Evaluation of the effectiveness of mustard (*Brássica júncea*) as a CO_2 sequestering agent at elevated temperatures

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Annotation. Preservation and increase of soil fertility is one of the main tasks of modern agriculture. The use of siderates is one of the technologies of ecologization of agriculture. In the framework of this study we evaluated the possibility of using mustard (*Brássica júncea*) as a CO_2 trap in conditions of elevated temperatures. It was shown that with increasing temperature from 20 to 30°C there is an increase in carbon fixation in the phytomass of plants. The maximum carbon fixation in mustard (*B. júncea*) phytomass was established at a temperature of 30 C and amounted to 439.5 kgC/ha.

1 Introduction

Today, special attention and solutions are needed for problems related to global changes in the natural environment, the reduction of biodiversity and the sustainability of ecological systems, and soil degradation. In recent decades, significant focus has been placed on the rising concentration of greenhouse gases in the atmosphere due to anthropogenic activities, as this increase contributes to the rise in environmental temperature [1]. The main greenhouse gases emitted from human activities are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), fluorinated gases (F-gases) [2]. The contribution of carbon dioxide to the greenhouse effect is about 80%, methane - 18-19%, the remaining 1-2% are nitrous oxide and other gases [3]. Agricultural intensification has put the agri-food sector of the economy on a par with the petrochemical sector in terms of environmental impact [1]. According to the Federal State Statistics Service of the Russian Federation, greenhouse gas emissions from the agro-industrial sector in 2021 amounted to 121.3 million tons of CO_2-eq/year. This is comparable to emissions from own industrial production and use of industrial products (259.5 million tons of CO_2-eq./year) [4]. In agriculture, nitrous oxide (N_2O) emissions occur mainly during the production and application of nitrogen fertilizers, as it is released as a by-product of nitrification and denitrification processes [5]. Methane (CH_4) is released during methanogenesis under anaerobic conditions in soils and manure stores, intestinal fermentation and incomplete combustion of organic matter [6]. Carbon dioxide fluxes are mainly due to uptake during photosynthesis by plants and release through respiration, including by soil heterotrophs, decomposition and combustion of

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organic matter [7]. Each year, CO_2 emissions from soil respiration into the atmosphere exceed the amount emitted from the combustion of fossil fuels by about 10 times the amount emitted from the burning of fossil fuels [8].

Greenhouse gas fluxes in the agro-industrial sector can be estimated through carbon balance. The carbon balance of ecosystems has been the subject of research to identify sources and sinks of atmospheric CO_2 in an attempt to develop strategies to reduce anthropogenic greenhouse gas emissions [9,10]. Annual crop ecosystems are very dynamic and pose different challenges than perennial forests and other perennial woody vegetation systems, especially in countries with variable climates [11]. Crop production on the one hand leads to the absorption of atmosphericCO_2, on the other hand the final fate of assimilated carbon depends on the nature and use of crop production, the management of crop residues, the capacity of the soil to store carbon [12]. In order to estimate the size of the carbon footprint, carbon balance calculations have been made to identify opportunities to optimize the distribution in the agricultural production chain [13]. Thus, it is necessary to continuously monitor the carbon balance in agriculture and assess its changes in the changing natural environment. The goal of reducing greenhouse gas emissions is to curb the increase in the annual average temperature on the planet and, as a consequence, to prevent climate change, which will have a negative impact on the agro-industrial sector. The approach of using siderates as green fertilizers is widely known [14]. Siderates are certain varieties of crops that, when grown, increase the amount of nutrients in the soil, stimulate soil microbiological activity, and help reduce pathogens. Cover crops or post-harvest residues help to improve and maintain a protective cover on the soil surface, e.g. after harvesting winter crops. Growing and tilling sidedress crops will capture carbon dioxide from the atmosphere and fix the carbon in plant biomass [15,16].

The objective of this study was to determine the possibility of reducing carbon dioxide emissions under a changing climate by growing mustard (*B. júncea*) to reduce the effects of climate change and increase soil organic matter content.

2 Materials and methods

To evaluate the efficiency of mustard (*B. júncea*) as a CO_2 trap under conditions of elevated temperatures, a vegetation experiment was established in the greenhouse of Kazan Federal University. Plant growth was carried out under constant conditions: day/night illumination period was 16/8 h, soil moisture was 40% of full moisture capacity, relative air humidity was 50-55%. Plant growth was carried out in three isolated rooms of the greenhouse, in which an individual temperature regime was maintained: 20°C, 25°C, and 30°C. To evaluate the effect of temperature on CO_2 sequestration, mustard morphometric indices (root length, stem length, biomass) were determined on 14, 21 and 40 days according to GOST R 59370-2021, on the 40th day - chlorophyll content using Force-A (Dualex) portable device [17]. Gray forest soil was used for plant cultivation, as this type is the most typical for soils of the Republic of Tatarstan. Soil pH, electrical conductivity according to GOST 26423-85 and total water holding capacity according to GOST 28268-89 were evaluated. Granulometric composition of the soil was determined using a laser diffractometer BlueWave Microtrack (USA) according to ISO 13320:2020.

According to the obtained data soil pH was 6.3±0.2, electrical conductivity EC 37.2±1.4 mSm/cm, water capacity 48.3±9.25 %, granulometric composition according to Ferre - dusty clay loam (sand - 20.5 %, clay - 13.5 %, dust - 66 %).

In this work CO_2 emission from the soil was evaluated by the level of soil respiratory activity according to ISO 16072:2002 with the end of the Nexis GC-2030 Shimadzu gas chromatograph (Japan) on 14, 21 and 40 days. All measurements were carried out not less than in threefold repetition. Statistical processing of the obtained results was performed using Microsoft Office Excel 2016 (USA). All data presented in the figures and table contain mean values and standard deviations (SD). The significance of differences was assessed using the Mann-Whitney test at $p < 0.05$ in the package Statistica 13.0 (Statsoft, USA).

3 Results

The efficiency of atmospheric carbon fixation in plant phytomass depends on the plant growth rate, one of the limiting factors affecting this process is the ambient temperature. At the first stage we evaluated the influence of ambient temperature on the growth of Sarepta mustard growing mustard of Sarepta (*B. júncea*). For this purpose, the length of root, stem and biomass of plants grown at 20, 25 and 30°C were determined on 14, 21 and 40 days of the experiment. The obtained data are presented in Figure 1 (a, b, c).

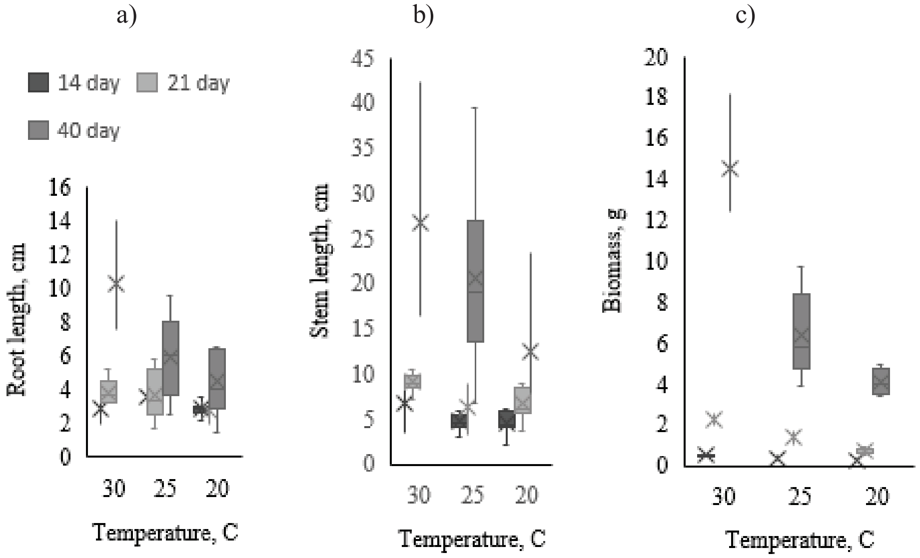

Fig. 1. Lengths of root (a), stem (b) and biomass of mustard (*B. júncea*) (c), at 14, 21 and 40 days of vegetation, grown at 30, 25 and 20°C.

The most significant increase in temperature affected the morphometric characteristics of mustard (*B. júncea*) on the 40th day of the experiment. It was found that root, stem and biomass length increased 2.3, 2.2 and 3.5 times with increasing temperature from 20 to 30°C ($p < 0.05$).

The physiological state of plants is characterized by the content of chlorophyll in leaves, at low chlorophyll content the process of photosynthesis is less efficient, which leads to a decrease in the efficiency of CO_2 capture from atmospheric air. Chlorophyll content did not significantly change either as a function of the duration of the experiment or as a function of the temperature of the growing experiment (Figure 2).

Temperature change has both direct effect on urine microorganisms and indirect effect due to changes in the development of plant root system. At the next stage we evaluated the effect of temperature on soil respiratory activity during growth of mustard on 14, 21 and 40 days of vegetation experiment, the data are presented in Figure 3. On the 14th day of the vegetation experiment soil respiratory activity was the lowest, the values of respiratory activity varied from 0.0015±0.001 $\mu gCO_2/m^2*h$ at 20°C to 0.005±0.003 $\mu gCO_2/m^2*h$ at 25°C. At 21 days, the highest value of soil respiratory activity was determined at 25°C

(0.024 ± 0.0045 $\mu gCO_2/m^2*h$). At the end of the experiment, an increase in temperature from 20 to 30°C resulted in a 4-fold increase in respiratory activity. To estimate the carbon balance on the basis of respiratory activity data, we calculated the amount of carbon emitted during soil respiration at different temperatures of mustard (*B. júncea*) vegetation (Figure 3). Thus, at 20°C, carbon emission amounted to 2.05 kgC/ha, increasing the temperature to 25 and 30°C led to an increase in carbon emission by 1.7 and 1.5 times, respectively.

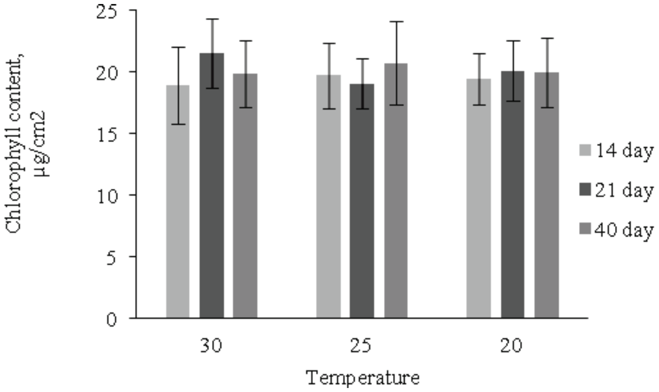

Fig. 2. Chlorophyll content in mustard (*B. júncea*) leaves grown under different temperature conditions.

Further we evaluated the efficiency of application of Sarepta mustard (*B. júncea*) as a CO_2 trap. For this purpose, we determined the carbon balance as the difference between the calculated values of the amount of carbon fixed in plant biomass and the amount of carbon released in the process of soil respiration during plant growth in different temperature regimes. The obtained data are presented in Table 1.

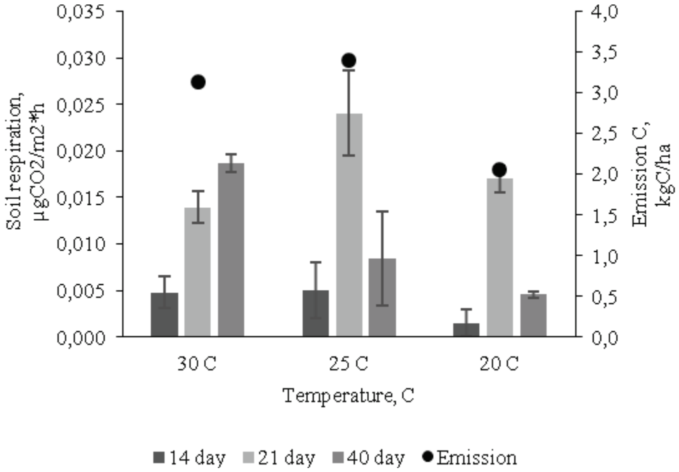

Fig. 3. Soil respiratory activity at 14, 21 and 40 days/carbon emission when mustard (*B. júncea*) was grown at different temperatures.

Table 1. Carbon balance of mustard (*B. júncea*) under cultivation at different temperatures.

Temperature, °C	C sequestration in mustard biomass, kg/ha	Carbon emission by soil respiration, kgC/ha	C balance, kgC/ha
30	442.6±15.59	3.13	439.47
25	255.8±35.78	3.40	252.4
20	132.7±5.97	2.05	130.65

4 Discussions

Today, there are various technologies to reduce the concentration of greenhouse gases in the atmosphere. Two methods of climate change mitigation are divided. The first group is aimed at preventing pollution before pollution occurs. The second group of methods is aimed at control and implies the use of processes and technologies that help to remove the generated pollution [18]. Wang D.D. (2017) identifies 5 classes of environmental technologies: the use of more energy efficient equipment; the introduction of low-carbon energy (biofuels, solar, wind); green design technology (use of more environmentally friendly materials); technologies to eliminate pollution at the end of processes through the use of various cleaning equipment; and technologies to implement effective management, reducing pollution at the initial stage through monitoring, the use of computing programs and human awareness [19].

Technologies such as no-till and reduced tillage, which minimize soil disturbance; agroforestry, in which trees and shrubs are integrated into agricultural landscapes, are classified as negative emission technologies that increase carbon sequestration by storing carbon in both above-ground biomass and soil; these practices help to preserve soil structure, reduce erosion and conserve organic matter, leading to increased carbon storage [20-21]. In addition to the above technologies, cover crops are also used. Cover crops are a promising and sustainable agronomic practice to improve soil health and crop yields in agroecosystems. Indeed, cover crops can regulate several ecosystem services such as nutrient cycling, soil fertility, mitigation of extreme weather events, pollination and climate and water regulation. Soil cover crops are also used as forage crops and have a significant impact on plant and soil biodiversity [22]. The use of siderate crops as ground cover crops contributes to the greening of agriculture. Siderate crops are considered as cheap, accessible, effective green fertilizers, which, if properly used, can be a renewable source of organic matter, contribute to the improvement of soil physical properties and the cultivation of sideral crops for fallow has a great potential [23-24].

An increase in ambient temperature has both positive and negative effects on plant growth, and these effects depend on many factors, such as the plant species, its adaptation to the conditions, the availability of moisture and nutrients, and the duration and degree of temperature increase. According to literature data, prolonged temperature stress leads to a decrease in biochemical processes and limitation of plant growth, especially in the initial stages of plant development. Thus, in a study by Virgilija Gavelienė et al. (2022), an increase in temperature from 25 to 30°C contributed to the reduction of lateral roots by 14 and 16 % for different species of lupin (*Lupinus polyphyllus*) [25]. For example, in Jitendra Kumar et al. (2016) showed that high temperature stress contributed to the decrease in lentil biomass, also due to insufficient accumulation of photosynthetic substances [26]. Similarly, high yield losses in legumes under heat stress have also been reported [27].

This study shows that an increase in ambient temperature from 20 to 30°C resulted in an increase in morphometric characteristics and biomass of mustard (*B. júncea*). The carbon balance, calculated as the difference between the amount of carbon captured by the phytomass of mustard (*B. júncea*) plants and the amount of carbon extracted from the soil during respiratory activity, was positive for all temperature regimes of vegetation. It was shown that with increasing temperature the efficiency of carbon sequestration in the phytomass of mustard (*B. júncea*) plants from 20 to 25°C increased by 1.9 times and from 25 to 30°C by 1.7 times. Thus, mustard (*B. júncea*) can be recommended for use as a sideral crop after winter wheat with subsequent stocking of phytomass in the soil to increase CO_2 capture from the atmosphere and increase organic matter in the soil.

5 Conclusion

Agricultural production, while providing the main food supply, also causes climate change, water pollution and biodiversity loss. Sustainable agricultural development is therefore an important aspect for global food security. Climate change leads to the need to implement modern methods of new technologies to reduce negative impacts. The use of plants adapted to higher ambient temperatures that can produce more biomass and positively affect soil fertility under changing conditions is an urgent task.

Based on the data of vegetation experiment, it is shown that the increase in temperature from 20 to 30°C led to an increase in carbon fixation in the phytomass of mustard (*B. júncea*) by 3.4 times. Thus, mustard (*B. júncea*) can be considered not only as a honey, oilseed and sideral crop, but also recommended as an effective carbon fixer under conditions of elevated temperatures.

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