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# A Technological System for Using Waste Warm Water from Energy Facilities for Effective Agriculture

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**Abstract.** The waste warm waters from power plants, owing to their temperature regime (25–38°C) and the volumes of discharge, allow for their use for heating of open ground areas in agriculture. Underground heating by such water is a new, special heat and irrigation method which enables not only purposeful regulation of temperature conditions of the crop growing environment, but also dissipates heat in the soil, thus cooling the water for its reuse. This makes it possible to reduce the thermal pollution of water sources.

**Key words:** waste water heat, soil temperature, soil heating, water regime, recycling, cooling

## 1. Introduction

Thermal land reclamation, aimed at utilizing the wastewater heat from energy facilities and at improving the temperature conditions of the plant growing environment, is an important and little used reserve so far in improving farmland productivity and obtaining high and stable crops in the open ground areas.

The purpose of this work is the reduction of heat pollution of natural water objects by utilization of low-potential warm waste waters for heating the open ground areas and increasing crops productivity. The research objectives are:

– the study of the peculiarities and regularities of temperature regime formation of typical light loamy black soils in terms of year-round heating by warm waste waters;
– setting the amount of heat losses by the heating system during the year for different parameters of the heating system;

– the study of the influence of the ground heating system on soil processes and the yield of perennial grasses.

The rational use of fuel and energy resources is today one of the global problems of the world, the successful solution of which will result, in a decisive sense, not only in the further development of the world community, but also in the preservation of its residence areas. In addition to the purely economic losses associated with the lack of much of the produced energy utilization, heat release into the environment leads to environmental damage. Usually, it is heat pollution that is associated with the natural water use as a cooling agent in industrial processes, as for the power plants. Warm water changes the thermal and biological modes of reservoirs and has a harmful effect on their inhabitants. The water, heated to a temperature of 20–30°C, acts as a suppressing factor on fish and other inhabitants of water reservoirs, and if the water temperature rises to 36°C – the fish dies. The most significant sources of heat pollution are thermal power plants (TPP) and nuclear power plants (NPP). The efficiency of modern NPP is about 30–35%, and of TPP it is 35–40%. This means that most of the thermal energy (60–70%) is released into the environment (Balghouthia et al 2005, Dalampakis et al 2017, Dudnik et al 2020, Issakhov 2014). Modern nuclear power plants use cooling towers and reservoir coolers. The flow rate of the water which cools turbine capacitors is approximately 50 $m^3/s$ per 1000 MW of electric power, and its temperature should not be increased by more than 10°C. To release this amount of heat, it is necessary to have a scope of the reservoir-cooler mirror of 10–12 $km^2$ per 1000 MW, and the amount of water that goes for evaporation should reach $30 \cdot 10^6$ $m^3$/year. This problem becomes especially acute in the context of global warming, since the operation of energy companies and their technological indicators are clearly dependent on climatic factors. Heat energy vulnerability from climatic changes is revealed precisely through heat removal systems, their improvement and search for the alternative ones is the main factor in counteracting the climate changes. Thus, in assessing the situation, for example, for the south of Ukraine, it is important to ensure that the current vegetation values of the main meteorological characteristics are close to, or already in the range of their predicted changes (Agrawal et al 2019). In addition, the last years are characterized by record temperature highs (for example, the average air temperature in the 2020 vegetation period was 19.3°C, with an average annual rate of 17.1°C) and an increase in seasonal irregular rainfalls. These changes in the weather and climatic conditions of Western Polissya ecozone of Ukraine (Korobiichuk et al 2020), indicate a steady tendency to increase the aridity of the climate in the region. In particular, recent years are characterized by record temperature highs (for example, in 2020, the average air temperature during the growing season was 16.6°C, with an average annual rate of 13.5°C) and increasing seasonal irregularity of precipitation.

Therefore, the world energy policy is currently focused not on increasing production, but on saving energy resources, increasing their efficiency, and reducing the energy intensity of production.

A considerable amount of scientific work has been devoted to the problem of finding effective ways of utilization and use of low-potential heat (Korobiichuk et al 2019, Love et al 2018, Madden et al 2013, Prats et al 2012). The main restrictive factor for the usage of circulating warm waters by nuclear and thermal power plants is their relatively low temperature, but they carry considerable thermal potential. Works to develop, on the basis of warm waste water, low-release waste resource conservation technologies for agricultural and bio productive production (so-called energy-biological complexes) are carried out, which allow us to obtain significant amount of foodstuffs, to use fuel and energy, water and other natural resources, to substantially reduce the water pollution, and to increase the efficiency of energy objects (Balghouthia et al 2005, Rakovec and Hočevar 1988, Rokochynskiy et al 2019a).

One of the important components of the energy biological complex, as well as an independent direction of the use of warm waste waters, can be the direction of thermal reclamation, which is realized through the use of warm water for heating open ground and irrigation of crops. It should be noted that research on the effectiveness of soil heating by warm waste waters are conducted in the United States, France, Germany, Bulgaria, Russia and other countries (Dalampakis et al 2017, Issakhov 2014, Rokochynskiy et al 2019b, Vasiliev and Remizov 2004, Vasiliev 2011, Vostrikov et al 2014, Vostrikov 2015).

## 2. Methods and Techniques

The research program envisaged systematic monitoring of soil and air temperature, water temperature in the heating system, soil moisture, precipitation, agrochemical properties of soils, and yields of perennial grasses. The soil temperature was measured from a depth of 0 to 1.0 m, with the interval of 10 cm, and further to 2.0 m with the interval of 0.5 m, both in and between the pipe joints. Measurements were carried out once a day at 13:00 using TM-10 exhaust thermometers. The study of the water regime of soil was carried out by systematic observations of precipitation and soil moisture to a depth of 1.0 m.

The amount of heat dissipated in the soil was determined with the measurements of water temperature at the inlet and outlet and was calculated by the formula:

$$q = \frac{Q\,C\,(T_n - T_k)}{F},$$

where

$q$ – heat transfer per unit area, $W/m^2$;
$Q$ – water flow in the pipeline, $m^3/s$;
$C$ – water thermal capacity, $J/m^3{\cdot}°C$;
$T_n$, $T_k$ – water temperature at the entrance to the system and at the exit, °C;
$F$ – area of the heating system, $m^2$.

The technology of ground heating is implemented using a system of pipelines (heaters) with the diameter of up to 50 mm, which are placed into the ground at the depth of 0.5–0.6 m with the interval of 1.0–1.5 m from each other. The water passed with the temperature of 25–38°C. Heaters of the length of 50 m were connected on one side to the distribution pipeline of the diameter of 100 mm and the length of 12–17 m, and on the other side – to the collecting pipeline of the same diameter and length, thus forming like a "battery". The ground heating area was in the range of 600–850 $m^2$ depending on the distance between the heaters. The research was carried out according to the following options: control (unheated field), ground heating with $b = 1.0$ m, and ground heating with $b = 1.5$ m, where $b$ – the distance between the pipelines. The scheme of alternative waste water heat utilization system of energy objects is shown in Figure 1.

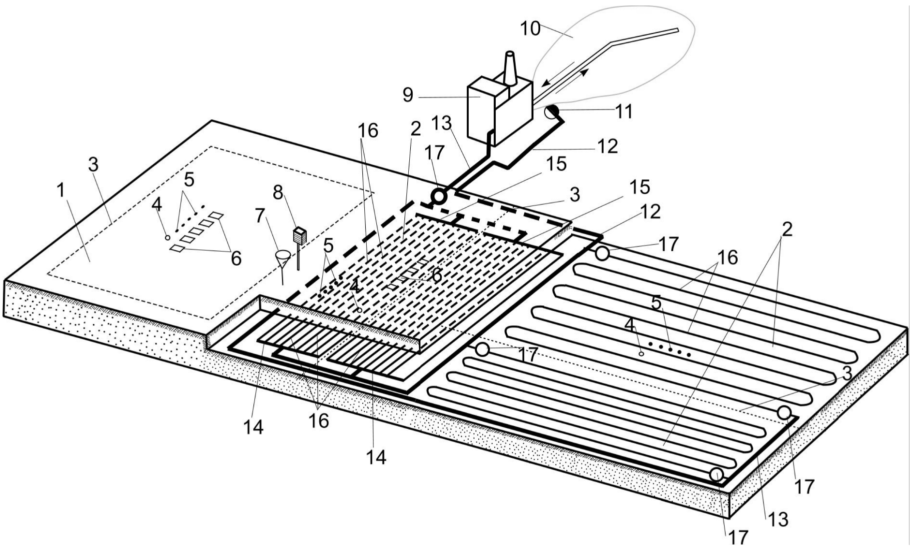


**Fig. 1.** The general scheme of the experimental area for heating the soil with low-potential heat: 1 – unheated field (control); 2 – heated fields; 3 – field boundaries; 4 – well for measuring groundwater levels; 5 – thermometers; 6 – lysimeters; 7 – rain gauge; 8 – meteorological point; 9 – energy facility; 10 – cooling pond; 11 – pumping station; 12 – hot water supply pipeline; 13 – branch pipe of cooled water; 14 – distribution pipeline; 15 – prefabricated pipeline; 16 – heating pipes; 17 – regulating wells

For studying the processes of water cooling during the movement of pipelines, as well as heat dissipation into the ground, it was planned to lay pipes of the diameter of 50 mm according to the "snake" scheme with a distance between pipes of 1.0 m and 1.5 m. The overall length of the pipeline is 600 m. The speed of water in the pipelines was regulated by valves, which were installed in the control wells and measured by flow meters.

The choosing the parameters of the heated network (diameter of pipes, depth of laying, distance between pipes) is based on the need for uniform heating of the root layer of the soil, efficient water cooling, preservation of pipelines during tillage mechanisms.

The choice of water velocity in the pipes and the depth of their laying was determined by thermal calculations which show that the velocity of water in the pipelines must be taken in the range of 0.15–0.25 m/s, the distance between the pipes in the range of 1.0–2.0 m, and the depth of laying is not more than 1.0 m, as with increasing depth increases the thermal resistance of the soil.

The temperature parameters of the waste water used as a heat carrier in the ground heating system are shown in the Table 1.

**Table 1.** Normalized average monthly water temperatures at the inlet to the ground heating system, ($t$, °C)

| Months | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
| 14.1 | 13.7 | 17.7 | 22.0 | 27.8 | 33.1 | 34.6 | 32.7 | 27.8 | 23.6 | 20.6 | 12.6 |

The studies were carried out at the black earth loamy soils with a bulk mass of the root-containing soil layer (0–60 cm) – 1.31 t/m$^3$ with humus content up to 6%.

The research investigations were carried out at the Kursk Nuclear Power Plant (Russian Federation), and waste waters of Kursk NPP were used as a low-potential source (Fig. 2).


**Fig. 2.** Location of the study area

## 3. Results and Discussion

The presence of linear heat sources in the ground creates a complex picture of the temperature distribution across the ground profile, which depends on the coolant temperature, the distance between them, and the weather conditions.

Ground heating using circulating warm water allows to raise the temperature at all points in the ground profile. The maximum thermal effect from ground heating is observed at the depth of laying the tube heaters (7.3–11.1°C). The temperature effect decreases with the distance from the heaters. At the ground surface it is 2.2–2.5°C. The thermal effect at a depth of 5 cm from the ground surface is 0.9–2.4°C, and at the depth of 20 cm – 3.8–4.2°C (Table 2, Fig. 3).

**Table 2.** Measured average monthly temperatures of the ground profile, ∘C (April)

| Research variant | Line | Depth of measurement, cm | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 5 | 10 | 15 | 20 | 40 | 60 | 80 | 100 |
| Heating effect ($b$ = 1.0 m) | above the pipe | 7.3 | 8.0 | 9.2 | 9.8 | 14.1 | 17.3 | 14.4 | 13.2 |
| | in the middle between the heaters | 7.2 | 7.5 | 8.7 | 9.5 | 12.0 | 13.5 | 12.8 | 11.3 |
| Heating effect ($b$ = 1.5 m) | above the pipe | 7.4 | 8.2 | 9.3 | 9.9 | 13.8 | 16.7 | 13.5 | 10.3 |
| | in the middle between the heaters | 7.0 | 7.2 | 7.7 | 8.8 | 10.5 | 12.0 | 11.8 | 10.6 |
| Control | | 4.9 | 4.9 | 5.1 | 5.6 | 6.3 | 6.2 | 6.1 | 5.5 |

It should be noted that the thermal effect is a variable that depends on both climatic conditions and water temperature in the heating system. The most unstable effect on ground temperature from heating is observed in the upper horizons. For example, we give the value of the thermal effect during the year for the heating option with $b$ = 1.0 m (Table 3).

**Table 3.** The thermal effect from ground heating during a year ($b$ = 1.0 m)

| Depth of measurement, cm | Thermal effect, °C | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
| 5 | 1.1 | 4.6 | 5.3 | 4.4 | 3.5 | 3.2 | 2.5 | 1.8 | 1.6 | 1.5 | 1.2 | 1.1 |
| 10 | 1.4 | 4.8 | 6.4 | 4.8 | 3.8 | 3.6 | 2.9 | 2.6 | 2.4 | 1.8 | 1.6 | 1.5 |
| 20 | 3.2 | 5.9 | 7.1 | 5.7 | 4.2 | 3.9 | 3.8 | 3.4 | 2.7 | 1.9 | 1.9 | 1.8 |
| 40 | 7.2 | 7.9 | 8.3 | 7.7 | 6.8 | 6.5 | 5.4 | 5.3 | 5.3 | 5.1 | 4.7 | 4.2 |
| 60 | 7.5 | 8.3 | 8.6 | 8.2 | 8.1 | 8.0 | 7.7 | 7.0 | 7.0 | 6.2 | 5.9 | 5.7 |
| 80 | 7.2 | 7.5 | 8.8 | 8.1 | 7.9 | 7.4 | 7.2 | 6.7 | 6.8 | 6.6 | 6.3 | 6.0 |

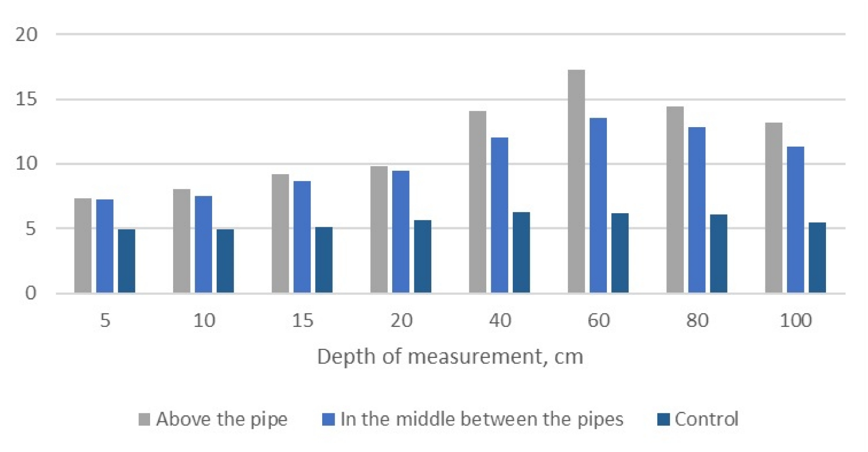


**Fig. 3.** The thermal effects of ground heating (for the distance between the heaters $b$ = 1.0 m)

Thus, the maximum temperature effect from heating is observed in March and was 5.3°C at the depth of 5.0 cm and 8.6°C at the depth of laying the heating pipes. In February, this effect is slightly smaller and is respectively 4.6°C and 8.3°C. The minimum effect of heating was observed in the autumn and it was 1.1–1.6°C. This is due primarily to the low temperature of the inlet water, which at that time is at the level of 12–14°C. At the depth of 60 cm, the thermal effect during the year varies insignificantly. This feature of the ground temperature is related to the ability to accumulate heat and retain it for a long period. Accumulation of heat by the ground leads to an increase in the number of active temperatures in the arable layer, thus heating contributes to the creation of more favorable conditions for the growth and development of crops. During the growing season, the number of active temperatures increases by 156.3–680.5°C, which is 20–25% higher than this figure for the unheated area.

In addition, the ground heating has an impact on the formation of the temperature regime of surface air. The temperature of the surface layer of air increases in the conditions of ground heating by 0.8–2.1°C depending on the state of vegetation and climatic factors. This increase in surface air temperature is a positive moment, especially in early spring and autumn, as it increases the duration of the frost-free period. For the conditions of the Kursk region, frosts on the surface of the heated ground occur 8–10 days later than in the control area. In spring, the value of ground temperature is 5°C, which indicates the beginning of the growing season for most crops, occurs on heated areas 15-18 days earlier, and in autumn the temperature transition through 5°C occurs 6–8 days later, thus increasing the growing season in on average for 3–4 weeks. Already in late March, the temperature of the arable ground layer exceeds 10°C, and in mid-April, it is above 15°C.

At the same time, as the ground is heated in such systems, the process of cooling the coolant takes place. Observations on the operation of the underground heating system showed that the degree of cooling of the water in the pipelines depends on the mode of operation of the system and external factors (Table 4, Fig. 4, Fig. 5).

**Table 4.** The average values of the cooling water (°C) in the underground heating system, depending on water velocity

| Water velocity in the pipeline, m/s | Spring | Summer | Autumn | Winter |
|---|---|---|---|---|
| The distance between the pipelines $b$ = 1.0 m, the length of the pipeline $l$ = 600 m | | | | |
| 0.15 | 8.4 | 8.2 | 7.9 | 7.3 |
| 0.25 | 6.8 | 6.6 | 6.3 | 6.1 |
| 0.30 | 5.6 | 5.3 | 5.2 | 4.7 |
| The distance between the pipelines $b$ = 1.5 m, the length of the pipeline $l$ = 600 m | | | | |
| 0.15 | 9.2 | 8.7 | 8.6 | 8.2 |
| 0.25 | 7.1 | 7.1 | 7.0 | 6.7 |
| 0.30 | 6.4 | 5.8 | 5.6 | 5.2 |

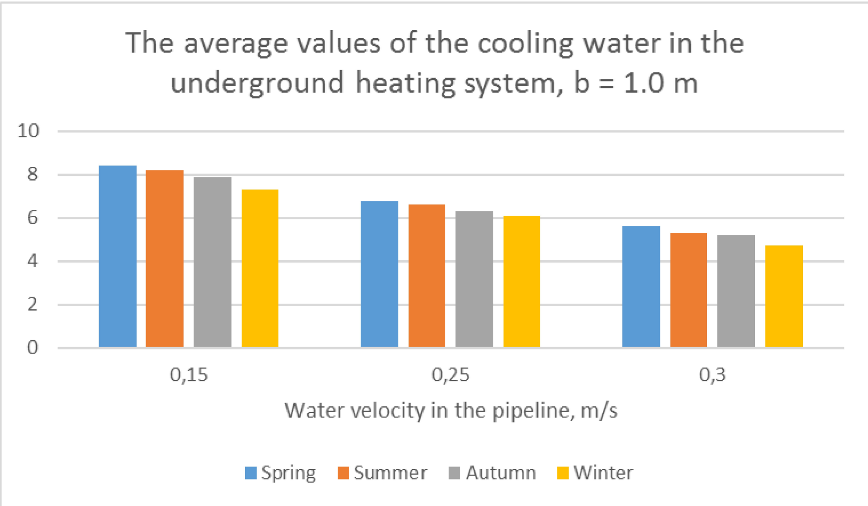


**Fig. 4.** Dynamics of cooling water (°C) in the underground heating system with parameters: the distance between the pipelines $b$ = 1.0 m; the length of the pipeline $l$ = 600 m

Increasing the water velocity in the pipeline leads to a decrease in the value of its cooling. If water velocity is 0.15 m/s, it is cooled by years of research to 7.3–8.4°C ($b$ = 1.0 m), then at a velocity of 0.3 m/s – only to 4.7–5.6°C. Increasing the distance between the pipes from 1.0 m to 1.5 brings the cooling value by 7 . . . 15%, but the heat transfer varies from 9.8–12.4 W/m$^2$ ($b$ = 1.0 m) to 8.7–10.4 W/m$^2$ ($b$ = 1.5 m).

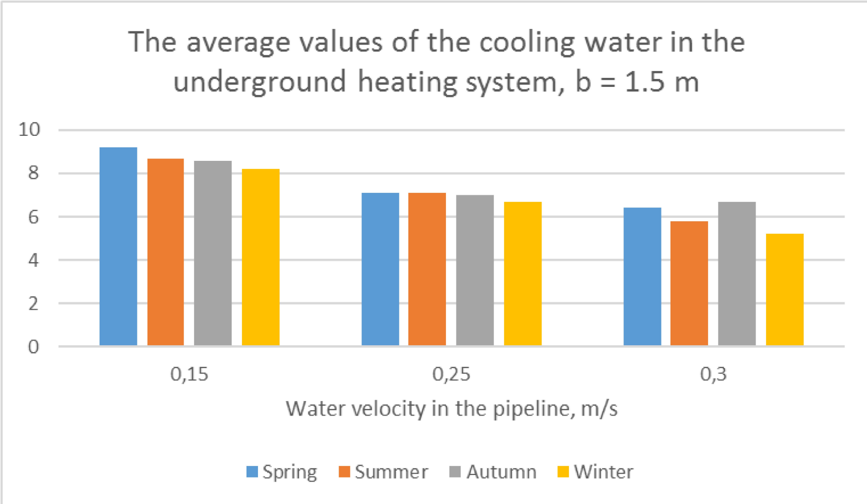


**Fig. 5.** Dynamics of cooling water (°C) in the underground heating system with parameters: the distance between the pipelines $b$ = 1.5 m; the length of the pipeline $l$ = 600 m

Changing the temperature conditions in the active ground layer causes changes in the formation of the ground water regime. Studies have shown that ground moisture in the heated areas in the spring period is 22–27% higher than unheated due to its earlier thawing and more efficient absorption of meltwater. In the summer, the humidity in the ground layer of 0–70 cm decreases by 12–15% depending on the temperature of the coolant. In the future, the humidity of the heated areas stabilizes at the humidity level in rainy conditions. In winter, when there is no absorption of moisture by plants and there is minimal evaporation, the humidity of the heated areas increases compared to the unheated by 4–8%. In general, ground warming under natural moisture conditions does not significantly reduce the moisture content of the active layer throughout the growing season, at the same time, it leads to the redistribution of moisture at the ground profile. Its decrease is performed in the area of the location of the tube-heaters and redistribution in the intertubular space and in the upper layers. With insufficient rainfall, there is a significant drying of the ground near the tube heaters in the radius of 10—12 cm, which significantly reduces the thermal conductivity in this zone and deteriorates the heat transfer between the pipeline system and the ground. Therefore, in order to maintain the required level of heat transfer and a favorable water-air mode of the active layer, it is necessary to humidify the ground.

Increasing the ground temperature during thermal reclamation leads to a change in the environmental situation into the ground, which is resulted in enzymatic activity. In black soils protease and urease activity increases, resulting in improved nitrogen nutrition of plants (Table 5). Under the influence of heating, invertase activity improves, resulting in its turn in improved carbohydrate nutrition of plants.

**Table 5.** Ground heating effect on urease activity, mg $NH_4$+ per 100 g soil for 3 h

| Research option | Horizon, cm | Agricultural culture | | | |
|---|---|---|---|---|---|
| | | Perennial herbs | | | |
| | | 8.06 | 23.07 | 13.08 | 14.09 |
| Heating | 0–30 | 20.0 | 23.6 | 27.2 | 20.0 |
| | 30–50 | 10.8 | 20.2 | 24.6 | 26.5 |
| Control | 0–30 | 15.4 | 20.0 | 22.2 | 18.2 |
| | 30–50 | 13.0 | 18.0 | 20.0 | 19.6 |

Analysis of phosphate activity under heating conditions showed that phosphatase activity decreased. This is explained by the fact that in the heating conditions the amount of mobile phosphorus increases, and this leads to a decrease in the number of phosphorous mineralizing bacteria (Table 6).

**Table 6.** Black soils heating influence on phosphatase activity, mg of $P_2O_5$ per 2 g of soil per day

| Research option | Horizon, cm | Agricultural culture | | | |
|---|---|---|---|---|---|
| | | Perennial herbs | | | |
| | | 8.06 | 23.07 | 13.08 | 14.09 |
| Heating | 0–30 | 0.74 | 0.86 | 0.52 | 0.51 |
| | 30–50 | 0.64 | 0.88 | 0.46 | 0.53 |
| Control | 0–30 | 0.77 | 0.89 | 0.61 | 0.49 |
| | 30–50 | 0.84 | 0.76 | 0.54 | 0.53 |

Underground heating affects the biological activity. The release of $CO_2$ from the ground surface in the spring and autumn growing season increases by 40.0–85.7%. In the summer growing season, the increase of $CO_2$ emissions is only 5–10%, and in severely dry periods the difference is insignificant.

An important indicator of soil microbiological activity is the cellulosolytic activity of soil microflora. It is known that the predominant part of organic matter is cellulose, so the rate of its decomposition can characterize the decomposition of organic matter in the soil. Studies have shown that the top of 0–30 cm ground layer is more active, and with the depth cellulosolytic activity falls, and especially sharply in unheated areas. The analysis of seasonal dynamics shows that the highest cellulosolytic activity is observed in spring and early summer (Table 7).

Reducing ground moisture slightly reduces its activity in the summer. Autumn rains increase the cellulosolytic activity of the soil.

The formation of nutritional regime changes at the heated areas. The content of mobile phosphorus and potassium, and nitrate nitrogen, increases, and the content of ammonia nitrogen decreases.

The study of the acid-alkaline state of the soil showed that heating by 0.2–0.3 units increases the pH of the soil and increases the activity of potassium ions in 1.5 times.

**Table 7.** Influence of soil heating on cellulosolytic activity

| Research option | Horizon, cm | Definition date | | |
|---|---|---|---|---|
| | | 25.05<br>24.06 | 11.07<br>10.08 | 9.09<br>9.10 |
| Heating | 0–30 | 59.0 | 38.7 | 47.4 |
| | 30–50 | 43.2 | 31.8 | 11.9 |
| Control | 0–30 | 52.2 | 21.0 | 19.2 |
| | 30–50 | 19.9 | 14.0 | 8.9 |

Analysis of the activity levels of calcium ions is under control (pCa 2.54–2.47), and in heated ground conditions (pCa 2.7–2.85) showed a decrease in the level of activity of calcium ions at the heat-reclaimed lands. The calculated values of potassium potentials (pH – pK) and (pK – 0.5rCa) indicate saturation of the soil solution of the heated ground with potassium ions. The level of lime potential (pH – 0.5rCa) indicates the deterioration of the calcium state of the heated areas (5.4–6.1). The rate of the sodium potential pNa – 0.5pCa and the ratio of pNa/pCa indicate the possibility of development salinity processes in heated soils.

Under the conditions of Kursk region and for the black soils, the underground heating allows us to obtained 3–4 crops of perennial grasses, as compared to 2 crops on the control sites. In combination with irrigation heating, it gives an increase in the yield of perennial grasses on the green mass by 66–93%. The effect of the heating on the yield is also significant, since it is 27–40%.

## 4. Conclusions

1. One of the rational ways to solve the energy conservation problem is to use heat from the waste waters from energy companies to heat open ground areas and to grow crops. The most significant heat sources are heat and nuclear power plants, which produce low-temperature thermal waters with the temperature of 28–35°C.
2. Heating of the ground by using circulating warm water enables increasing the temperature at all points of the ground profile. The maximum thermal effect from ground heating is observed at the depth of the layer of the tube heaters (7.3–11.1°C). The temperature effect decreases with the distance from the heaters.
3. Ground heating allows for extending the growing season for growing crops by 3–4 weeks, which can shift the harvesting process to an earlier period and maximize the yield of the crops grown.
4. Ground heating in natural moisture conditions does not lead to a significant reduction of moisture reserves in the active layer throughout the growing season. Heating leads to a redistribution of moisture over the bulk profile, and to a decrease in the area of the location of the tube heaters, and to the redistribution in the inter-tube space and into the upper horizons.

5. Heating black soils gives the increase in protease and urease activity, which lead to better plant nitrogen nutrition and to better invertase activity, resulting thus in improved plant carbohydrate nutrition. Ground heating activates cellulolytic activity, especially in the upper 0–30 cm soil layer. The formation of the nutritional regime changes, the content of mobile phosphorus and potassium, nitrate-nitrogen increases, and the content of ammoniacal nitrogen decreases.
6. Ground heating is a new, special heat-reclamation method that not only purposefully regulates the temperature conditions of the crop growing environment, but also dissipates heat into the ground, thus cools the water for re-use, contributes to the utilization of the produced waste heat, and stabilizes the environment.

## References


Agrawal K. K., Tejpal Y., Rohit M. (2019) Effect of soil moisture contents on thermal performance of earth-air-pipe heat exchanger for winter heating in arid climate: In situ measurement, *Geothermics*, **77**, 12–23. https://doi.org/10.1016/j.geothermics.2018.08.004 Get rights and content.

Balghouthia M., Koolia S., Farhata A., Daghariw H. (2005) Experimental investigation of thermal and moisture behaviors of wet and dry soils with buried capillary heating system, *Solar Energy*, **79** (6), 669–681. https://doi.org/10.1016/j.solener.2005.06.011.

Dalampakis P., Gelegenis J., Ilias A., Ladas A. (2017) Technical and economic assessment of geothermal soil heating systems in row covered protected crops: A case study from Greece, *Applied Energy*, **203** (1), 201–218. https://doi.org/10.1016/j.apenergy.2017.06.029 Get rights and content.

Dudnik A., Kuzmych L., Trush O., Domkiv T., Leshchenko O., Vyshnivskyi V. (2020) Smart Home Technology Network Construction Method and Device Interaction Organization Concept, *IEEE Second International Conference on System Analysis & Intelligent Computing (SAIC'2020)*, DOI: 10.1109/SAIC51296.2020.9239220.

Issakhov A. (2014) Mathematical modeling of thermal process to aquatic environment with different hydro meteorological conditions, *Sci. World J.*, 632–635.

Korobiichuk I., Drevetsky V., Kuzmych L., Kovela I. (2020) The method of multy-criteria parametric optimization, *Advances in Intelligent Systems and Computing*, **1140**, 2020. Automation 2020: Towards Industry of the Future, 87–97. doi.org/10.1007/978-3-030-40971-5. – Available at: https://link.springer.com/chapter/10.1007/978-3-030-40971-5_9.

Korobiichuk I., Kuzmych L., Kvasnikov V. (2019) The system of the assessment of a residual resource of complex technical structures, *MECHATRONICS 2019: Recent Advances Towards Industry 4.0*, 350–357. https://doi.org/10.1007/978-3-030-29993-4_43.

Love R. V., Wüest A., Zappa M., Fink G., Bouffard D. (2018) Tributaries affect the thermal response of lakes to climate change, *Hydrol. Earth Syst. Sci.*,**22**, (1), 132–141.

Madden N., Lewis A., Davis M. (2013) Thermal effluent from the power sector: an analysis of once-through cooling system impacts on surface water temperature, *Environmental Research Letters*, **8**, 2–8.

Prats J., Val R., Dolz J., Armengol J. (2012) Water temperature modeling in the Lower Ebro River (Spain): heat fluxes, equilibrium temperature, and magnitude of alteration caused by reservoirs and thermal effluent, *Water Recourses*, **48** (5), 230–245.

Rakovec J., Ho˘(c)evar A. (1988) Simulation of soil- and air-microclimate modifications using soil heating with warm water, *Agricultural and Forest Meteorology*,**42** (1), 41–52. https://doi.org/10.1016/0168-1923(88)90065-2.

Rokochynskiy A., Volk P., Frolenkova N., Prykhodko N., Gerasimov I., Pinchuk O. (2019a) Evaluation of climate changes and their accounting for developing the reclamation measures in Western

Ukraine, *Scientific Review Engineering and Environmental Sciences*, 28 Issue 1(83), 3–13. DOI: 10.22630/PNIKS.2019.28.1.1. http://iks_pn.sggw.pl/PN83/A1/zeszyt83art1en.html.

Rokochinskiy A., Jeznach J., Volk P., Turcheniuk V., Frolenkova N., Koptiuk R. (2019b) Reclamation projects development improvement technology considering optimization of drained lands water regulation based on BIM, *Scientific Review Engineering and Environmental Sciences*, 28 Issue **3** (85), 432–443. doi: 10.22630/PNIKS.2019.28.3.40. http://iks_pn.sggw.pl/PN85/A11/zeszyt85art11en.html.

Vasiliev N. N., Remizov Yu.V. (2004) Energobiological complexes as a method of utilization of waste heat of large power facilities and the creation high-intensity waste-free production, *Atomic science issues and technology*, **1**, 57–60.

Vasiliev A. M. (2011) Development of greenhouse farms subject to the use of potential of power generating enterprises, *Science Journal of Russian Scientific Researches of Institute of Land Reclamation Problems*, 2, 1–7.

Vostrikov V. P. (2015) Heat reclamation system for heating the soil with waste warm waters, *International Scientific Institute "EDUCATIO"*, **6** (13), 131–134.

Vostrikov V. P., Pinchuk O. L., Gnatyuk V. N. (2014) Soil Water Regime in the Tunnel Shelters at Heating Water Filled Shells-Sleeves and Drip Irrigation, *Universal Journal of Food and Nutrition Science* – USA, **2** (1), 7–17 (http://www.hrpub.org/ download/20140105/UJFNS2-11101752.pdf).