Effect of cabbage species on CO_2 emission from soils in case of short-term green manuring of fallow fields in the Baikal region

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Abstract. The formation of the seasonal CO_2 flux depending on the species of cabbage crops used for short-term summer green manuring of the fallow field in the Baikal forest-steppe zone was studied. In field experiments on gray forest soil during the warm season, CO_2 emission rates per day were measured in options with white mustard (*Sinapis alba* L.) and oil radish (*Raphanus sativus* var. *oleifera* Metzg). The black follow served as the control. The total CO_2 flux from the soil was calculated by identifying different periods in the fallow treatment technology (before sowing green manure crops, vegetation, and the period after biomass plowing). An increase in the intensity of CO_2 release from the soil after the plowing of green mass was revealed. The enhancement of mineralization processes due to the newly received organic matter of mustard biomass was 27-100%, and radish - 48-142% in relation to the black fallow. The CO_2 emission data corresponded with the yield and quality indicators of the studied cabbage crops. It has been established that from the position of regulation of carbon dioxide fluxes, the use of white mustard for short-term green manure in the conditions of the region is more expedient than oil radish.

1 Introduction

The introduction of short-term green manure directly into the fallow field in the conditions of the forest-steppe zone of the Baikal region makes it possible to combine the positive properties of green manure and pure (black) fallows for regional farming. Green manure improves the physical properties of soils (structural composition, water and air regimes), and also increases the reserves of labile soil organic matter [1]. Black fallows effectively store moisture and improve the phytosanitary condition of fields [2].

The problem of greenhouse gases in agrocenoses is currently receiving considerable attention [3]. The factors regulating gaseous carbon losses from agricultural soils, as well as the possibility of its sequestration, are being actively studied [4]. Part of the research in this aspect is devoted to agricultural technologies, including green manure [5-7]. It has been shown that the timing, method, and depth of incorporation of the green manure crop biomass affect the value of the CO_2 flux [8, 9].

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Studies on the effect of short-term green manuring of a fallow field with cabbage crops on CO_2 emission from the soil are rare. The use of oil radish as green manure crop led to an increase in carbon losses after the plowing of fresh organic matter into the soil [10]. In the conditions of the forest-steppe zone of the Baikal region, the effect of increased losses depended on a complex of factors. Among the most significant are the qualitative characteristics of green mass, soil fertility and predecessor. The question remained open as to whether the species of cabbage crop will have an impact on the formation of carbon fluxes with a given farming method.

The task of the research is to study the features of CO_2 emission from gray forest soil during short-term green manuring of the fallow field by different species of cabbage crops in the conditions of the forest-steppe zone of the Baikal region.

2 Materials and methods

The studies were carried out at the agroecological station of the Siberian Institute of Plant Physiology and Biochemistry of the Siberian Branch of the Russian Academy of Sciences (53° 33'58.75" N and 102° 35'23.90" E). The territory is located in the northwestern part of the forest-steppe zone of the Irkutsk region. According to [11], the type of climate in this area is considered to be quite humid, with moderately warm summers. The sum of active temperatures (>10 °C) reaches 1732 °C, and their period lasts an average of 116 days. The long-term average (1981-2010) "norm" of precipitation from May to September is 235 mm. At the same time, about 60% of their total number falls on July-August.

Field experiments were carried out during 2015-2017, which differed in terms of heat and humidity. Conditions in 2015 turned out to be closer to the long-term average. In 2016, the period of dryness coincided with the sowing of green manure crops (3rd decade of June) and the beginning of the growing season. In 2017, a lack of precipitation, combined with low temperatures, was noted in August and September (the period after the plowing of biomass into the soil). But the growing season this year was favorable for the growth and development of plants.

The soil of the experimental plot is gray forest medium loamy (Greyic Phaeozems Albic [12]). The properties of the arable horizon are as follows: composition density - 1.0-1.2; C_{org} -1.5-2.1%; $N_{tot.}$ - 0.13-0.26%; pH_{H2O} - 6.9-7.1; pH_{KCl}, 5.8-6.0; the amount of exchange bases is 23.2-28.4 mg / 100 g.

Observations of CO_2 emission from the soil and recording the productivity of green manure crops were carried out in field experiments on the basis of the first field of a five-field crop rotation (fallow/short-term green manure fallow - potato - corn - wheat - barley; 1 rotation). Approaches to conducting experiments with short-term summer green manure of the fallow field and taking into account carbon fluxes in them are described in detail in [10]. The scheme of experiments included options: 1 – black fallow (control); 2 – short-term green manure of the fallow field by sowing white mustard (*Sinapis alba.* L.); 3 – short-term green manure of fallow field by sowing oil radish *(Raphanus sativus* var. *oleifera* Metzg.). The sowing rate for both crops was 2 million viable seeds per ha. The accounting area of each option in the experiment is 80 m^2.

Data processing was carried out using the statistical package SigmaPlot14.0. The normality of data distribution in the sample was assessed using the Shapiro-Wilk test. To identify differences between the options ($p \leq 0.05$), Student's t-test and One Way ANOVA followed by a multiple comparison procedure (Fisher LSD Method) were used. The tables and figures show the values-of the mean and standard deviation.

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3 Results

The intensity of carbon dioxide release from the soil in both options with green manure differed significantly ($p \leq 0.05$) from the traditional black fallow (Figure 1). The rate of CO_2 emission increased in the second half of the observation season, coinciding with the accumulation of biomass of green manure crops, as well as immediately after the plowing of green mass into the soil. In the option with oil radish, the indicators were generally higher than with white mustard. Thus, during the period of active vegetation of radish, the maximum values varied from 6.5 to 12.0, and in mustard from 4.9 to 10.6 g/m^2 day. Immediately after the plowing of the biomass (the first 2 weeks), the fluctuation limits also differed (5.8–7.1 and 4.1–6.6 g/m^2 day, respectively), but it was not always possible to confirm the differences statistically. By the end of the observations, the differences between the options were leveled, including in comparison with the control.

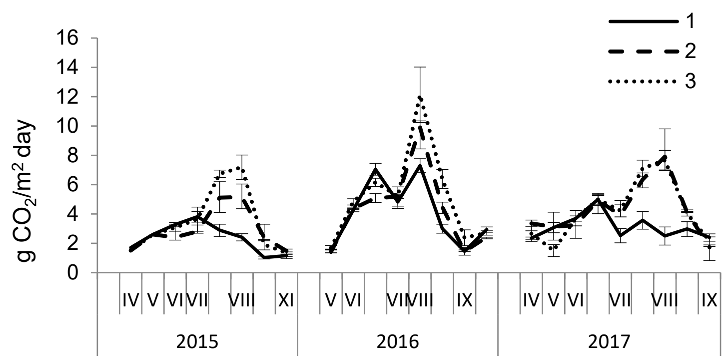

Fig. 1. Dynamics of CO_2 emission rate from the soil surface during short-term green manuring of the fallow field by different species of cabbage crops in experiments on gray forest soil of the Baikal forest-steppe zone. Options: 1 – black fallow (control), 2 - green manure by sowing white mustard; 3 - green manure by sowing oil radish.

An assessment of the total CO_2 emission, carried out separately for the periods "before sowing green manure", "vegetation" and "after plowing the biomass into the soil", clearly showed the differences between the options (Table 1). Relative to the black fallow, the total CO_2 flux during green manure increased precisely during the growing season of plants, as well as after their plowing into the soil in all years. At the same time, the indicators in the option with white mustard were lower than with oil radish. However, statistically significant ($p \leq 0.05$) differences in fluxes between the options with green manure crops during the growing season turned out to be only in 2015. In 2016, their value did not differ much between all options, including the control. The reason could be unfavorable conditions for the vegetation of plants (moisture deficiency, which led to sparse sowing). The total CO_2 flux after plowing of oil radish biomass significantly differed from that of mustard both in 2015 and 2016. Only in 2017, when the conditions for the decomposition of the incoming biomass turned out to be unfavorable (lack of heat and moisture), to confirm statistically the differences between the indicators in the options failed with green manure crops.

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Table 1. The total CO_2 emission from soil in field experiments with short-term green manure of the fallow field with different species of cabbage crops on gray forest soil of the Baikal region, g/m^2.

CO_2 emission for the period	2015			2016			2017		
	1	2	3	1	2	3	1	2	3
Before sowing	21±3^a	29±4^a	22±2^a	44±3^a	41±5^a	47±3^a	46±9^a	39±7^a	33±9^a
Vegetation	38±4^a	42±8^a	56±11^b	77±9^a	81±11^a	85±14^a	45±6^a	78±14^b	81±9^b
After plowing	28±4^a	56±14^a	68±12^b	49±6^a	62±8^a	77±15^b	42±4^a	57±3^b	62±3^b
Option: 1 - black fallow (control), 2 - green manure by sowing white mustard; 3 - green manure by sowing oil radish. Different letters indicate the differences ($p \leq 0.05$) between the options within the period of the study for each year.									

The yield of the above-ground mass of white mustard over the years of the study as a whole turned out to be lower than that of oil radish (respectively 1.0-2.0 and 2.1-4.8 kg/m^2; table 2). However, the differences were statistically significant only in 2016 and 2017, when the conditions for growth were significantly different. Due to the unequal provision of seasons with moisture in 2016, the minimum yield was obtained, and in 2017 - the maximum, and in both green manure crops. In the conditions of 2016, the yield of oil radish exceeded the indicators for mustard by 1.8, and in 2017 - by 2.7 times. At the same time, in all years, mustard was distinguished by a narrower ratio of above-ground mass/roots and a high content of dry matter in the aboveground mass, which was mainly confirmed statistically. In general, the studied crops had a number of quantitative and qualitative differences, which could affect both the contribution of root respiration to the CO_2 flux from the soil surface during the plant vegetation and the mineralization of plant organic matter in the soil after plowing.

Table 2. The parameters of the biomass of cabbage crops accumulated over 35-40 days from sowing, in field experiments with short-term green manuring of the fallow field on gray forest soil of the Baikal region (n = 4).

Year	Cabbage crop	Above-ground mass, kg/m^2 (wet weight)	Above-ground mass/root ratio	Dry matter in the above-ground mass, %
2015	Mustard white	2.10±0.60^a	7.6±0.3^a	13.4±0.5^a
	Oil radish	2.78±0.74^a	9.7±2.1^a	9.7±1.0^b
2016	Mustard white	1.10±0.19^a	5.8±0.5^a	11.1±2.5^a
	Oil radish	1.96±0.42^b	8.2±0.4^b	6.8±1.0^b
2017	Mustard white	1.69±0.33^a	6.3±0.9^a	15.1±4.0^a
	Oil radish	4.54±0.40^b	8.9±1.2^b	7.9±1.2^b
Different letters show the differences ($p \leq 0.05$) between the options within the year of the study.				

4 Discussion

The increase in the total CO_2 flux during the growing season of the studied crops relative to the black fallow is a consequence of the respiration of roots and rhizosphere microflora [13]. As shown, the intensity of carbon dioxide emission processes in the option with mustard was lower than in radish. The yield indicators of the studied crops changed in a similar way. The contribution of roots to the CO_2 flux in white mustard could be corrected due to a narrower ratio of aboveground mass/roots, but, apparently, in comparison with oil radish, it remained generally smaller. It is impossible to exclude the dependence on the species of field crop and parameters of rhizosphere respiration. However, this is a task for further research.

The increase in CO_2 emission in the period after the plowing of green mass into the soil, regardless of the cultivated crop, confirmed the earlier revealed increase in gaseous carbon losses from the soil under the influence of short-term green manure [10]. However, according to the calculations (Table 3), the increase in CO_2 emission over this period in relation to the black fallow in the option with white mustard in all years turned out to be less than with oil radish (27-100% and 48-142%, respectively). Accordingly, the effect of enhancing mineralization processes from the plowing of white mustard biomass was less pronounced than from oil radish. The reason could be not only the lower yield of mustard, but the difference in quality of the incoming biomass. The role of qualitative characteristics of plant residues when they are included in the processes of mineralization-immobilization has been repeatedly pointed out [14]. It is known that shoots of plants are mineralized more actively than roots [15]. According to our data, the ratio of the above-ground part to the roots of white mustard was narrower. Consequently, after plowing, the soil of this option received a more significant part of the hardly mineralizable biomass. The above-ground part of white mustard had a higher content of dry matter, which could also contribute to the formation of CO_2 flux from the soil. Previously, it was shown that the water content of green manure tissues negatively correlates with its value [10].

Table 3. The enhancement of the mineralization processes in the period after the plowing of green mass cabbage crops into the soil.

Year	Cabbage crop	Total emission of C-CO_2 for the period after plowing, g/m^2		Delta C-CO_2 (GM - BF), g/m^2	Increase of C-CO_2, %
		Green manure (GM), g/m^2	Black fallow (BF), g/m^2		
2015	Mustard white	56±14^a	28±3	28	100
	Oil radish	*68±12^b		40	142
2016	Mustard white	62±8^a	49±6	13	27
	Oil radish	*77±15^b		28	57
2017	Mustard white	57±3^a	42±4	15	36
	Oil radish	*62±3^a		20	48

[a]the indicator differs from the option with black fallow at $p \leq 0.05$. Different letters indicate statistically significant differences ($p \leq 0.05$) between the options within the year of the study.

5 Conclusion

Thus, the species of cabbage crops influenced the formation of the CO_2 flux from gray forest soil during short-term green manure of the fallow field in the conditions of the forest-steppe zone of the Baikal region. The rate of CO_2 emission under white mustard sowing was generally lower than under oil radish sowing. After the green manure biomass was plowed into the soil, the differences between the options became more distinct. The increase in the total CO_2 flux over this period in relation to the traditional black fallow in the option with white mustard in all years turned out to be less than with oil radish (by 27-100% and 48-142%, respectively). Accordingly, the enhancement the processes of mineralization from the plowing of white mustard biomass in comparison with oil radish turned out to be less pronounced. The reasons may be not only the lower yield of mustard, but also the qualitative characteristics of the planted biomass. From the standpoint of regulation of greenhouse gas flows through agricultural practices, the use of white mustard for short-term green manure of a fallow field in the conditions of the forest-steppe of the Baikal region is more expedient than oil radish.

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