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Influence of Camelina crops on soil CO_2 emissions

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Abstract. The Green Deal poses different challenges for EU agriculture, and this production will cost more and will be reflected on the global market once agriculture is included in the emissions trading system. Sustainable land management will be crucial to achieving the EU's climate neutrality target by 2050, as it will increase the amount of carbon captured and stored in plants and soils. Agriculture's role in carbon sequestration is most closely linked to soil as a carbon sink. Soils have the potential to act as significant carbon sinks, storing carbon that would otherwise be released into the atmosphere as CO_2. Through practices such as cover crops, reduced tillage, and organic farming, farmers can improve soil carbon sequestration, contributing to climate mitigation efforts. The aim of the present study was to track the dynamics of soil CO_2 emissions during the vegetation of Camelina in different intercropping systems and, on this basis, to evaluate the possibilities for sustainable management of carbon in the soil. After the three-year studies, we can recommend the use of Camelina as monocultures and especially in mixed crops with legumes as a step towards sustainable management of CO_2 emissions and towards the so-called carbon agriculture. This approach has the additional advantage of biologically nourishing the soil with nitrogen, as well as creating more favorable conditions for the development of the soil microbiome.

Key words: greenhouse gases, climate change, agriculture, European Green Deal, Fit for 55 package.

Introduction

Greenhouse gas emissions are accelerating climate change, which is why the European Union has committed to reducing them by 55% by 2030 through the "Fit for 55" package (EU, 2019a). It includes proposals for amendments to existing legislation and new proposals in the areas of climate and energy, which, together with the European Climate Law (EU, 2021), are part of the European Green Deal - the EU's roadmap towards net zero emissions (EU, 2019b).

The Green Deal poses different challenges for EU agriculture, and this production will cost more and will be reflected on the global market once agriculture is included in the emissions trading system. Sustainable land management will be crucial to achieving the EU's climate neutrality target by 2050, as it will increase the amount of carbon captured and stored in plants and soils.

Carbon dioxide (CO_2) is the greenhouse gas emitted in the largest quantities by various types of anthropogenic activities (Kweku et al., 2018). Energy supply is responsible for 27.4% of greenhouse gas emissions in the EU in 2022, while inland transport is responsible for 23.8% of emissions. Greenhouse gas emissions from the industry sector account for 20.3%, commercial services and households for 11.9% and agriculture for 10.8% of greenhouse gas emissions (Eurostat, 2022). On the other hand, land use, land use change and forestry contribute to reducing emissions as plants absorb carbon dioxide and other gases, with the sector's positive impact accounting for 7% of total emissions.

The agricultural sector is increasingly recognized as an important player in global climate action (COM, 2020). As the world grapples with the challenges of climate change, the concept of carbon markets has emerged as a powerful tool to incentivize and reward sustainable agricultural practices. Agriculture's role in carbon sequestration is most closely linked to soil as a carbon sink. Soils have the potential to act as significant carbon sinks, storing carbon that would otherwise be released into the atmosphere as CO_2. Through practices such as cover crops, reduced tillage, and organic farming, farmers can improve soil carbon sequestration, contributing to climate mitigation efforts. Healthy soils not only store more carbon, but also improve water retention, reduce erosion, and increase yields, offering multiple benefits (Mielcarek-Bocheńska & Rzeźnik, 2021).

Camelina [*Camelina sativa* (L.) Crantz], also called false flax, linseed dodder, or gold-of-pleasure is an oilseed crop in the Brassicaceae family. Camelina's adaptation to vast areas of the world, combined with its unique oil composition and properties useful for the production of biofuels, jet fuel, biobased-products, feed, and food has resurfaced interest in this ancient crop (Berti et al., 2016). In recent years, the cultivation of camelina has increased due to its short vegetation season, modest agricultural and environmental requirements, high seed and biomass yield, high seed oil content, high polyunsaturated fatty acids content in the oil, and multiple uses (Veljković et al., 2022). An advantage of camelina as a biodiesel is its low greenhouse gas emission, 75–80% less than petrofuels (Moser, 2010).

The aim of the present study was to track the dynamics of soil CO_2 emissions during the vegetation of Camelina in different intercropping systems and, on this basis, to evaluate the possibilities for sustainable management of carbon in the soil.

Materials and methods

Experimental design

The study was conducted on the territory of the Experimental Base of the Agricultural University-Plovdiv within the framework of the SCOOP project activities in the period 2022-2024 (three-year experimental studies).

A total of 11 experimental variants were studied, each of which was set in three repetitions. Five of them are monocultures - Camelina K1 variety Luna, Camelina K2 variety Lenka, Camelina K3 Local variety, Pea and Vetch. The remaining six variants are mixed crops of the three varieties of Camelina and, respecttively, pea or vetch - K1+Pea, K2+Pea, K3+Pea, K1+Vetch, K2+Vetch, K3+Vetch.

Field surveys

Measurements of CO_2 emissions from the soil were carried out periodically during the crop vegetation period (April-May 2022, March-May 2023, March-June 2024), according to the main phenological phases of crops development. The measurement of the carbon dioxide release was carried out using a portable measuring device Q-box CO650, Qubit Systems Inc., Canada, equipped with a CO_2 sensor (Fig. 1).

Fig. 1. Measurement of CO_2 emissions from soil (with and without vegetation) using a portable measuring device Q-box CO650, Qubit Systems Inc., Canada (May, 2024).

In parallel, soil temperature and humidity values were measured using a portable Soil Humidity Meter TR 46908 (Turoni, Italy), as they are key factors influencing the activity of soil microorganisms.

Statistical evaluation

Raw data have been processed by descriptive statistical analysis, t-test (dependent samples), and Pearson rank correlation. All analyses were performed with the software package Statistica 7.0 (Statsoft Ltd, 2004) and/or SPSS 21 (IBM Ltd., 2023).

Results and Discussion

In 2022, the CO_2 emissions from the soil in the 11 experimental variants ranged from 739.98 ppm (Vetch) to 1019.22 ppm (Vetch), i.e. the lowest and highest concentrations were recorded in the monoculture of vetch, with an average value of 875.70 ppm. Higher CO_2 emissions from the soil were recorded in the monoculture of Camelina K2 Lenka (854.58 ppm), as well as the mixed culture of Camelina K2 Lenka + Pea (853.76 ppm) and Camelina K2 Lenka + Vetch (850.44 ppm), which is an indication of more intensive microbial processes in the soil rhizosphere.

The analysis of the obtained data on CO_2 emissions in 2022 shows a slightly pronounced decreasing trend ($p<0.05$) with increasing soil temperature during the vegetation (from 11°C in April to 21°C in June 2022). A number of authors indicate that at higher temperatures (about 20°C) and in the presence of sufficient humidity (about 60%), the metabolic activity of soil microorganisms increases, which leads to increased emissions of CO_2 released during respiration and decomposition of organic matter. A possible explanation for our results could be sought in the impact of crops, which manifests itself in two directions - suppression of microbial activity or capture of released CO_2 through the photosynthesis process.

The total amount of CO_2 emissions from soil + vegetation gives an idea of the potential of the plant cover on the soil to sequestrate CO_2 released during soil respiration thanks to the photosynthesis process and to include it in the synthesized biomass. This contributes to the reduction of greenhouse gases released into the atmosphere and is considered one of the mechanisms for their sustainable management. The greatest effect on CO_2 reduction of the studied experimental variants was demonstrated in the mixed crops of Camelina K2 Lenka + Pea, as well as Camelina K2 Lenka + Vetch, as well as the monoculture of Camelina K2 Lenka ($p<0.05$). The other two tested Camelina varieties have a weaker CO_2 reduction coefficient in monoculture, but in mixed crops they also show good results ($p<0.05$), of which Camelina K1 Luna is better.

In 2023, the CO_2 emissions from the soil in the 11 experimental variants ranged from 1723 ppm (Vetch) to 2039.56 ppm (Camelina K1 Luna), with an average value of 1765.74 ppm. The highest CO_2 emissions were recorded from the soil in the Camelina monoculture from all three varieties, followed by the Pea monoculture and the Vetch monoculture.

The analysis of the data obtained in 2023 on CO_2 emissions from soil respiration in the studied periods shows a clearly pronounced increasing trend ($p<0.05$) with increasing soil temperature during the vegetation period (from 9.7°C in March to 20.31°C in May).

When comparing the arithmetic mean values for CO_2 emissions from bare soil and soil + vegetation, it is proven that they progressively decrease with the increase in the aboveground biomass of cultivated plants, that is, with an increase in their photosynthetic surface - the difference in CO_2 in March is 35.34 ppm, and the difference in CO_2 in May is 139.87 ppm ($p<0.05$).

The greatest effect for CO_2 capture of the studied experimental variants was found for monoculture Vetch, monoculture Camelina K1 Luna and monoculture Camelina K2 Lenka, with data from mixed crops of Camelina K3 + Pea, as well as Camelina K1 Lenka + Pea, as well as Camelina K2 Lenka + Vetch ($p<0.05$). The other two tested varieties of Camelina have a lower CO_2 capture coefficient in monoculture, but in mixed crops they also show good results ($p<0.05$), with Camelina K1 Luna being the best. Overall, the reduction in carbon dioxide emissions in the initial phases of crop vegetation ranges from 2.10 to 5.25%, with an average of 3.26%, while in May the reduction is in the range of 4.45 to 11.13%, with an average of 8.35% (Fig. 2). The most stable results in reducing emissions are observed with Camelina variety Lenka both in monoculture and in mixed crops with vetch and peas.

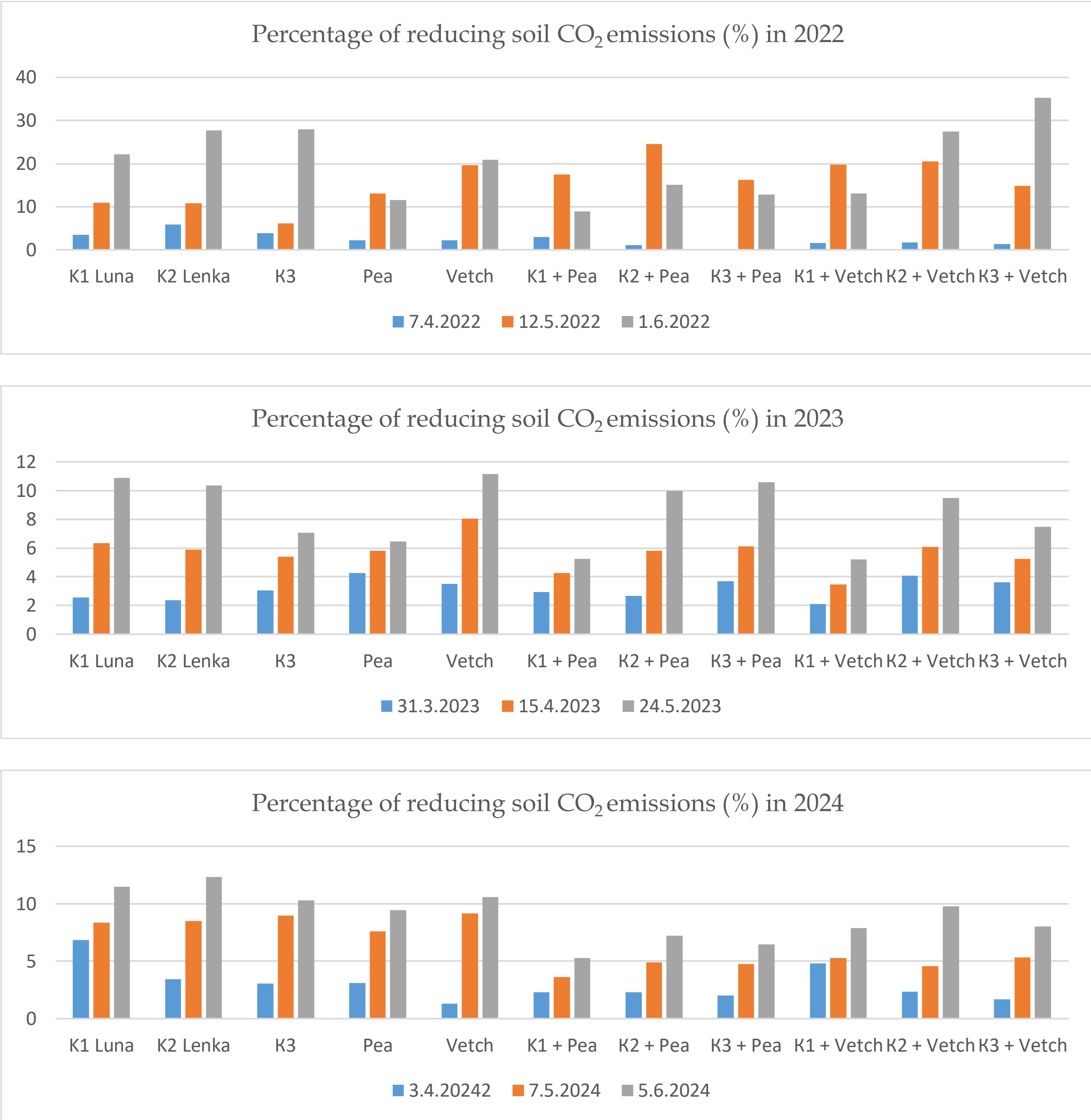

Fig. 2. Potential of Camelina for reducing CO_2 emissions during crop growth.

In 2024, the CO_2 emissions from the soil in the ranged from 1698 ppm (Camelina K3 + Pea) to 2065 ppm (Camelina K1 Luna). The highest CO_2 emissions were recorded from the soil in the Camelina monoculture and all three varieties, followed by the Vetch mono-culture.

When comparing the arithmetic mean values for CO_2 emissions from bare soil and soil + vegetation, it was confirmed that they progress-sively decrease with the increase in the above-ground biomass of cultivated plants, that is, with an increase in their photosynthetic surface - the difference in CO_2 in March is 47.65 ppm, and the difference in CO_2 in May is 141.67 ppm ($p<0.05$).

The greatest effect for CO_2 capture of the studied experimental variants was found for the monoculture of Vetch, monoculture of Pea and monoculture of Camelina K2 Lenka, followed by the mixed crops of Camelina K1 Luna + Pea, Camelina K2 Lenka + Pea, Camelina K1 Luna + Vetch and Camelina K2 Lenka + Vetch ($p<0.05$). The remaining variety Camelina K3 has a weaker coefficient of CO_2 capture both in monoculture and in mixed crops.

Overall, the reduction of carbon dioxide emissions in the initial phases of crop vegetation ranges from 2.24 to 5.28%, with an average of 3.77%, while in May the reduction is in the range of 5.00 to 7.82%, with an average of 6.41%. The most sustainable results in reducing emissions are observed again with Camelina K2 Lenka both in monoculture and in mixed crops with vetch and pea.

Statistical processing of the results for the three years of the experiment (2022-2024) shows a significant reduction in CO_2 emissions from plant cover on the soil ($p<0.05$) (Table 1).

Table 1. Test for significant differences between CO_2 emissions from bare soil and soil+vegetation

		Paired Differences					t	df	p
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Soil – soil + vegetation 2022	150.73	44.07	13.29	121.13	180.34	11.343	32	0.001
Pair 2	Soil – soil + vegetation 2023	151.43	47.25	14.25	119.69	183.17	10.630	32	0.001
Pair 3	Soil – soil + vegetation 2024	115.76	39.62	6.89	101.71	129.81	16.786	32	0.001

Carbon capture through agricultural methods can be defined as an environmentally friendly business model that rewards land managers for implementing better land management practices, which leads to an increase in carbon absorption in living biomass, dead organic matter and soils by increasing carbon capture and/or reducing carbon emissions to the atmosphere, while respecting ecological principles that favor biodiversity and natural capital in general.

Carbon capture through agricultural practices would be a new source of income for land managers, who in many cases could simultaneously benefit from the benefits of more productive and sustainable land. Furthermore, carbon capture practices through agricultural practices often have co-benefits for biodiversity, enhance ecosystem services and help land managers to be more resilient to climate change.

Financial incentives can come from public or private sources and reward land managers for their management practices that increase atmospheric carbon storage or the actual amount of carbon sequestered. This is particularly relevant as low-carbon foods can have a recognized added value that can create a competitive advantage for land managers implementing carbon capture practices through agricultural practices.

Conclusions

As a result of the three-year field experiments in different intercropping systems with Camelina, the following important conclusions can be drawn:

1) The three tested Camelina varieties (Luna, Lenka and K3) are suitable for growing in Bulgaria as monocultures.

2) Mixed crops of Camelina with legumes (peas and vetch) create more favorable conditions for soil rhizosphere microbial communities, which is proven by the measured higher intensity of soil respiration.

3) Mixed crops of Camelina and legumes have better abilities to reduce carbon emissions compared to monocultures of these species.

4) Of the three studied Camelina varieties, more sustainable results in the three years of testing are obtained with mixed crops of Camelina K2 Lenka, followed by Camelina K3, although in 2023 the monoculture Camelina K1 Luna had the highest carbon sequestration coefficient.

In conclusion, we can recommend the use of Camelina as monocultures and especially in mixed crops with legumes as a step towards sustainable management of CO_2 emissions and towards the so-called carbon agriculture. This approach has the additional advantage of biologically nourishing the soil with nitrogen, as well as creating more favorable conditions for the development of the soil microbiome.

This study on the CO_2 sequestration potential of Camelina is one of the first of its kind, not only nationally but also globally. It highlights the contributions of the funding project, both methodologically and practically, to addressing the challenges facing agriculture in achieving the climate neutrality objectives set out in EU policies.

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