

## THE IMPACT OF CROP ON GHG EMISSIONS FROM CLAY SOILS: CASE STUDY OF LATVIA

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### Abstract

Agriculture is a source of three primary GHG: CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O. In order to reduce agricultural GHG emissions, agricultural practices have to promote sustainable land management by helping to prevent soil erosion and creating the potential to increase soil carbon stock. Sustainable soil management includes reducing tillage and introducing legumes in crop rotation. The aim of the study is to identify the impacts of the soil tillage and the cultivated crops on formation of GHG emissions. The study site has 24 experimental fields where two types of soil tillage have been used and four crops were grown (wheat *Triticum aestivum*, rape *Brassica napus*, beans *Vicia faba* and barley *Hordeum vulgare*). Soil humidity, soil temperature and measurements of GHG emissions have been carried out during the plant vegetation period from 2018 to 2020. GHG emissions were measured using Picarro G2508. A total of 460 measurements of GHG emissions were made in 2018, 2019 and 2020. The minimum value of N<sub>2</sub>O emission is -19.5 g ha<sup>-1</sup> day<sup>-1</sup>, but the maximum is 273.4 g ha<sup>-1</sup> day<sup>-1</sup>. CH<sub>4</sub> emission has a minimum value of -84.8 g ha<sup>-1</sup> day<sup>-1</sup>, and a maximum of 514.1 g ha<sup>-1</sup> day<sup>-1</sup>. The minimum value of CO<sub>2</sub> emission is -13.0 kg ha<sup>-1</sup> day<sup>-1</sup>, but maximum of 1026.7 kg ha<sup>-1</sup> day<sup>-1</sup>. The results of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions show a significant discrepancies between the arithmetic mean and the median values which indicates the observed extreme values. Kruskal-Wallis test showed statistically significant differences in GHG emissions by crop groups.

**Key words:** GHG emissions, crop production, soil tillage, agriculture GHG emissions.

### Introduction

In line with the 17 Sustainable Development Goals set by the United Nations, the world population must be able to provide while reducing GHG emissions and reaching climate neutral economy. These objectives should be achieved through transforming existing approaches of farming practices (Sachs *et al.*, 2019). Crop production occupies 12–14% of the available land area. Since 1961, the amount of food calories per capita has increased by about a third, while consumption of vegetable oils and meat has doubled. At the same time, the use of inorganic nitrogen fertiliser has grown nearly nine times (Arneeth *et al.*, 2019).

The development of the economy, including agricultural production, will inevitably lead to an increase in atmospheric GHG emissions. In order to reduce the environmental impact on agriculture, it is necessary to understand the effect of soil management and the role of soil in the context of GHG emissions (Valujeva *et al.*, 2016; Valujeva, Nipers *et al.*, 2020; Valujeva, Pilecka *et al.*, 2020) increase in bio-based production is restricted by emission reduction targets set by climate policies. Meanwhile, the changes in Common Agricultural Policy after 2020 offer each Member State to develop targeted and regional specific policies to meet socio-economic and environmental targets at national scale. Sustainable land management requires understanding of trade-offs among multiple demands expecting from agriculture, land use, land use change and forestry sectors. Shifting

from customary crops to crops with higher economic return can give immediate contribution to achieve socio economic targets, but at the same international commitments require maintenance of existing carbon stocks and increase of carbon sequestration capacity which can be achieved by changing farming practices. South-eastern region of Latvia is chosen as a relevant case study to show trade-offs between simultaneous increase in both bio-based production and carbon stock. The aim of the study is to find optimal approach for land use and improvements of management practices in south eastern region of Latvia to simultaneously increase bio based production and carbon stock. We use spatial land use model under different optimisation scenarios. Results show that production can be increased by 35.1%, while carbon regulation function kept constant, but this rises another problem as it has a negative impact on the supply of biodiversity (-9.2%). Agriculture is a source of three primary GHG emissions: CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O. GHG emissions are caused by fermentation processes in the intestines of livestock, manure management, soil management, liming, use of urea. In Latvia, agriculture is the second largest sector behind energy, which contributes to GHG emissions, and soil management is the largest emitter of N<sub>2</sub>O emissions – 60.8% (NIR, 2019). Agricultural soils are responsible for 18% of global GHG emissions (Ozlu *et al.*, 2018). Soil emissions depend on the biophysical processes of the soil and the uptake and decomposition of organic substances in the soil. The

main GHG sources are the use of organic and synthetic fertilisers. Nitrogen fertilisers are important for crop production, but the excessive use of fertilisers may increase GHG emissions. Inorganic fertilisers affect GHG emissions from soil, affecting microbial activity and root respiratory processes that affect nitrification and denitrification processes (Ozlu *et al.*, 2018). High ground water levels, poor soil drainage properties and soil sealing contribute to denitrification and N<sub>2</sub>O formation (Bouwman *et al.*, 2002). CO<sub>2</sub> is produced under aerobic conditions and is affected by root activity, microbiological processes, plant residues, as well as microclimate, terrain and catalytic properties in colloid solutions of clay (Muñoz *et al.*, 2010). In order to reduce GHG emissions from agriculture and their impact on global warming, agricultural practices need to ensure sustainable land management. Such practices include reducing soil tillage, which helps to prevent soil erosion and creates potential to increase soil carbon stock and can improve CH<sub>4</sub> consumption (Johnson *et al.*, 2007). Although agriculture generates a significant share of global GHG emissions, it can also contribute to climate change mitigation, as a crop rotation has the potential to reduce or at least not generate more GHG emissions from agriculture (Plaza-Bonilla *et al.*, 2018). Introduction of crop rotation in agricultural lands is considered to be a good solution to increase carbon stock (Poeplau *et al.*, 2015). In order to reduce nitrogen (N) losses in the environment and to reduce GHG emissions, alternative crop systems are promoted, assessing both the system and the culture to be cultivated (Autret *et al.*, 2019). By carefully designing and following the rules of sustainable agricultural practice, the change in crop rotation containing legumes and cereals is rapidly reducing demand for N fertilisers (wheat by 13–30%), without reducing wheat productivity or grain quality (Plaza-Bonilla *et al.*, 2017). The cultivation of legume crops has been proposed as a way of reducing GHG emissions because they are able to deposit atmospheric N and thus reduce the need for external or other nitrogen fertilisers. On the other hand, the introduction of rapeseed in the crop rotation has a positive effect as it breaks the cycle of plant pathogens by reducing the need for pesticides to grow future crops (Vinzent *et al.*, 2017). The formulation of GHG emissions depends on a number of factors that determine the amount of GHG emissions that occur at a particular type of management and need to be verified at national and regional scales (Oertel *et al.*, 2016) methane (CH<sub>4</sub>). In Latvia, measurements of GHG emissions in the agricultural sector have been launched and are implemented in several directions. Firstly, research on GHG emission reduction measures and develops future scenarios for GHG emissions in Latvia (Kreismane *et al.*, 2016; Lēnerts *et al.*, 2016;

Lenerts, Berzins, & Popluga, 2016; Lenerts, Popluga, & Naglis-Liepa, 2019; Nipers, Pilvere, & Zeverte-Rivza, 2017; Pilvere & Lenerts, 2015; Zeverte-Rivza, Popluga, & Berzina, 2017) and there is a large potential for land to be used in efficient agricultural production. National task is set for the next years in Latvia to retain agricultural land for agricultural production, in order to efficiently manage approximately 2 million ha. The agricultural sector is an important source of nitric oxide (N<sub>2</sub>O). Secondly, experimental studies are carried out on farms where CH<sub>4</sub> measurements are carried out and solutions are sought to reduce CH<sub>4</sub> emissions in the livestock sector (Berzina *et al.*, 2017, 2018; Grinfelde *et al.*, 2018; Jonova *et al.*, 2018b, 2018a; Jonova, Ilgaza, & Grinfelde, 2017) to measure the amount of methane (CH<sub>4</sub>). Thirdly, field and laboratory studies are being carried out to analyse not only GHG emissions from soil, but also to determine the effect of fertilizers on GHG emissions (Eihe *et al.*, 2019, 2020; Frolova *et al.*, 2017, 2018; Grinfelde *et al.*, 2019). Currently, there is a lack of understanding of the impact of cultivated crops on GHG emissions in heavy clay soils, which occupy most of the Zemgale region, where mainly wheat and rapeseed are grown. The aim of this study is to identify the difference in GHG emissions by crop.

#### Materials and Methods

Measurements of GHG emissions were carried out in the experimental farm of Latvia University of Life Sciences and Technologies located at Platones parish of Jelgava municipality. The study site has 24 experimental fields where two types of soil tillage have been used (conventional soil tillage with mould-board ploughing at a depth of 22–24 cm and reduced soil tillage with disc harrowing at a depth below 10 cm) and four crops were grown (wheat *Triticum aestivum*, rape *Brassica napus*, beans *Vicia faba* and barley *Hordeum vulgare*). Measurements of GHG emissions (N<sub>2</sub>O, CH<sub>4</sub>, CO<sub>2</sub>) in field conditions have been carried out on clay soil *Cambic Calcisol* according to IUSS Working Group WRB, (2015). Measurements of GHG emissions have been carried out in the growing season of 2018, 2019 and 2020. GHG measurements from agricultural soils were performed using a mobile spectrophotometer Picarro G2508, which allows simultaneous measurements of N<sub>2</sub>O, CH<sub>4</sub> and CO<sub>2</sub> gases with an average interval of one second. Measurements were performed in three chambers for each study plot. Non-transparent chambers with a base diameter of 23 cm and a chamber volume of 3 litres were used. The base is made of metal, and its lower edge is sharpened to make it easier to place in the soil. A non-transparent dome is placed on the base (Frolova *et al.*, 2018). The chamber's connections to the Picarro G2508 were made using commercially

Table 1  
Values for GHG emissions descriptive statistics

Statistic	N <sub>2</sub> O, g ha <sup>-1</sup> day <sup>-1</sup>	CH <sub>4</sub> , g ha <sup>-1</sup> day <sup>-1</sup>	CO <sub>2</sub> , kg ha <sup>-1</sup> day <sup>-1</sup>
Nbr. of observations	460	460	460
Nbr. of missing values	0	0	0
Minimum	-19.5	-84.8	-13.0
Maximum	273.4	514.1	1026.7
Range	292.8	598.9	1039.8
Median	0.0	-0.4	23.1
Mean	4.8	37.7	66.6
Variance (n)	456.8	5398.3	10971.2
Standard deviation (n)	21.4	73.5	104.7

manufactured stainless steel connections. Soil moisture measurements were performed prior to soil GHG emissions measurements using the Lutron soil moisture meter PMS-714, which measures soil moisture at the surface of the soil. Air temperature measurements and air pressure measurements were carried out using barometric pressure gauge Diver DI 500, Eijkelkamp. The chamber's air temperature and air pressure meter was placed in the chamber just before the dome was secured. The measurement time was 400 seconds (Grinfelde *et al.*, 2017; Valujeva *et al.*, 2017). In order to transform the measurement of the concentration of Picarro G2508 into greenhouse gas emissions per hectare, the equation for the ideal gas position was used for the conversion of the emission factor to a concentration per day (Formula 1).

$$F = p \cdot \frac{V}{A} \cdot \frac{\Delta c}{\Delta T} \cdot \frac{273}{T+273}, \text{ where} \quad (1)$$

F – emissions from soil (g ha<sup>-1</sup> day<sup>-1</sup>); p - gas density in mg m<sup>-3</sup>; V – the volume of the chamber in m<sup>3</sup>; A – camera area m<sup>2</sup>; Δ c/Δ T – mean change in concentration at ppm s<sup>-1</sup>; T – camera temperature in °C.

Descriptive statistics, box plots, and the Kruskal-Wallis test have been used for data processing because the data do not correspond to the normal distribution, for data processing (Ruxton & Beauchamp, 2008; Vargha & Delaney, 1998) using XLSTAT software.

## Results and Discussion

During the study period, a significant amplitude of GHG emission fluctuations is observed. Table 1 summarises the results of GHG measurements and gives an insight into N<sub>2</sub>O, CO<sub>2</sub> and CH<sub>4</sub> statistics. A total of 460 observations were made in 2018, 2019 and 2020. The minimum value of N<sub>2</sub>O is -19.5 g ha<sup>-1</sup> day<sup>-1</sup>, maximum of 273.4 g ha<sup>-1</sup> day<sup>-1</sup>. CH<sub>4</sub> has a minimum value of -84.8 g ha<sup>-1</sup> day<sup>-1</sup>, and a maximum of 514.1 g ha<sup>-1</sup> day<sup>-1</sup>. The minimum value of CO<sub>2</sub> is -13.0 g ha<sup>-1</sup> day<sup>-1</sup>, maximum of 1026.7 g ha<sup>-1</sup> day<sup>-1</sup>. The results of all gas emissions measurements show a significant discrepancy between the arithmetic mean and the median values, indicating observed extreme values.

The next step is to analyse the differences in each GHG emission in the context of crops grown. Figure 1 shows the distribution of N<sub>2</sub>O emissions depending on the crop. The highest dispersion of N<sub>2</sub>O emission is observed from barley-grown soils, but the lowest from the beans. Extreme maximum values affecting the average values of emissions are observed for all crops, as well as extremely negative values for beans, wheat and rapeseed. The highest average N<sub>2</sub>O emission is formed by barley, while the lowest is formed by rapeseed. It appears that in the fields where beans were grown, a significant difference in N<sub>2</sub>O emissions was observed compared to the fields of rapeseed and barley. There is also a significant difference in N<sub>2</sub>O

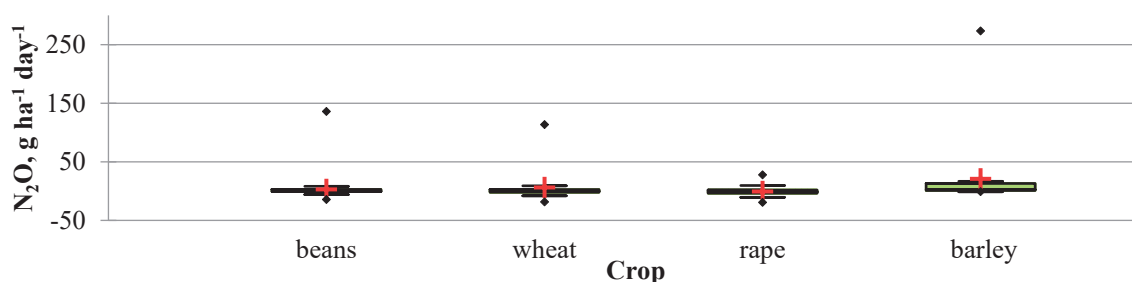


Figure 1. N<sub>2</sub>O emissions by crop groups.

Table 2

Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Two-tailed test

	N <sub>2</sub> O, g ha <sup>-1</sup> day <sup>-1</sup>   beans	N <sub>2</sub> O, g ha <sup>-1</sup> day <sup>-1</sup>   wheat	N <sub>2</sub> O, g ha <sup>-1</sup> day <sup>-1</sup>   rape	N <sub>2</sub> O, g ha <sup>-1</sup> day <sup>-1</sup>   barley	Groups		
N <sub>2</sub> O, g ha <sup>-1</sup> day <sup>-1</sup>   beans		1.336	5.956	-6.942	A		
N <sub>2</sub> O, g ha <sup>-1</sup> day <sup>-1</sup>   wheat	-1.336		4.766	-6.893		B	
N <sub>2</sub> O, g ha <sup>-1</sup> day <sup>-1</sup>   rape	-5.956	-4.766		-8.756		B	
N <sub>2</sub> O, g ha <sup>-1</sup> day <sup>-1</sup>   barley	6.942	6.893	8.756				C

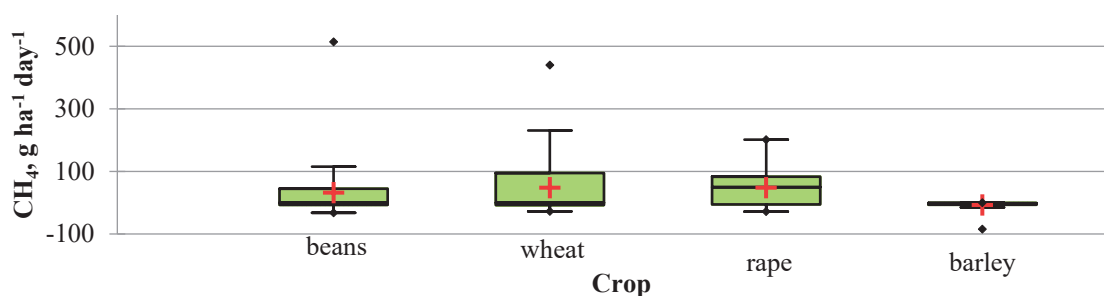


Figure 2. CH<sub>4</sub> emissions of by crop groups.

emissions from wheat fields compared to rapeseed and barley. Barley from the perspective of N<sub>2</sub>O, compared to other crops, produces significantly higher emissions, while rape-grown soils emit significantly lower emissions.

The independent samples Kruskal–Wallis test were used to test Null Hypothesis: *The distribution of N<sub>2</sub>O emissions is the same for different crops.* As the computed p-value was lower than the significance level alpha=0,05, one should reject the null hypothesis, and accept the alternative hypothesis. The risk to reject the null hypothesis while it is true is lower than 0.01%. Steel-Dwass-Critchlow-Fligner procedure was used to analyse the impact of differences between crops on N<sub>2</sub>O emissions (Table 2).

The distribution of CH<sub>4</sub> emissions by crop groups is shown in Figure 2. The largest distribution of CH<sub>4</sub> emissions has been observed from wheat-grown soils,

while the smallest for barley, where extreme negative values have also been observed. Value of CH<sub>4</sub> emissions depending on the crop grown. It appears that the only culture that has a significant impact on CH<sub>4</sub> emissions compared to other crops is barley. In all three options, emissions have decreased. For other crops, the average values of CH<sub>4</sub> do not differ significantly.

The independent samples Kruskal–Wallis test were used to test Null Hypothesis: *The distribution of CH<sub>4</sub> emissions is the same for different crops.* As the computed p-value was lower than the significance level alpha=0.05, one should reject the null hypothesis, and accept the alternative hypothesis. The risk to reject the null hypothesis while it is true is lower than 0.01%. The Steel-Dwass-Critchlow-Fligner procedure was used to analyse the effect of differences between crops on CH<sub>4</sub> emissions (Table 3).

Table 3

Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Two-tailed test

	CH <sub>4</sub> , g ha <sup>-1</sup> day <sup>-1</sup>   beans	CH <sub>4</sub> , g ha <sup>-1</sup> day <sup>-1</sup>   wheat	CH <sub>4</sub> , g ha <sup>-1</sup> day <sup>-1</sup>   rape	CH <sub>4</sub> , g ha <sup>-1</sup> day <sup>-1</sup>   barley	Groups		
CH <sub>4</sub> , g ha <sup>-1</sup> day <sup>-1</sup>   beans		-1.375	-3.419	4.580	A		
CH <sub>4</sub> , g ha <sup>-1</sup> day <sup>-1</sup>   wheat	1.375		-1.262	5.037		B	
CH <sub>4</sub> , g ha <sup>-1</sup> day <sup>-1</sup>   rape	3.419	1.262		6.400		B	
CH <sub>4</sub> , g ha <sup>-1</sup> day <sup>-1</sup>   barley	-4.580	-5.037	-6.400				B

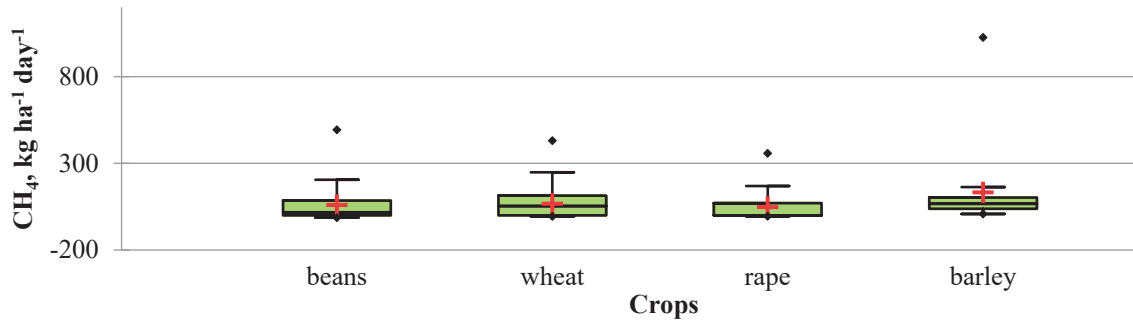


Figure 3. CO<sub>2</sub> emission by crop groups.

Table 4

Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Two-tailed test

	CO <sub>2</sub> , kg ha <sup>-1</sup> day <sup>-1</sup>   beans	CO <sub>2</sub> , kg ha <sup>-1</sup> day <sup>-1</sup>   wheat	CO <sub>2</sub> , kg ha <sup>-1</sup> day <sup>-1</sup>   rape	CO <sub>2</sub> , kg ha <sup>-1</sup> day <sup>-1</sup>   barley	Groups	
CO <sub>2</sub> , kg ha <sup>-1</sup> day <sup>-1</sup>   beans		-1.366	1.114	-5.568	A	
CO <sub>2</sub> , kg ha <sup>-1</sup> day <sup>-1</sup>   wheat	1.366		2.172	-3.517	A	
CO <sub>2</sub> , kg ha <sup>-1</sup> day <sup>-1</sup>   rape	-1.114	-2.172		-7.162	A	B
CO <sub>2</sub> , kg ha <sup>-1</sup> day <sup>-1</sup>   barley	5.568	3.517	7.162			B

Figure 3 shows the distribution of CO<sub>2</sub> emissions depending on the crop. Large scatter and extreme values of CO<sub>2</sub> emissions have been observed for all crops. The highest average value was observed from the soils where barley was grown – 307.261 kg ha<sup>-1</sup> day<sup>-1</sup>, while the lowest average value of CO<sub>2</sub> emissions was observed in the rapeseed fields - 205.796 kg ha<sup>-1</sup> day<sup>-1</sup>. There is no significant difference between beans, wheat and rapeseed in the formation of CO<sub>2</sub> emissions. Barley has been reported to produce emissions of 5.568 kg ha<sup>-1</sup> day<sup>-1</sup> higher than beans and 7.162 g ha<sup>-1</sup> day<sup>-1</sup> higher than rapeseed with a significant difference.

The independent samples Kruskal–Wallis test were used to test Null Hypothesis: *The distribution of CO<sub>2</sub> emissions is the same for different crops*. As the computed p-value was lower than the significance level alpha=0.05, one should reject the null hypothesis, and accept the alternative hypothesis. The risk to reject the null hypothesis while it is true is lower than 0.01%. Steel-Dwass-Critchlow-Fligner procedure was used to analyse the impact of differences between crops on CO<sub>2</sub> emissions (Table 4).

**Conclusions**

The results of the three-year studies show a significant variability in GHG emissions, especially the extreme values for N<sub>2</sub>O emissions, which reach of 273.4 g ha<sup>-1</sup> day<sup>-1</sup>. Analysing GHG emissions from clay soils by crop groups, the Kruskal-Wallis test shows a statistically significant difference in the effect of cultivated crops on GHG emissions. N<sub>2</sub>O emissions showed a statistically significant difference between crop groups. Barley has a significant effect on CH<sub>4</sub> emissions compared to other crops. In future studies, it is necessary to increase the number of plots where measurements are made and the number of measurements by in-depth study of plots where barley is grown. An analysis of the effect of preculture on GHG emissions from clay soils is required.

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