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SIMULATION OF TEMPERATURE IN PEAT MUCK SOIL

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Abstract. Soil temperatures predicted with the use of temperature gradient method (GRAGRO model) were compared with those measured at the experimental site.

The experimental data are close to the theoretical values. Unfortunately the some differences exist. The lack of agreement between the simulated and measured data is sometimes disappointing (end of simulation), but indicates more than anything else the areas in which our knowledge is lacking.

Presented results indicates that the model can be used for predicting the change of temperature of soil but the further studies in both the field and model verification need to pay respect to infiltration of water into soil after rain and measuring of thermal conductivity of soils.

Keywords: soil temperature, simulation, peat muck-soils.

INTRODUCTION

Heat transfer in soils is important for a description of plant environment in a number of ways. First of all, it is one of the important terms in the energy balance of the earths surface and consequently, it directly influences temperature regimes near the surface, both in the upper soil and lower air layers.

Secondly, in many instances, there exist a strong relation between heat transfer and moisture transfer in the soil. The processes of evaporation and dew formation are therefore influenced by the soil thermal behaviour [3].

Soil temperature is one of the most important factors for vegetable crop production, as it influences germination, seedling emergence, early growth of plants, maturation and yield. In general, three cardinal temperature levels for germination have been defined: the minimum and maximum temperatures below and above which no germination occurs, and the optimum temperature giving the highest germination rate. For Poland, the optimum temperature of the soil varies from 15 to 25 ^{o}C and it depends on the kind of crop [5].

Temperature variations within the soil profile is determined by the temperature variation at the soil surface and the soil thermal properties, e.g., thermal conductivity and capacity [2,8]. Effects of temperature on plant growth were given by Robertson [7] and Bierhuizen [1].

The purpose of this paper was to compare soil temperatures predicted with the use of temperature gradient method (GRAGRO model) with those measured at the experimental site.

EQUATIONS APPLIED AND SOIL PARAMETERS

Heat conduction in soil

Heat transfer in vertical direction in soil can be considered as consisting of a molecular heat conduction. Transport of heat by convection, vaporization and condensation, and by radiation are generally of minor importance. The magnitude of the heat flux in a homogenous soil is proportional to the temperature gradient and the thermal conductivity [4]:

$$q_h(z,t) = -\lambda \nabla T(z,t) \tag{1}$$

where: q_h - heat flux (W m^{-2}), z - depth (m), t - time (s), T - temperature (K), λ - thermal conductivity of the soil (W m^{-1}K^{-1}).

Equation (1) is known as the one-dimensional form of Fourier's Law of heat conduction.

The difference in heat flux into and out of an elementary soil element with thickness dz equals the rate of storage:

$$-\nabla q_h(z,t) = \rho c(\partial T(z,t)/\partial t) \tag{2}$$

where: ρ - specific mass (kg m^{-3}), c - specific heat per unit mass (J kg^{-1} K^{-1}), ρc - heat capacity of the soil per unit volume (J m^{-3} K^{-1}).

Finally, a differential equation for heat conduction in soils can be written as:

$$\nabla[\lambda \nabla T(z,t)] = \rho c(\partial T(z,t)/\partial t). \tag{3}$$

Soil characteristics and parameters

Two independent thermal properties enter into a quantitative description of the heat transfer by conduction: thermal conductivity λ, and heat capacity per a unit of volume ρc.

Thermal conductivity

The soil thermal conductivity dependents on the soil-water content, density, chemical composition, and soil temperature.

Field or laboratory measurements of λ are based on the specific solutions of Eq.(3), depending on the method used, geometry and boundary conditions.

Thermal conductivity of peat soil was calculated according to De Vries [2]. A regression analysis gave the following empirical relation:

$$\lambda = 1.41\, x_{\mathrm{w}} + 0.03 \tag{4}$$

where: λ - thermal conductivity, and x_{w} - volumetric water content.

Volumetric heat capacity

Heat capacity per a unit of volume of soil (ρc) equals the sum of the volumetric heat capacities of its various phases. Denoting the subscripts for the solid phase, water and air as *s, w* and *a* respectively, one can write:

$$\rho c = x_{\mathrm{s}}\rho_{\mathrm{s}}c_{\mathrm{s}} + x_{\mathrm{w}}\rho_{\mathrm{w}}c_{\mathrm{w}} + x_{\mathrm{a}}\rho_{\mathrm{a}}c_{\mathrm{a}} \tag{5}$$

where: x denotes volumetric fraction of a phase.

According to the values of ρ and ρc given by de Vries, air contribution can be neglected.

Distinguishing only between mineral (subscript *m*) and organic (subscript *o*) matter, we arrive at:

$$\rho c = x_{sm}\rho_{sm}c_{sm} + x_{so}\rho_{so}c_{so} + x_{w}\rho_{w}c_{w}\,. \tag{6}$$

For a typical peat soil, with $x_{sm} = 0$ and $x_{so} = 20$, ρc - values range from 0.5 10^{6}J m^{-3}K^{-1} at absolute dryness to 3.4 10^{6}J m^{-3}K^{-1} at saturation ($x_{\mathrm{w}} = 0.80$) [3]. The soil heat capacity per a unit of volume was assumed as 0.6 10^{6}J m^{-3}K^{-1}.

MODEL OF HEAT FLOW IN THE SOIL

There are a few known methods to find heat flux in the soil. One of these methods is known as a temperature gradient method (GRAGRO model). If λ is known and measurements of soil temperature at certain depths are available, heat flux can be computed according to Eq.(1) as the product of λ and a vertical temperature gradient ∇T. De Vit and Van Keulen [9] explained the principle of transport processes.

Figure 1 shows a model of a uniform soil column placed on an insulating layer. To calculate temperature as a function of depth and time, the column is divided into ten equal layers or compartments with a thickness of 5 cm. In the model the flow of heat may occur by diffusion and/or by the transport of water with different temperature (e.g., rain or irrigation)[6].

The temperature of each layer is found by dividing volumetric heat content by volumetric heat capacity per layer. At the beginning of the simulation run, the initial volumetric heat capacity is obtained from the heat capacity of soil, the relative amount of solid per cm^3 of soil, the initial water content and the heat capacity of water.

Heat flow caused by the flow of water, depends on the flow rate of crossing the boundary of two adjacent layers, the temperature of the flowing water and the heat capacity of the water.

The flow of heat by diffusion depends in general on the temperature gradient and the heat conductivity. Heat conductivity depends on the water content according to the Eq. (4). The flow of heat into the first layer depends on the air temperature and the conductivity of the first layer. The heat flow of a layer is given by the difference of inflow and outflow of heat for that layer.

The temperature of the layers is obtained by dividing the heat content by the heat capacity of the layer.

Predicted soil temperatures (T,^{o}C) were compared with soil temperatures measured at the experimental field site.

The flow charts of this part of GRAGRO model (subroutine TEMPA) which concerns soil temperature are presented in Fig. 2.

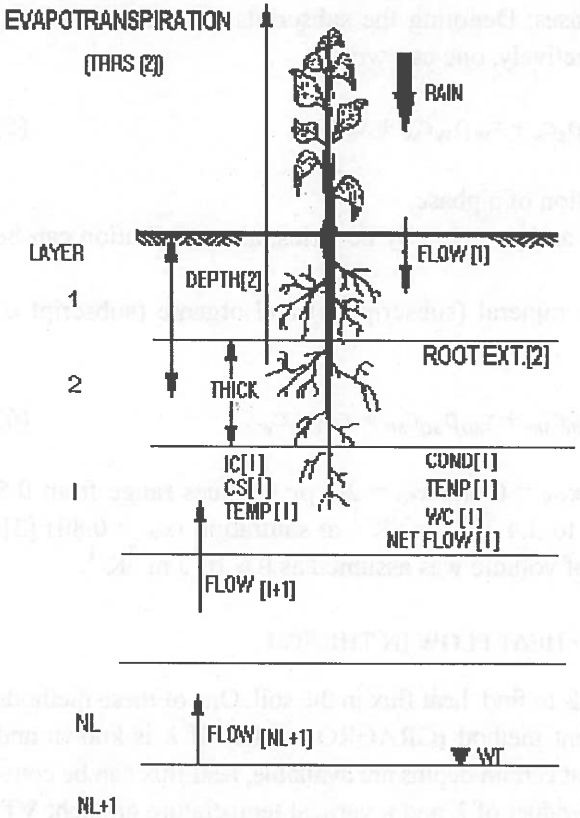

Fig. 1. Physical concept of the model.

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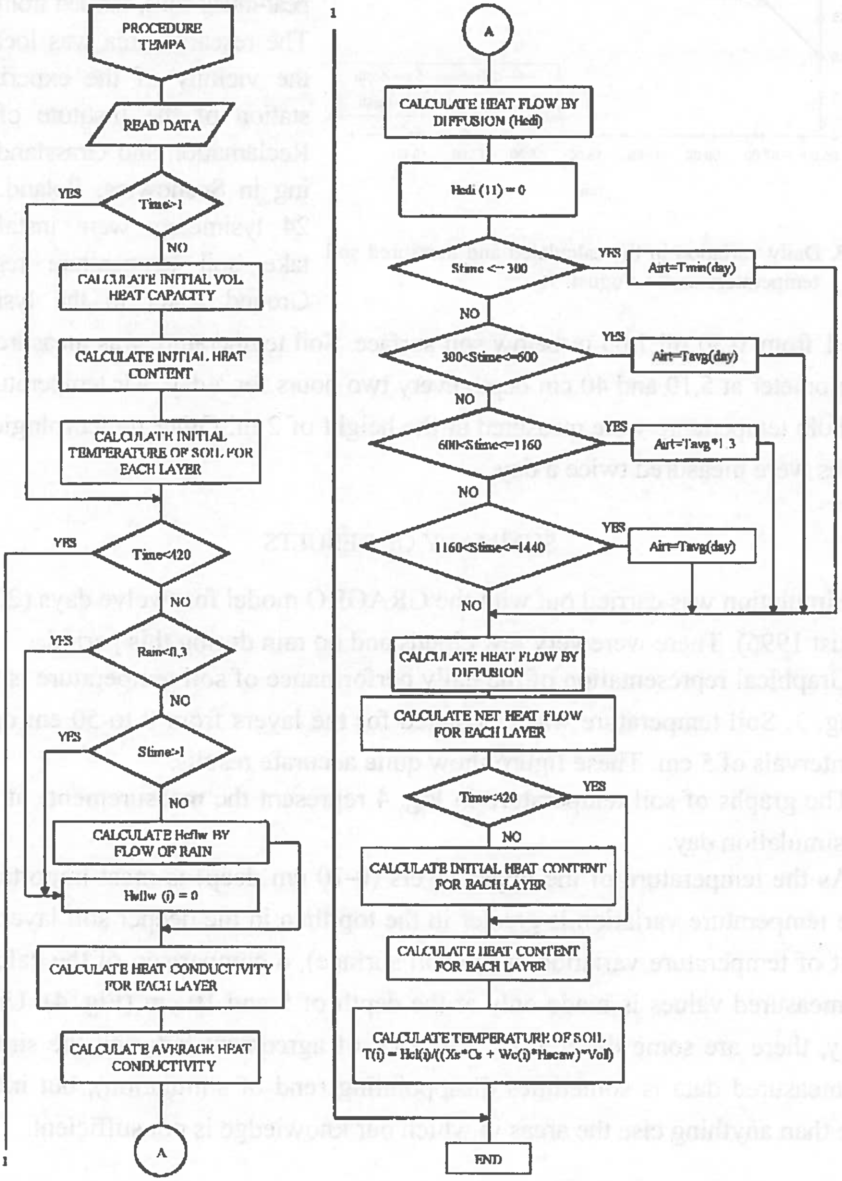

Fig. 2. The flow chart of the subroutine TEMPA.

MEASURING SITE

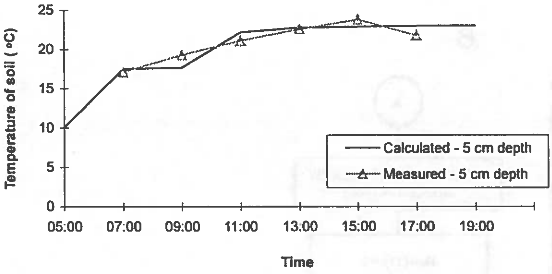

Fig. 3. Daily variation in the calculated and measured soil temperature on 27 August, 96.

The experimental area was peat-muck soils, formed from sedge. The research area was located in the vicinity of the experimental station of the Institute of Land Reclamation and Grassland farming in Sosnowica, Poland. Here, 24 lysimeters were installed to take soil temperature regularly. Ground water in the lysimeters varied from 0.50 till 1.00 m below soil surface. Soil temperature was measured by a thermometer at 5,10 and 40 cm depth every two hours for a day. Air temperature and wet bulb temperature were measured at the height of 2 m. Other meteorological variables were measured twice a day.

SUMMARY OF RESULTS

Simulation was carried out with the GRAGRO model for twelve days (20-31 in August 1996). There were very few clouds and no rain during this period.

Graphical representation of the daily performance of soil temperature is shown in Fig. 3. Soil temperature was calculated for the layers from 0 to 50 cm deep, at the intervals of 5 cm. These figure show quite accurate results.

The graphs of soil temperature in Fig. 4 represent the measurements at 7 a.m. of a simulation day.

As the temperature of the upper layers (0-10 cm deep) is most important and since temperature variation is greater in the top than in the deeper soil layers (as a result of temperature variation at the soil surface), a comparison of the calculated and measured values is made only at the depth of 5 and 10 cm (Fig. 4). Unfortunately, there are some differences. The lack of agreement between the simulated and measured data is sometimes disappointing (end of simulation), but indicates more than anything else the areas in which our knowledge is not sufficient.

CONCLUSION

Presented results indicats that the GRAGRO model can be used for predicting temperature changes in the soil but further studies on both field and model verification need to be undertaken to consider infiltration of water into the soil after rain and measuring of soil thermal conductivity.

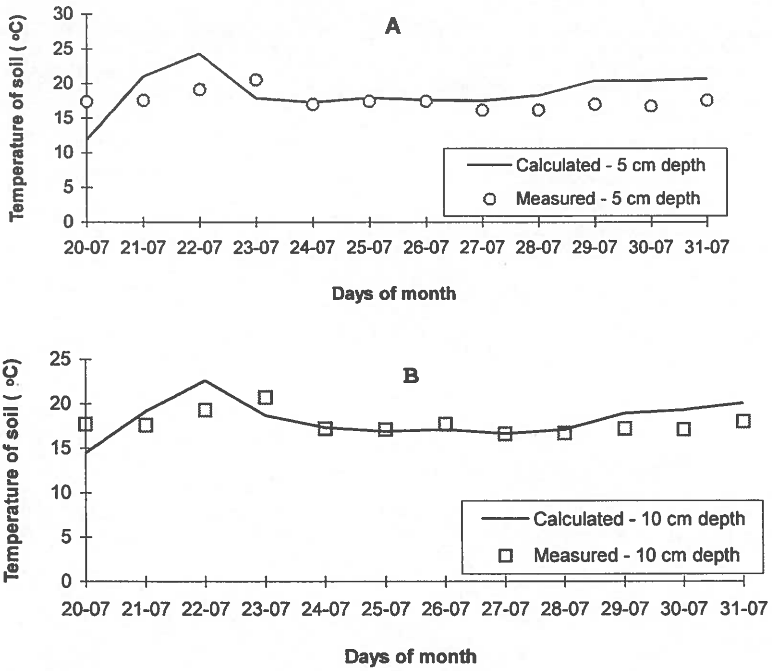

Fig. 4. Measured and calculated soil temperature under grass growing on peat soil at Sosnowica at A - 5 cm, B - 10 cm depth.

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