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Influence of Vegetation on the Thermal Balance of Different Soil Types Used for Recultivation

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Abstract. Vascular vegetation experiments were carried out with a universal grass mix (Lolium perenne rosemary 30%, Lolium perenne esquire 25%, Festuca rubra casanova 25%, Festuca rubra gondolin 20%). In this study were used mineral waste with a strong acid reaction and soils from three regions - Sofia, Chelopech and Gorubliane. The soils had different contents of humus, nitrogen, mechanical composition and soil reaction. The plants had the best growth on the soil from Sofia, which had the highest humus and nitrogen content. The differences in fresh and dry weight of above-ground biomass of plants growing on different soils in June and July were much more significant than those obtained in October. Biomass data for the autumn season suggests that higher clay content and higher soil reaction of soil from Gorubliane significantly reduced the amount of bioavailable for plants pollutants fraction. The second part of this paper focuses on measurements and analysis of thermal processes in the active layer. The objectives are to determine the soil thermal properties, heat transfer processes and to use a thermal model, determine soil surface heat flow under atmospheric forcing. This model is validated using soil temperature and micrometeorological data from a field measurements.

Key words: soil recultivation, soil thermal properties, heat transfer processes, plants growing

Introduction

Different plant species are used for the biological recultivation - mostly beans and cereal grasses and some certain species of trees (Tabakov & Petrova, 2006; Petrova, 2009; Petrova *et al.*, 2016). The purpose of the biological reclamation is to restore the fertility properties of the disturbed terrains for their future exploitation. The selection of the plants must be in accordance with the environmental conditions, the type of soil and the climatic characteristics of the area. It is possible to use them separately or in combination, depending on the conditions of the environment and the topography of the terrain (Ghose, 2005; Glick & Wong, 2003; Sheoran *et al.*, 2010).

The organic matter in the soil plays an important role for the development of plants. It includes humification products (aerobic decomposition) and not completely decomposed plant and animal residues. The humus content in the soil determines its structure and fertility. The humus is a major source of mineral salts and energy for all soil organisms. Biogenic macro- and microelements which are vital for the plants (nitrogen, phosphorus, sulfur, potassium,

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calcium, iron, copper, manganese, zinc, etc.) permeate through mineralization of organic substances in the soil solutions. Their availability depends on the soil reaction. The most suitable for the development of most plants is the slightly acidic or neutral soil reaction - pH 5.5 - 7.0. The influence of soil pH on plants is considered to be direct and indirect. The direct influence is immediately and predominantly associated with anion and cation ingestion. The indirect influence of soil acidity can be related to the increase or decrease in the the solubility of nutrients.

The physical-mechanical soil composition influences its hydrothermal regime and its aeration. Heavier clay soils have a better hydrothermal regime than light sandy soils due to the fact that the clay connects better the water. On the other hand, the aeration is better for the sandy soils.

Materials and Methods

Vascular experiments were performed in 5 pots with a volume of 25 dm^3 each. At the bottom of the vessels was laid 5 cm layer of gravel with a particle size of 0.5-3 cm. Mineral waste from a mine waste pile was placed upon the gravel, with a layer height of 20 cm. Over the mineral waste were laid 15 cm of soil. For the experiment were used soils from three regions - Sofia, Chelopech and Gorubliane. On the Fifth of May, 2018, three of the pots were planted with a universal grass mixture (7 g/pot). The composition of the grass mixture was as follows: Lolium perenne rosemary 30%, Lolium perenne esquire 25%, Festuca rubra casanova 25%, Festuca rubra gondolin 20%. The other two pots served as controls (Table 1). The plants grew under natural climatic conditions and during the period May - August they were watered when periods of drought have occurred.

The height and weight of fresh above-ground biomass of plant were determined in early June, July and October. The dry weight of above-ground biomass was determined after drying the biomass at 105 °C.

The pH determination was performed according the International Standart BDS ISO 10390 - an instrumental method for the routine determination of pH using a glass electrode in a 15 (V/V) suspension of soil in water (pH-H2O). The soil mechanical composition was determined by the method of Kachinsky. The humus content was determined by the Thurin method. The total nitrogen content in soil (ammonium-N, nitrate-N, nitrite-N and organic N) was determined by Kjeldahl digestion, according the International Standart BDS ISO 11261 l. For the determination of the content of heavy metals and metalloids in the soil was used a standardized method of sampling ISO 22036: 2008 - microwave acid decomposition of sediments, sludge, soils and oils. Concentrations of heavy metals and arsenic were determined by ICP-OES.

An electronic pyranometer was used to determine the direct and reflected solar radiation fluxes. A four-channel thermometer-logger S0141 was used for measuring the evolution of soil temperature. The CO_2 content was determined by a gas detector-logger BZ30. The thermal conductivity coefficient was calculated on the basis of the cooling curve obtained by a laboratory equipment designed for this purpose.

Data processing

The quality of the soil was assessed by statistical analysis of the height of the grass. Since to produce reliable conclusions these tests require normally distributed data, the normality of the height datasets for each experiment was preliminary affirmed by using Shapiro-Wilk test at a significance level $p < 0.05$. After that one-way analysis of variances (ANOVA) was applied to test if the difference between the mean values of the grass height for any given experimental period is statistically significant. If the difference between any pair groups is not significant, the procedure was stopped, making decision that we should accept equality between the means of the quantity considered. But if the results from one-way ANOVA suppose the availability of at least one couple with different means, a Turkey procedure was performed in addition to determine which pair have different means. Both ANOVA and Turkey tests were performed at a significant level of 0.05.

Results and Discussion

The used mineral waste was characterized through a strong acidic reaction (Table 2). The total sulfur content of the mineral waste was 13.176 g/kg - 1.32%, of which 0.42% was sulphide sulfur and 0.9% - sulphate. According to preliminary data on the mineral waste the sulphide sulfur was included mainly in the pyrite, which ranged from 2 to 4%. Table 3 shows that copper, lead and arsenic were in hgh concentrations in the waste, and the same was a source of acidic drainages due to the activity of acidophilic haemolitotrophic microflora.

The soils from Sofia and Chelopech were classified as sandy clay loam and the soil from Gorubliane - as clay loam (Table 2). According to the classification of soils, regarding the soil reaction, the soil from Sofia was neutral, the soil from Chelopech - medium acidic and the soil from Gorubliane - slightly alkaline.

The humus content was found to be highest in the soil from Sofia - 3.21% (Table 3). In the soil from Chelopech the humus content was lower - 0.98%. The poorest in humus was the soil from Gorubliane - 0.57%. The nitrogen content in soils was also different and depended on the amount of humus (Table 3). With the highest content of nitrogen was characterized the soil from Sofia and with the lowest - the soil from Gorubliane.

According to the national legislation (Article 5 of Guidance № 3/1 Aug 2008 On The Eligible Content Of Harmful Substances In Soils) the soils were not contaminated with heavy metals and arsenic.

Fig. 1 and 2 represent the fresh and dry weight of the above-ground grass biomass. The measurement in June was done 35 days after the seeding. The data in July was obtained 20 days after the first mowing of the grasses. The results for the fresh and dry weight of the grass in October were obtained three months after the second mowing. The Fig.s show that the plants had the best growth on the soil from Sofia, which had the highest humus and nitrogen content.

Shapiro-Wilk test performed for the grass height showed that the grass height datasets are normally distributed. A summarizing of the results from assessment of the normality of the grass height datasets for the three type of soil is shown on Fig. 3.

Result from statistical analysis are presented in Table 4. The difference between average value of the height of the grass is statistically significant when it is bigger than critical difference.

Table 1. A scheme of the experiment.

№	Description
1	Soil from Sofia with plants
2	Soil from Chelopech with plants
3	Soil fromGorubliane with plants
4	Soil from Chelopech without plants
5	Soil fromGorubliane without plants

The grass on the soil from Chelopech germinated lately, as that soil had the most acidic reaction and lower humus and nitrogen contents. The height of the plants and their above-ground biomass in all measurements were lower than the plants growing on the soil from Sofia. With the smallest height and above-ground biomass was the grass growing on the soil from Gorubliane, characterized by heavier mechanical composition and the lowest humus and nitrogen contents. The observed iron chlorosis was due to the slightly alkaline soil reaction from Gorubliane, which made it difficult for the plants to absorb the iron salts.

The differences in fresh and dry weights of above-ground biomass of plants growing on different soils in June and July were much more significant than those obtained in October (Fig. 1 and 2). It is very likely that during the summer period, through the capillary water, a solution with increased concentrations of As, Cu and Pb to have reached the plant roots, as a result from the used mineral waste leachate. The mobility of heavy metals and arsenic was higher in soils from Sofia and Chelopech, which were sandy clay loam compared to the soil of Gorubliane, which had a heavier mechanical composition.

Table 2. Mechanical composition and soil reaction.

№	Description	Mechanical composition	pH (H_2O)	pH (KCl)
1	Soil from Sofia	sandy clay loam	7,00	5,93
2	Soil from Chelopech	sandy clay loam	5,65	4,39
3	Soil from Gorubliane	clay loam	7,53	6,48
4	Mineral waste	-	3,07	2,65

Table 3. Contents of humus, nitrogen and heavy metals in the tested soils.

№	Description	Humus, %	C, %	Kjeldahl-N, %	As, mg/kg	Cu, mg/kg	Fe, mg/kg	Pb, mg/kg	Zn, mg/kg
1	Soil from Sofia	3.21	1.92	0.297	8.9	57.8	9406	50.7	122
2	Soil from Chelopech	0.98	0.57	0.196	9.2	140	9513	28.9	96.9
3	Soil from Gorubliane	0.57	0.33	0.118	<5	70.3	8673	17.8	60.9
4	Mineral waste	-	-	-	30.2	133	10235	339	112

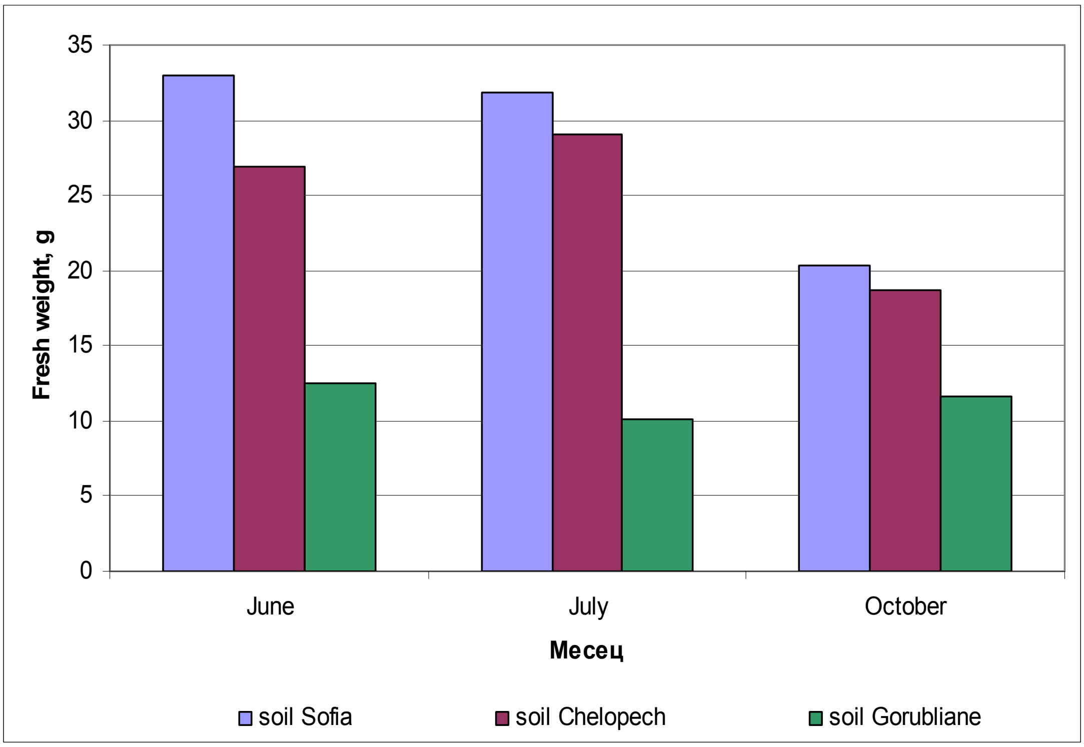

Fig. 1. Weight of fresh above-ground biomass

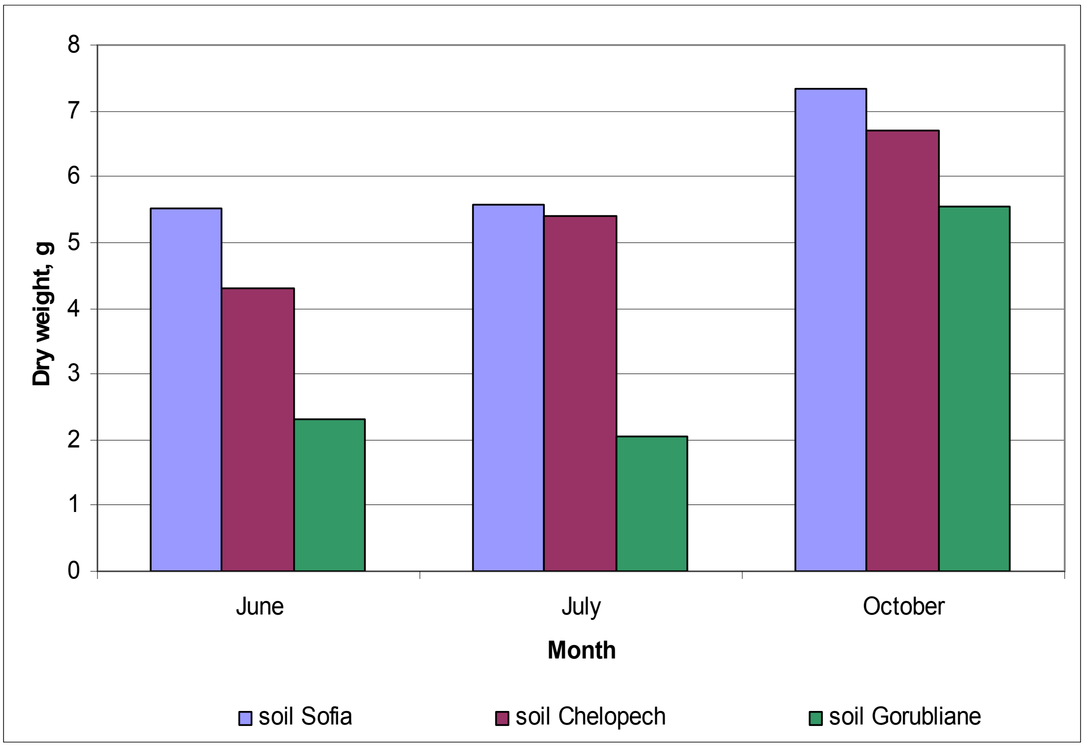

Fig. 2. Weight of dry above-ground biomass

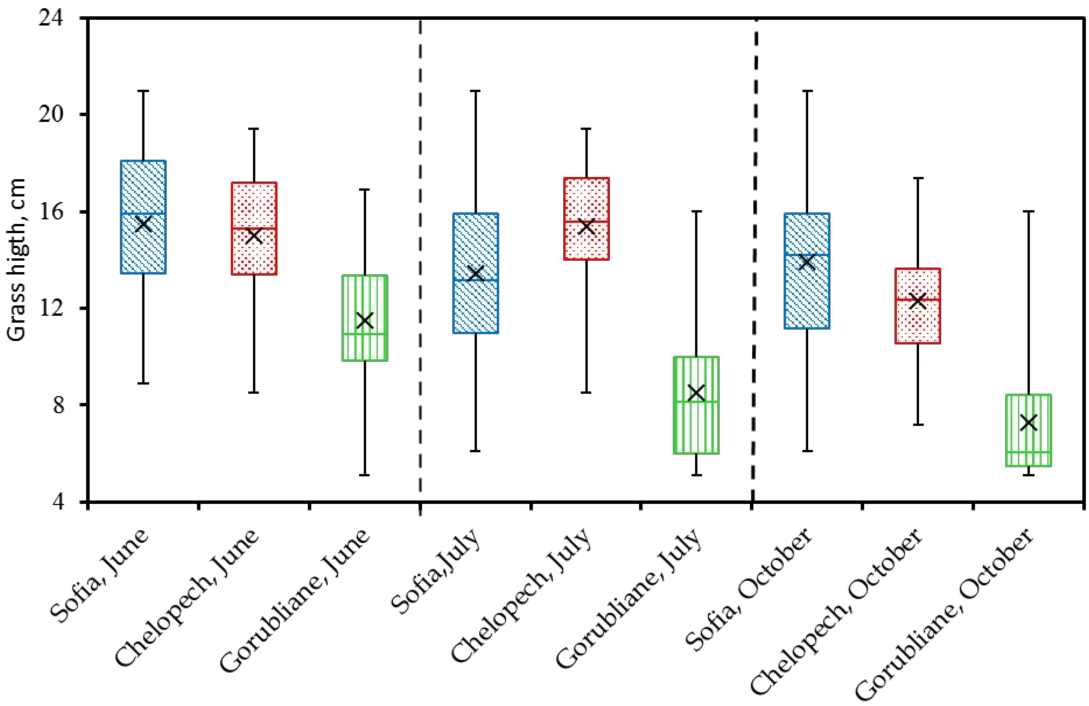

Fig. 3. Box plots of the grass heigth dataset: median (line across box), mean value (small cross in the box), minimum and maximum values (lower and upper ends of the whisker, respectively), interquartile range containing 50% of values (box)

Table. 4. Results from statistics - mean values of the grass height, difference between the mean values for each couple of datasets, p-values and critical difference. Legend: ns – no statistical significance, * - p<0.05; ** - p<0.01; *** - p<0.001.

Month	Soil, group 1	Mean values, cm	Soil, group 2	Mean values, cm	Difference between means, cm	p-Value	Critical difference, cm
June	Sofia	15.51	Chelopech	15.02	0.49	ns	1.89
	Sofia	15.51	Gorubliane	11.50	4.00	***	
	Chelopech	15.02	Gorubliane	11.50	3.52	***	
July	Sofia	13.44	Chelopech	15.40	1.96	ns	2.14
	Sofia	13.44	Gorubliane	8.54	4.90	***	
	Chelopech	15.40	Gorubliane	8.54	6.86	***	
October	Sofia	13.91	Chelopech	12.30	1.61	ns	1.76
	Sofia	13.91	Gorubliane	7.30	6.60	***	
	Chelopech	12.30	Gorubliane	7.30	5.00	***	

The content of clay in the soil of Gorubliane was higher than that of the two other soils. Higher clay content and higher soil reaction significantly reduced the amount of bioavailable for plants pollutants fraction.

Fig. 4 shows the ratio of fresh and dry plant biomass. In the wet months of June and July, this ratio for all three soils was in the range of 5.9 - 6.2. In October some of the grasses were dry, and for that reason the ratio was lower - in the range 2.1 - 2.8.

From the obtained results, it can be seen that on the growth of the grass at mineral waste used for recultivation, generating waters contaminated with heavy metals and metalloids, influences a whole complex of factors, determining the mineral nutrition of the plants, the water and air regime, the mobility of the pollutants and others.

The second phase of the study aims to estimate the amount of solar radiation passed through the plant layer, which together with the physicochemical composition leads to different soil heating and consequently influences the quantity and quality of the biomass vegetating on it.

The energy balance equation in its general form contains the following components:

$$(R+Q)(1-A)+L\downarrow-L\uparrow-G-H-\lambda E=F, \quad (1)$$

where R is the direct solar radiation, Q is the solar radiation diffused by the atmosphere, A is the surface albedo (the ratio of the reflected to the fallen radiation), $L\uparrow$ and $L\downarrow$ are respectively the values of the long-wave radiation emitted from the earth's surface and that one emitted from the atmosphere toward the earth's surface, G is the downward heat flux in the soil, H is the convective upward heat flux, λE is the hidden (latent) heat of water evaporation from the earth layer, F is the sun energy, which through photosynthesis has converted to the mass of plant cover for the period in consideration.

Due to the fact that the grass in all three pots was of the same type, it can be assumed with sufficient accuracy that the albedo would be the same for the three surfaces. Since the pots were exposed to the same weather conditions and to the same watering regime, it can be assumed that the vertical heat flux H and the soil moisture E in the three pots were also the same. Then, the part of the solar radiation absorbed by the plant layer was roughly equal to the difference between the radiation G passing through it and the radiation absorbed by the soil.

A fairly good evaluation of the heat flux in the soil can be made using the Fourier equation adapted to the conditions under consideration (CAMPBELL & NORMAN, 1998):

$$G=\frac{\sqrt{2}A_0\kappa}{d}G=\frac{\sqrt{2}A_0}{d},G=\frac{\sqrt{2}A_0}{d} \qquad (2)$$

where G is heat flux measured in $J/(m^2.s)$, A_0 is the temperature amplitude on the soil surface, κ is the thermal conductivity coefficient, d is the characteristic damping depth - the depth at which the soil temperature decreases e-times.

To determine the heat flux through the soil, the values of variables, which it depends on, must be successively measured or calculated.

The volumetric heat capacity c_v can be determined from the following equation

$$c_V=\frac{\kappa}{D_H}, \qquad (3)$$

The coefficient of thermal conductivity κ was measured by a suitable laboratory equipment.

The thermal diffusivity of the soils D_H was determined by measuring the temperature as a function of time t and depth z. If A_1 and A_2 are the temperature amplitudes of depths z_1 and z_2, respectively, then $A_i = (A_{i,\,max} - A_{i,\,min})/2$ and the thermal diffusivity is:

$$D_H=\frac{\pi\left(z_1-z_2\right)^2}{\tau\left(\ln\frac{A_1}{A_2}\right)^2}, \qquad (4)$$

where τ is the period of diurnal temperature changes (BROIDO, 1970).

The calculations of D_H are based on the soil temperatures evolution measured at two depths (z_1=5 cm; z_2=15 cm). The measured soil parameters needed to calculate the diffusivity are shown in Table 5.

The fluctuations of the soil temperature were measured with the thermologger.

After D_H was calculated, the values of c_v were also determined using equation (3).

The depth ($z_{T\,=\,const}$) at which diurnal temperature fluctuations were no longer noticed was calculated by the following equation (BROIDO, 1970):

$$z_{T=\text{const}}=385\sqrt{D_H}\lg\frac{A_0}{0,1}, \qquad (5)$$

where the temperature amplitude at the soil surface A_0 was determined experimentally.

The last variable to be determined is damping depth d. The equation used for this purpose is:

$$d=\sqrt{\frac{2D_H}{\omega}}, \qquad (6)$$

where $\omega = 7{,}3.10^{-5}\ s^{-1}$.

Table 6. represents the values of all quantities required to compute the heat flux G in the soils, as well as the values of the flux itself.

Taking into account that the average net radiation during the day of the experiments was about 350 W/m^2 for the radiation through the grass layer was obtained about 15 - 20%.

The following figure shows the dynamics of CO_2 emitted from the grass for the three pots and the background. One can see that after sunset the emission of CO_2 from grass grew to 470 ppm.

Let's determine the CO_2 flux from the grass in the pots under the initial conditions given in Table 7.

The CO_2 flux density produced by the grass cover overnight can be estimated with good approximation from equation (CAMPBELL & NORMAN, 1998):

$$F_{CO_2}=g_{CO_2}\left(C_c-C_a\right)F_{CO_2=g_{CO2}\left(C_C-C_a\right)}F_{CO_2=g_{CO2}\left(C_C-C_a\right)} \qquad (7)$$

where g_{CO2} is the conductance of the leaves at the specific weather conditions during the experiment – formula 8. Finally, by equation the CO_2 flow rate per unit of grass area can be determined under these meteorological conditions – formula 9. That means that one pot produced about 1.5 liters of CO_2 during the night.

$$g_{CO_2} = \frac{1}{\frac{1}{0,11\sqrt{\frac{u}{d}}} + \frac{1}{g_0}} = \frac{1}{\frac{1}{0,11\sqrt{\frac{2}{0,02}}} + \frac{1}{0,13}} 0,15\,\mathrm{mol/m^2}s. \quad (8)$$

$$F_{CO_2} = g_{CO_2}(C_c - C_a) = 0,15(470.10^{-6} - 420.10^{-6}) = 7,5\,\mu\mathrm{mol/m^2}s.$$
$$F = g_{co_2}(C_C - C_a) = 0,15(470.10^{-6} - 420.10^{-6}) = 7,5\frac{??mol}{m^2 s}. \quad (9)$$

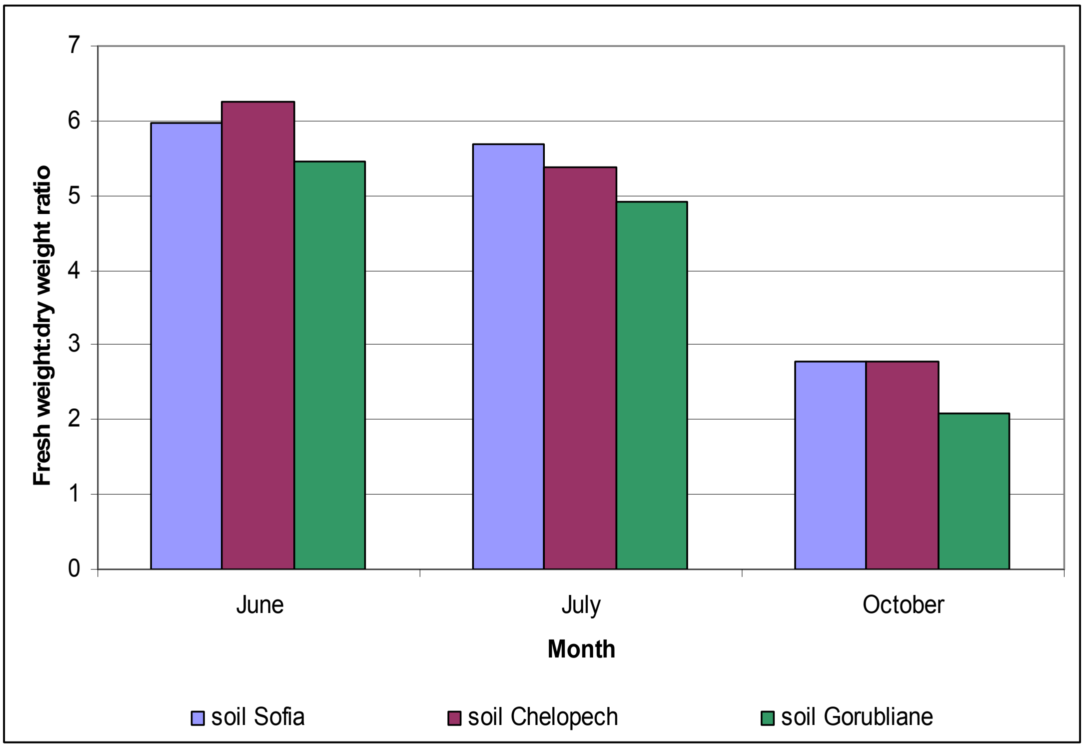

Fig. 4. Fresh-to-dry above-ground biomass ratio.

Table 5. Thermodynamic soil parameters.

Thermodynamic soil parameter	Pot 1	Pot 2	Pot 3	Pot 4	Pot 5
A_5 (°C)	8.5	7.7	7.8	8.6	8.5
A_{15} (°C)	2.5	2.5	2.8	3.2	3.2
κ, W/(m.K)	0.31	0.35	0.39	0.43	0.41
D_H, $m^2/s.10^{-7}$	2.43	2.87	3.46	3.72	3.81
c_V, MJ/m^3K	1.28	1.23	1.13	1.16	1.08

Table 6. Thermodynamic soil parameters.

Thermodynamic soil parameters	Pot 1	Pot 2	Pot 3	Pot 4	Pot 5
A_0, °C	9.5	9.8	10.2	11.5	11.3
d, m	0.08	0.09	0.098	0.1	0.102
$z_{t=const}$, m	0.38	0.41	0.46	0.48	0.49
G, W/m^2	52	54	57	70	65

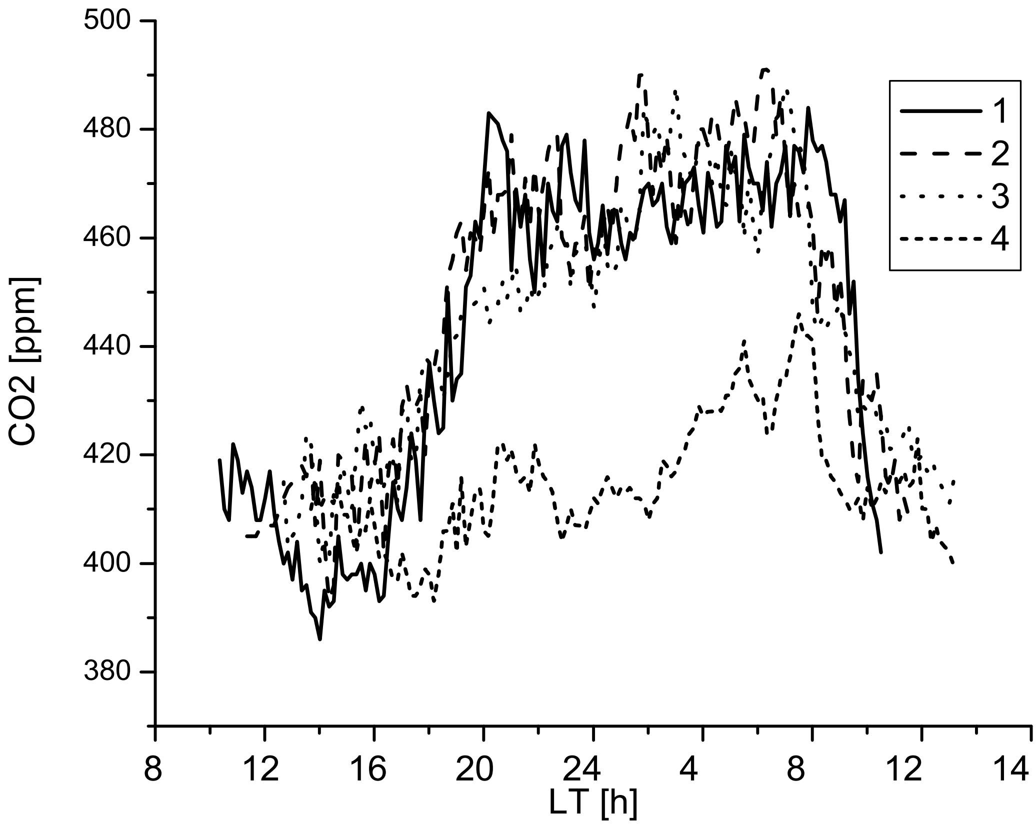

Fig. 6. Dynamics of CO_2 concentration in the volume of grass during the nigth. The curves 1, 2, 3 shows the dynamics of CO_2 concentration for pots 1, 2 and 3, respectively. The curve 4 indicates the evolution of the background CO_2 concentration.

Table 7. Initial conditions for CO_2 calculations.

Parameter	Value
Wind speed, u	2 m/s
CO_2 conductance of the grass leaves, g_0	0.13 mol/m^2.s
CO_2 background concentration, C_a	420 µmol/mol
CO_2 concentration in the grass volume, C_g	470 µmol/mol

Conclusions

The height of plants and their above-ground biomass in all measurements are lower than the plants growing on the soil from Sofia. With the smallest height and above-ground biomass was the grass grown on the soil of Gorubliane, characterized by a heavier mechanical composition with the lowest humus and nitrogen content;

Higher clay content and higher soil reaction values reduce in a significant manner the amount of bioavailable fraction of plant pollutants;

The ratio of fresh and dry plant above-ground biomass during the wetter months of June and July for all three soils is in the range of 5.9 - 6.2;

The coefficients of thermal conductivity and thermal diffusivity are bigger for soils with a higher rate of mineralization (Chelopech and Gorubliane);

The volumetric heat capacity is higher for soil with higher organic content (soil from Sofia);

About 15 - 20% of solar radiation passes through the grass layer;

At night, in the absence of photosynthesis and low wind, the grass of each pot emits about 1.5 liters of CO2.

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