root system (more than 1 m)	Shallow root system (up to 50-80 cm)
Eggplant	+	-
Pepper	+	-
Tomato	+	-
Cucumber	-	+

The specially designed fan heater can be removed. In that case, the proposed device can be used for an underground irrigation of vegetable crops, liable to the diseases caused by a surface irrigation [9].

In accordance with Technical Conditions 2248-027-41989945-04 of the Russian Federation, the inner layer of corrugated plastic pipes and couplings will be 1.1-1.8 mm thick round - cylindrical shell made of high density (low-pressure) polyethylene. The outer layer, securely fastened to the inner layer, will be the hollow corrugations made of high density (low-pressure) polyethylene, the wall thickness, height and spacing of which also depend on the diameter of the pipe. The operating temperature of corrugated plastic pipes and couplings is from -40°C to +90°C.

The thinness of plastic pipes predetermines their relatively small heat retention in the transfer of heat from the heat carrier to the air or soil.

The manufacture of the body of the fan from a material with electrical insulation and thermal insulation properties is necessary due to the following reasons. First, it is necessary to ensure electrical safety of work with the heating device. Second, the minimum thermal emission through the heat-insulating walls of the body provides a steady "draft" of the heated air to the upper nozzles, i.e. a steady circulation of the heat carrier is achieved even at a low temperature of its heating, which is important for the preservation of plants.

In addition, the thermal insulation property of the body helps to obtain an additional technical result when the device is in passive mode, i.e. when the power is turned off. In this state, the device effectively recuperates the heat accumulated in the soil to the air during night frosts or accumulates and pumps into the soil the excess heat from the air that generates during the day from the increased stream of sun in the glasshouse or plastic cover, even in the cold period [10].

4. Conclusions

One of the ways to ensure competitive advantages in vegetable growing in the protected ground is the use of cost-effective technologies of heating of greenhouses.

The device for air heating of the soil in protected ground conditions, developed by the fellow workers of the FSBEI of Higher Education Pskov State University, allows:

- to ensure an intensive development of the root system of vegetable crops;
- to hasten the planting time of seeds or seedlings, and, consequently, to increase a fruiting period;
- to prevent death of plants associated with frost and diseases, caused by temperature changes;
- to reduce the cost of heating of the protected ground;

- to provide an underground irrigation of vegetable crops, liable to a wide range of diseases caused by a surface irrigation.

The experimental model of the device was successfully tested in the Pskov region and allowed to justify the assumptions and power capacity of the fan heater of the developed device [11]. Further experimental studies will allow to perform a refined thermophysical calculation for plastic and glass greenhouses [12]. This calculation will help to establish an analytical connection between the required parameters of microclimate and the heat and substance flows (necessary for these required parameters), formed by the developed device.

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