Evaluation of the potential of rapeseed as green manure under conditions of elevated temperatures

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Abstract. Climate change affects all areas of human life, including agriculture. In agriculture, techniques have been developed and can be widely implemented to capture CO_2 from the atmosphere and reduce the carbon footprint of products, and, accordingly, the negative effects of climate change. One such approach is the use of green manure. In this paper, we assessed the CO_2 capture potential of rapeseed plants grown at different temperatures (20, 25 and 30°C) based on data on root growth, shoot growth, biomass increase, chlorophyll content and photosynthetic activity, in addition, the impact of rapeseed cultivation and increased temperatures on CO_2 emissions from the soil based on respiratory activity data. Elevated temperature (30°C) led to an increase in the length of rapeseed roots by 1.2–1.4 times, a decrease in shoot growth and biomass by 1.3–2.2 times, an intensification of photorespiration, and an increase in CO_2 emission from the soil by 1.5–2.5 times.

1 Introduction

Global climate change is projected to increase the frequency of particularly extreme events such as droughts, heat waves, flooding and storms. Such weather events will lead to a decrease in soil fertility, a decrease in productivity, and as a result, a decrease in the quality and quantity of agricultural products. The cause of climate change is the accumulation in the atmosphere of so-called greenhouse gases, which trap the sun's heat, re-radiate it and prevent it from returning back to space. The greatest contribution to global warming is made by CO_2, since it is produced in large quantities. Agriculture is a major source of GHG, contributing directly 14% of total global emissions [1, 2]. And changing the farming system can significantly reduce these emissions. The simplest approach is to use green manure, for example, grown after winter crops are harvested, which will reduce the emission of carbon in the form of CO_2 by bulk soil, capture its carbon in the form of plant biomass and return it to the soil [2–5]. Green manure fixes the atmospheric CO_2 and N_2 (when using leguminous GM) into biomass [6]. Vegetated soil is less exposed to water and wind erosion, its physical properties are improved [7]. It is important to note that the use of green manure leads to an increase in yield against the background of a decrease in the dose

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of chemical fertilizers applied [5, 8–10]. From the point of view of assessing the carbon footprint of plant products, an important factor is the increase in yield while reducing the dose of mineral fertilizers applied. A significant contribution to the carbon footprint of plant products is made by the use of mineral fertilizers, in particular nitrogen fertilizers. The production and use of nitrogen fertilizers is associated with the emission of N_2O into the atmosphere, which is also a greenhouse gas, while having a GWP of 273 times higher than that of CO_2 for a 100-year timescale [11]. In addition, a decrease in the dose of applied fertilizers leads to smaller amounts of field cultivation, and, accordingly, to a smaller amount of CO_2 emitted from the burned fuel. The effectiveness of the use of green manure fertilizers depends on the rate of growth of their biomass and the intensity of fixation of atmospheric N2 in the case of legumes. Quite often there was an assumption that an increase in ambient temperature is associated with an increase in the concentration of CO_2 in the atmosphere, which will lead to an increase in plant biomass, however, a number of studies in this area refute this thesis [20, 24–26]. The aim of the study was to determine the effect of ambient temperature on carbon fluxes in a model system when growing rapeseed as green manure.

2 Materials and methods

To assess carbon fluxes under changing climatic conditions, a vegetation experiment was carried out in a greenhouse at three temperature regimes: 20°C, 25°C, and 30°C. CO_2 content in the atmosphere (370-420ppm), illumination (light: dark 16h:8, light intensity 400-500 W/m^2), relative air humidity (50-55%), soil moisture (55-60% of total moisture capacity) maintained at the same level. During 45 days in the conditions of the greenhouse, the plants of spring rapeseed variety "Virage" were grown. For the cultivation of rapeseed, 3 containers sized 30*40*20 cm were used for each temperature regime. 10 kg of soil was placed in a container. Gray forest soil was used for the experiment. In the original soil, the pH, the content of $P_{soluble}$, $K_{soluble}$, N_{tot}, C_{tot}, particle size distribution were determined. To determine the content of total carbon and total nitrogen in soil, the dry combustion method was used according to DIN / ISO 13878 on the analyzer Elementar Vario MAX Cube (Germany) [12]. The mobile forms of phosphorus and potassium in the soil were determined by inductively coupled plasma spectrometry on an ICPE 9000 Shimadzu analyzer (Japan). The extraction of mobile forms of compounds of the elements was carried out using an ammonium acetate buffer solution with a pH of 4.8 according to ISO 27085-2012 [13]. Soil characteristics are shown in Table 1. Particle size distribution was determined using a BlueWave Microtrack laser diffractometer (USA) according to ISO 13320:2020 [14, 15].

Table 1. Soil characteristic.

Characteristic	Initial soil
pH	6.7±0.2
Ctot, %	4.14±0.11
Ntot, %	0.21±0.01
Psoluble, %	0.03±0.01
Ksoluble, %	0.07±0.01
Ferret particle size distribution	silty clayey loam (clay 30.52%, dust 75.43%, sand 0%)

On days 14, 21, 45, the morphometric parameters of plants (root length, stem length, biomass) and chlorophyll content were determined. The content of chlorophyll in the leaf epidermis was determined using a portable Force-A chlorophyll meter (Dualex) [16].

Emission of CO_2 from the soil was assessed by the level of soil respiratory activity according to ISO 16702:2002 [17] with the end on a gas chromatograph. On the 30th day, the intensity of photosynthesis was determined according to the method described by Zhou [18]. Photosynthesis intensity was measured on the 3rd fully expanded leaf on the main stem of four representative plants from each replication. For this, an open type gas exchange system (Li-Cor 6800, Li-Cor Inc., Lincoln, NE, USA) was used. All measurements were carried out for 5 minutes with a measurement interval of every 3 seconds.

All measurements were carried out at least three times. Statistical processing of the obtained results was carried out using Microsoft Office Excel 2010 (USA) and Statistica 10.0 software (StatSoft Inc., USA). All graphical data contain means and standard errors. The Mann–Whitney U Test and Kruskal–Wallis test were used to determine statistically significant differences ($p < 0.05$).

3 Results

In the dynamics of the vegetation experiment, the content of epidermal chlorophyll was assessed by fluorescent screening (Figure 1). The absence of significant differences ($p < 0.05$) in the level of chlorophyll content was established both in the dynamics of the experiment and for different temperature options. In rapeseed plants grown at 20ºC, the chlorophyll content varied in the range of 13-25 μg/cm^2, for plants grown at 25ºC, the chlorophyll content varied in the range of 13-27 μg/cm^2, for plants grown at 30ºC, the chlorophyll content varied in the range of 18-32μg /cm^2.

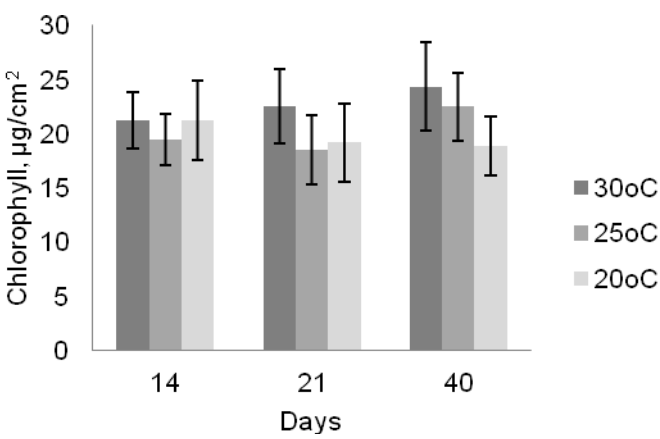

Fig. 1. The content of chlorophyll in the leaves of rapeseed grown under different temperature conditions.

Further in the dynamics of the vegetation experiment, the increase in root length (Figure 2, a), shoot length (Figure 2, b) and biomass (Figure 2, c) was estimated. It was found that during the entire vegetation experiment, the maximum root length was in rapeseed plants grown at 30°C; there was no significant difference between the lengths of the roots of plants grown at 20°C and 25°C ($p<0.05$). The maximum sprout length and plant biomass throughout the vegetation experiment was established for rapeseed grown at 25°C. According to the data obtained, plants grown at a temperature of 25°C were characterized by the maximum growth of roots (by 1.7 times), shoots (by 1.9 times), biomass (by 8.5 times) over 26 days of the vegetation experiment (from 14 for 40 days).

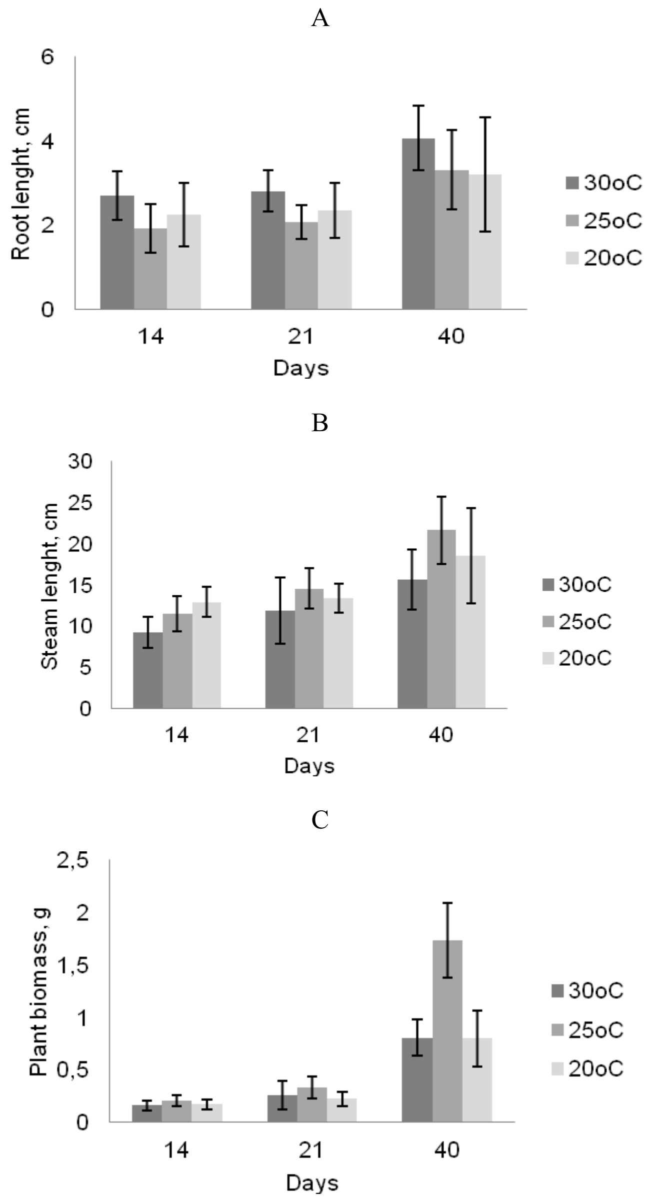

Fig. 2. Morphometric characteristics of rapeseed grown under different temperature conditions (a - root length, b - stem length, c - biomass).

On the 30th day, the intensity of photosynthesis was determined in rapeseed plants (Figure 3). According to the obtained data, the intensity of photosynthesis in plants, whose vegetation takes place at a temperature of 30ºC, varied from -98 to 333 $\mu mol/m^2*s$ with a median of 38 $\mu mol/m^2*s$. The intensity of photosynthesis in plants grown at 25°C and 20°C varied in a narrower range of 0–135 $\mu mol/m^2*s$ and -5–120 $\mu mol/m^2*s$, respectively. The median level of photosynthetic activity of rape plants grown at 25°C was 7.7, at 20°C it was 3.6 $\mu mol/m^2*s$.

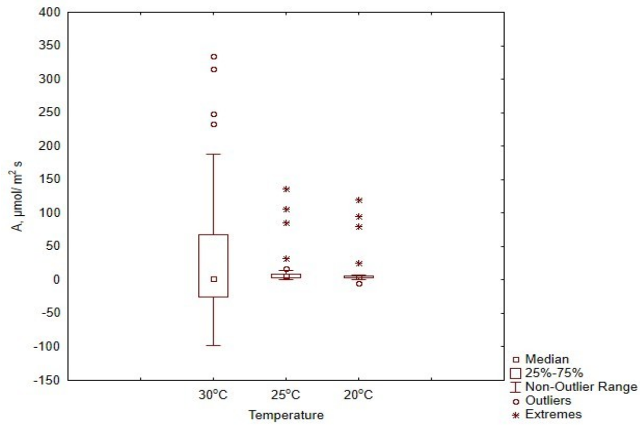

Fig. 3. The intensity of photosynthesis in rapeseed plants grown under different temperature conditions.

Further, an assessment was made of changes in the respiratory activity of the soil on which rapeseed plants were grown (Figure 4). According to the results obtained, the maximum respiratory activity of the soil was set on the 14th day of the experiment: 1.3 $mgCO_2$/g*h for the 30°C option, 1.1 $mgCO_2$/g*h for the 25°C option, 0.4 $mgCO_2$/g*h for the 20°C option. By day 21, respiratory activity decreases by 2.1-3.5 times. The respiratory activity of the soil did not differ significantly ($p > 0.05$) throughout the growing experiment for the variants of 25 and 30ºC. It should be noted that the level of soil respiratory activity at 20ºC significantly ($p < 0.05$) differed from the variants of 25 and 30ºC and was 1.3-5.3 times lower.

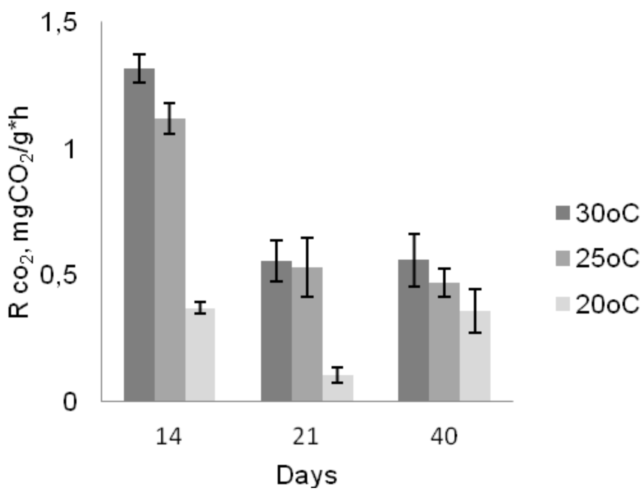

Fig. 4. Intensity of soil respiratory activity under rapeseed plants grown under different temperature conditions.

4 Discussion

According to IPCC data [19], the average global temperature is expected to increase by 2.6–4.8 °C by the end of the century, which will lead to significant changes in agriculture, namely, changes in crop yields. In this regard, not only the development of approaches to climate change prevention is relevant, but also the understanding of the consequences of climate change, ways to reduce the negative effect [20]. In this paper, we consider the effectiveness of using rapeseed as a green manure in terms of reducing the carbon footprint of plant products based on data on biomass growth and a decrease in soil respiration under different temperature conditions. Elevated temperature (30°C) led to an increase in the length of the roots by 1.2–1.4 times. Of the three studied temperature regimes, the optimal temperature for rapeseed growth is 25°C according to stem length and biomass data. However, it is worth noting the high correlation between stem length and plant biomass ($r = 0.91$). The use of the same type of soil, the same conditions of illumination and moisture in the dynamics of the growing experiment ensured the same absorption of nutrients by plants, which led to the absence of significant differences in the content of epidermal chlorophyll. It is known that the content of chlorophyll in plant leaves is an important parameter for understanding the physiological state and productivity of plants, as well as an important indicator for diagnosing the photosynthetic ability, the state of development and nutrition of vegetation [21]. At the same time, significant differences in the intensity of photosynthesis were established, due to the intensification of the process of photorespiration at a temperature of 30°C. It is known that photorespiration, in which O_2 is absorbed depending on the level of illumination and CO_2 is simultaneously released, is a powerful regulator of photosynthesis [22, 23]. An increase in the rate of photorespiration at high ambient temperatures leads to the inhibition of carbon assimilation and, accordingly, a decrease in the biomass of agricultural crops [20, 24–26]. In addition, an increase in ambient temperature can reduce not only the quantity but also the quality of the crop [20]. The increase in ambient temperature is associated with the activity of the soil microbial community. Thus, soil temperature and moisture are two main environmental factors affecting soil respiratory activity [27]. According to the data obtained, an increase in temperature in the vegetation experiment led to an increase in respiratory activity, the correlation coefficient between temperature and the level of respiratory activity is 0.76 - 0.94, while the maximum correlation was noted on the 14th day of the experiment. Thus, with an increase in temperature to 30°C, the emission of CO_2 from the soil increases by 1.5-2.5 times and the capture of C in the form of biomass of rapeseed plants decreases by 1.3-2.2 times.

5 Conclusion

Thus, an increase in ambient temperature leads not only to an increase in CO_2 emissions from the soil, but also to a decrease in the growth of plant biomass, which in turn leads to an increase in the carbon footprint of crop production.

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