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Original Research

Short-Term Inventory of GHG Fluxes in Semi-Natural and Anthropogenized Grassland

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Abstract

Climate change accelerates global warming and has thus become an increasing concern with need for prompt solutions. This process occurs due to increased atmospheric green house gas (GHG) emissions. The agro sector (crop and livestock agriculture) contributes 10 to 12% per year of the total global anthropogenic emission and tends to increase. Most agricultural GHG emissions are generated by intensively fertilized soils, enteric fermentation, and manure management. Remarkable GHG fluxes occurred from grasslands which occupy 69% of global agricultural land. The aim of this investigation was to evaluate and estimate GHG emissions in natural and abandoned grassland improved by managed fertilizing. Experimental data sets cover grassland (clay loam topsoil over silt loam, *Calc(ar)i-Endohypogleyic Luvisol*) abandoned more than 20 years, which has subsequently been fertilized with different rates of N and multiple NPK. Direct CO_2, N_2O, and CH_4 emissions were measured in differently studied treatments (semi-natural sward: Control (0), N_{60}, N_{120}, N_{180}, N_{240}, $N_{180}P_{120}$, $N_{180}K_{150}$, $N_{60}P_{40}K_{50}$, and $N_{180}P_{120}K_{150}$; cultural pasture: $N_{180}P_{120}K_{150}$) during vegetation period (2009). Decreasing tendency of emission fluxes was determined during vegetation period and employing lower fertilizer rates. Therefore, appropriate fertilizing rate ($N_{60}P_{40}K_{50}$) of extensive grassland should be considered for its mitigating impact on climate change.

Keywords: climate change, CO_2, N_2O, CH_4, grassland, fertilizing

Introduction

Intensive technologies have turned into a pressing issue on the global environmental state due to increasing generation of total long-lived GHG anthropogenic emissions that have a long-term influence on the global climate. The United Nations has summarized the GHG annual increase of 0.4 (CO_2), 0.6 (N_2O), and 0.25% (CH_4) [1] and called for stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system [2]. Agricultural land occupies about 40-50% land surface and generates about 10-12% of the total global anthropogenic emissions, or 5.1-6.1 Gt CO_2-eq per yr, and must play a role in climate change mitigation [3-5]. As EuroStat (2009) reports [6], the European Union (EU) and its 5% global population contributes up to 15% of total GHG emissions. Agriculture contributes 9% (462.22 Mt CO_2-eq/yr) GHG emissions and follows emissions from the energy sector of 27 EU Member States [7-9].

Despite the large CO_2 emissions from ecosystems, global net flux between cropland and atmosphere is approximately balanced, and is estimated to be about 1%, or 0.04 Gt CO_2-eq/yr [10]. CH_4 contributes to 3.3 Gt CO_2-eq/yr and N_2O – 2.8 Gt CO_2-eq/yr of total GHG emissions. The global share of CH_4 and N_2O emissions from agriculture is significant and accounts for about 60% and 50%, respectively, with annual mean gain of 17% (60 Mt CO_2-eq/yr) [5].

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On a global scale, the main sources of CH_4 and N_2O emissions are enteric fermentation, manure management and fertilized soils. N_2O is generated in soil as an outcome of nitrification and denitrification processes performed by microbial transformation of nitrogen [11]. Initial reasons of N_2O increase in arable land are associated with rising N rates, livestock manure, and biological N fixation [1]. This emission is regulated by environmental factors, namely soil moisture and temperature, content of nitrite and ammonia ions, and organic C availability for microorganisms [12, 13]. Agricultural and related domains produce biological CH_4 anaerobically during enteric fermentation, as well as management of flooded rise cropland and manure [1, 14]. Agricultural activities are able to reduce atmospheric CH_4 content by means of soil aeration. Biological oxidation there would decrease global CH_4 concentration in the 3-9% range [15].

Current initiatives suggest that GHG emission rates must be fully inventoried in agriculture for seeking mitigation measures [4]. Considerable atmospheric load is generated due to agricultural production and is strongly dependent on farming type, applied agricultural policy, and geographic characteristics. As Dambreville et al. [16] remarked, the effect of fertilizers on N_2O emissions is influenced by climatic conditions and soil characteristics, hence studies to regulate such emissions need to be performed in many different ecosystems and countries.

Grasslands (3,488 Mha, or 69%) occupy a large segment of global agricultural land (5,023 Mha). Consequently, measurement and prediction of GHG emissions from these ecosystems are of great importance [17]. Furthermore, the amount and composition of covering plant species impact considerably total GHG emissions in grassland ecosystems [18, 19]. Grasslands play an important role in the global carbon (C) cycle. Those ecosystems store at least 10% of the global soil organic matter (SOM) [20].

Total grassland area in Lithuania occupies 1.2 Mha. Due to domestic political-economic circumstances, about 50% of grasslands are abandoned (formerly pasture or arable land) and have been turning into natural habitats/climatic ecosystems during last two decades in Lithuania [17]. These abandoned anthropogenized plots are suitable for low intensity grazing with livestock (horse and cattle, sheep, goat) that protect abandoned extensive grassland from afforestation in temperate climate. There is a lack of knowledge about the effects of various fertilizing rates and techniques on gaseous emissions from grasslands.

The main aim of this investigation was to examine the impact of a single as well as multiple fertilizers on plant productivity and long-living biogenic greenhouse gas (CO_2, N_2O, and CH_4) emissions in semi-natural sward and cultural pasture. In this study, fertilizing abandoned semi-natural grasslands was employed, thus improving their productivity and conserving soil fertility in order to keep these territories unforested for extensive uses.

Experimental Procedures

Field experiments were carried out on fertilized semi-natural sward and cultural pasture at the Training Farm of Lithuanian University of Agriculture (54º52'N, 23º50'E) Kaunas district during the vegetation period of 2009. The soil was clay loam topsoil over silt loam (*Calc(ar)i-Endohypogleyic Luvisol*). Humus horizon was 25 cm deep. Soil pH was 6.97, humus content – 2.51%, P_2O_5 – 242 $mg \cdot kg^{-1}$, and K_2O – 124 $mg \cdot kg^{-1}$. Composite soil samples from 10 replicates were taken at a 15-20 cm depth using a (Nekrasov) auger in accordance with ISO 10 381-1:2002. The soil was preconditioned for 15-20 days at laboratory temperature (approximately 22ºC) before analysis. Soil chemical composition (Table 2) was used for evaluation of correlation with treatment biogenic micro gas emissions. Soil pH was recorded potenciometrically using 1 n KCl extraction, and mobile P_2O_5 and K_2O ($mg \cdot kg^{-1}$ of soil) by A-L method. Soil moisture also was continuously recorded using zond (HydroSense Campbell CS-620) and soil bulk density was measured with a meter (Fieldscout SC 900 Spectrum Technologies). The field test area of each fertilizing treatment was 10 m^2 (2 x 5 m). The N (ammonium saltpetre 34.4% N) and NPK (ammonium saltpetre 34.4% N + granulated superphosphate 19% P_2O_5 + potassium chloride 60% K_2O) application scheme of 9 treatments in semi-natural sward: Control (0), N_{60}, N_{120}, N_{180}, N_{240}, $N_{180}P_{120}$, $N_{180}K_{150}$, $N_{60}P_{40}K_{50}$, and $N_{180}P_{120}K_{150}$. Investigated cultural pasture was fertilized with $N_{180}P_{120}K_{150}$. P and K were applied before plant vegetation in early spring, N fertilizer was applied twice: at the end of April and after the 1st cut (beginning of July). Fresh mass (FM) weighing (g 0.2 m^{-2} per treatment) and drying (105ºC) were used to determine grassland productivity ($g \cdot m^{-2}$) and obtain dry mass (DM, %). Grassland botanical composition was determined on harvested vegetation.

GHG emissions were monitored by the static chamber method [21] using opaque circular chambers (0.05 m^{-3}), with 6 replicates per treatment. Cylindrical steel frames (20 cm high and 43 cm diameter) were inserted into the soil to a depth of 2 cm. 2 frames were placed in each plot. The frames remained in the soil and open to the atmosphere between samplings, except when removed for tillage and sowing. During the measurements the chambers were closed with an airtight lid simultaneously in all treatments, and the head space was sampled 3 times over a period of 1 hour. Gas fluxes were measured on 4 different dates at Kaunas district.

The measurements were carried out 2 or 3 weeks after fertilizer application every month between June and September in absence of frost stress. The gas samples were analyzed in the laboratory by infrared gas analyzer (MGA3000) calibrated separately for each gas using ML-800 gas standard (2 atm). Gas samples were analyzed on the same day evaluating volume concentrations (ppm) of trace gases. Daily net of ecosystem CO_2, CH_4, and N_2O exchange ($mg \cdot h^{-1} \cdot m^{-2}$) was calculated by integrating the 60-

Table 1. Yield and botanical composition of semi-natural grassland.

Treatments	FM, $g \cdot m^{-2}$	DM, $g \cdot m^{-2}$	Botanical composition, %		
			Grasses	Legumes	Forbes
Control	957.5	190.2	35	35	30
N_{60}	892.5	203.8	50	3	47
N_{120}	1,002.5	235.1	75	0	25
N_{180}	1,102.0	271.4	71	0	29
N_{240}	1,520.0	192.6	70	0	30
$N_{180}P_{120}$	1,700.0	386.2	40	50	10
$N_{180}K_{150}$	1,355.0	342.2	80	0	20
$N_{60}P_{40}K_{50}$	2,127.5	495.5	35	55	10
$N_{180}P_{120}K_{150}$	3,020.0	827.7	97	0	3
LSD_{05}	87.55	0.54	1.04	0.53	1.18
r ($p<0.05$)		0.8	0.1	0.3	0.8

minute fluxes determined by the meteorological measurements each day.

Thermal and irrigation conditions during the vegetation period were characterized by the sum of monthly precipitation and active air temperature (>10ºC), accordingly to those commonly used in Europe (G. Selianinov 1928 hydrothermal coefficient – HTK) [22]. High rates of hydrothermal coefficient (HTC=2.0 and 4.0) showed moisture abundance in June and August, but it was optimal in July (HTC=1.6), and too dry (HTK=0.9) in September 2009 (Fig. 1).

Results were evaluated statistically using package Statistica (StatSoft for Windows) programme ANOVA. The confidence limits of the data were based on Student's theoretical criterion. Standard error (SE), determination (R), and correlation coefficients (r) were calculated at the level of statistical significance $p<0.05$.

Results and Discussion

Grassland and intensively fertilized areas occupy about 20% of Earth's land surface [9] and about 50% of agricultural land in Lithuania, and therefore constitute significant GHG emission sources for exchanges of main biogenic gas between the biosphere and atmosphere contributing to climate change.

According to the results, fertilization impacted productivity and botanical composition of semi-natural grassland (Table 1). The application of heavy rate fertilizers increased FM and DM yield significantly (r=0.8), and changed sward composition increasing forbes (r=0.8), but negatively impacted the legume (r=0.3) share.

Data of this experiment have confirmed contributions to N_2O, CO_2, and CH_4 emissions of fertilized abandoned semi-natural grassland. In accordance with Dambreville et

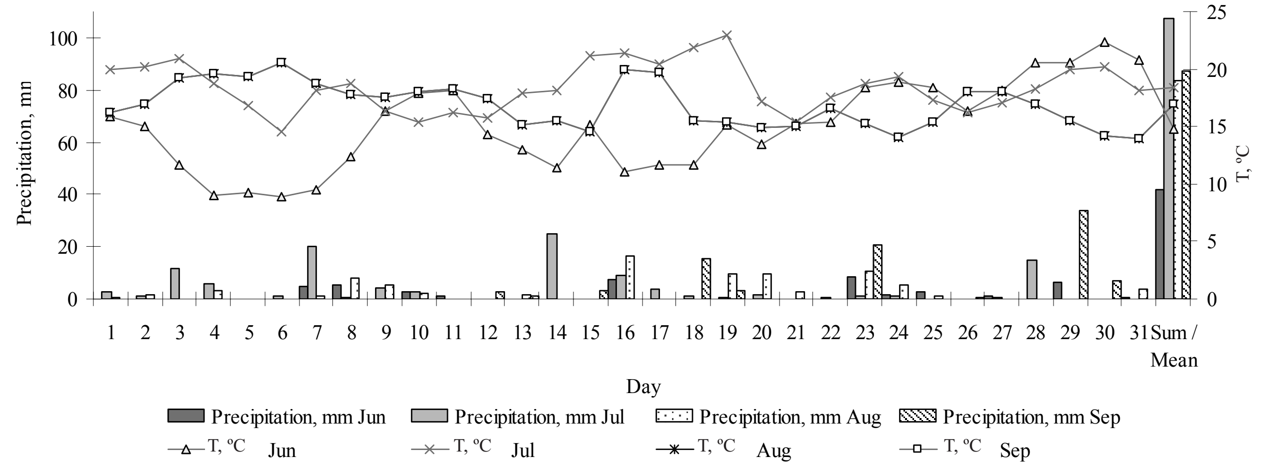

Fig. 1. Temperature and precipitation during vegetation period.

Table 2. Soil agrochemical mean parameters of semi-natural grassland ($p<0.05$).

Treatment	pH	N_{total}, %	P_2O_5, mg·kg^{-1}	K_2O, mg·kg^{-1}
Control	7.25	1.00	132.50	146.50
N_{60}	7.10	1.11	146.50	152.00
N_{120}	7.15	0.93	127.00	139.00
N_{180}	7.15	0.90	125.00	129.50
N_{240}	7.20	0.80	108.00	122.50
$N_{180}P_{120}$	7.30	1.35	197.00	120.00
$N_{180}K_{150}$	7.45	1.04	143.00	172.50
$N_{60}P_{40}K_{50}$	7.40	1.14	166.00	117.00
$N_{180}P_{120}K_{150}$	7.35	1.44	225.00	126.50

al. [16], identified emission trends depend on agricultural management and nutrient materials in various ecosystems.

N_2O Emissions

As Freibauer [23] reports, agriculture is the main producer of 75% of anthropogenic N_2O in Europe. Therefore, solutions have to be sought to reduce these emissions. Experimentally obtained N_2O emissions showed a decrease during vegetation period from June to September (Fig. 2). This is possibly due to the change in activity of nitrous oxide-producing microorganisms. Their activity depends not only on dissoluble substrate concentrations [24, 25], and fertilizer rates and types [26, 27], but also on environmental temperature, humidity, CO_2 concentration, etc. [28, 29]. At the end of summer some monitored environmental abiotic factors (soil moisture and temperature) that limited activity of microorganisms are in decrease, therefore N_2O emissions tend to be declining.

Total N content can be a driving parameter of nitrification, denitrification, and N_2O emissions [16], so it was monitored throughout the field experiment. A weak correlation (r=0.3) between soil total nitrogen (Table 2), but medium correlation between soil moisture (r=0.5), pH (r=0.6), and N_2O emissions were observed, possibly due to soil patterning. Nonetheless, strong interaction (r=0.9) was observed between climatic indices (temperature and precipitation), applied fertilizer and N_2O emission in grasslands.

Obtained N_2O emission rates (0.008-0.045 mg·h^{-1}·m^{-2}) were within the range reported in previous studies [16, 18, 20]. The lowest N_2O flux (0.008-0.023 N_2O mg·h^{-1}·m^{-2}) was obtained in control treatment of semi-natural grassland during June-September. $N_{180}P_{120}K_{150}$ rate stimulated the highest N_2O emission (0.009-0.045 mg·h^{-1}·m^{-2}) during vegetation period. Nonetheless the highest mean emissions between treatments was exceeded by N_2O emissions (0.025 mg·h^{-1}·m^{-2}) from $N_{180}K_{150}$ fertilizer treatment in June. The application of high K rate stimulates physiological activity of cell metabolism processes [31, 32] and possibly activates cells of soil microorganisms to also produce more active N_2O. Additionally, higher K content was observed in soil agrochemical composition due to soil heterogeneity (Table 2).

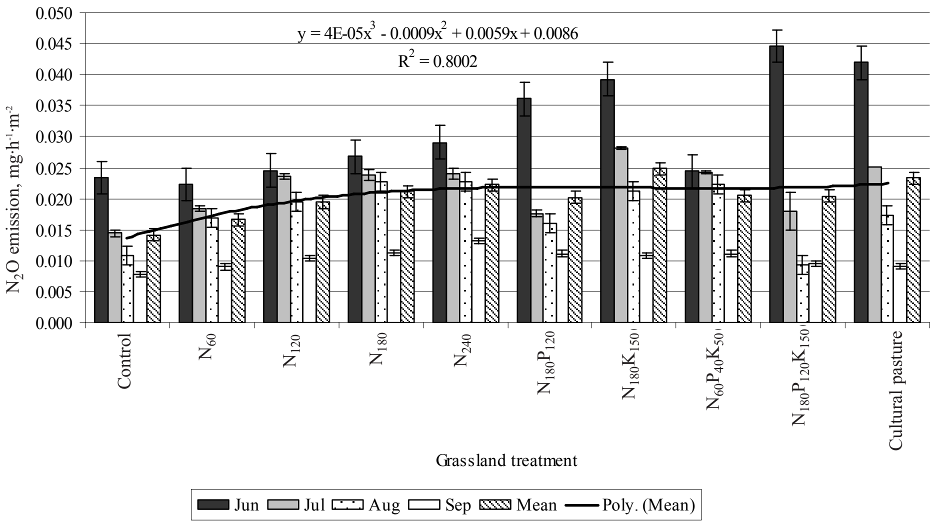

Fig. 2. Fertilizing impact on N_2O emission in semi-natural grassland during vegetation period ($p<0.05$; mean±SE).

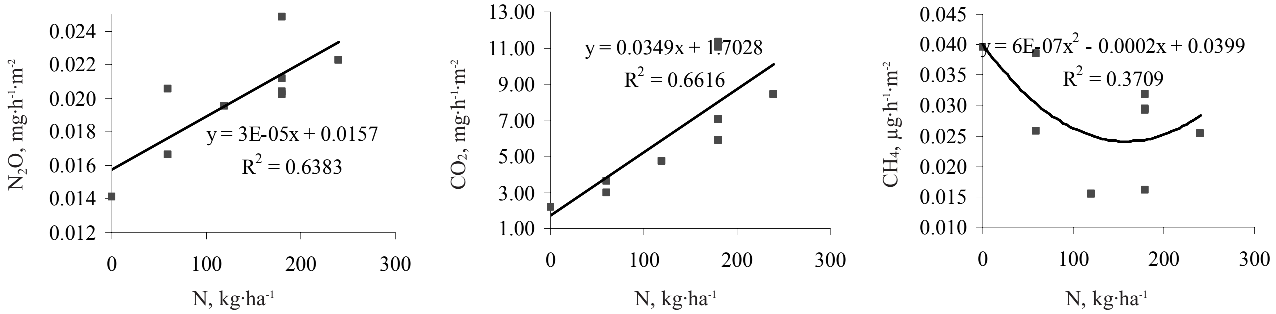

Fig. 3. Correlation between monomial N fertilizers rates and GHG emissions ($p<0.05$).

Comparing effects of different fertilizer applications showed higher reduction of mean N_2O emissions when applying balanced multiple (r=0.9) NP, NK, and NPK (Fig. 2), than monomial N (r=0.8) (Fig. 3). Analogical stimulation of N_2O emission due to the fertilizing effect on physiological activity of plants and soil microbes is referred in several studies [33-36]. Higher rates of N fertilizers caused some shifts in the sward botanical composition: the share of legumes decreased while that of grass increased (Table 2). Therefore, appropriate extensive grassland fertilizing with balanced mineral multiple fertilizers in optimal rates ($N_{60}P_{40}K_{50}$) can be applied with the purpose of decreasing mean N_2O emissions during vegetation period.

CO_2 Emission

The highest CO_2 fluxes are formed during anaerobic respiration and fossil fuel burning with a global annual increase of 0.4%, so finding new ways to reduce these emissions is essential [10]. Closely related to respiration and photosynthesis, the formation of CO_2 can be considered a function of environmental temperature (r=0.8), humidity (r=0.8), soil pH (r=0.7), and nutritional materials as reported by Kaiser and Ruser [12]. Nonetheless, a weak correlation (r=0.4) between CO_2 emission and soil mineral components was observed (Table 2). On the other hand, a strong correlation (r=0.8) between CO_2 emissions and fertilizing rates was observed in fertilized semi-natural grassland (Fig. 4). In accordance with multiple references [1, 4, 37], a strong correlation between CO_2 emissions and monomial (r=0.8) and multiple fertilizers rates (r=0.7) was observed in semi-natural and cultural grassland (Figs. 3 and 4). Regarding carbon balance, we assumed that obtained low FM and DM yield (Table 1) demonstrate low carbon uptake or fertilizer assimilation of extensive species of semi-natural grassland. Therefore, intensive fertilizing of extensive semi-natural grasslands would not be recommended seeking to decline CO_2 emissions and mitigate climate change.

CO_2 emission was developed by analogy to N_2O emission, both linked in a downward direction due to changing environment conditions during growing season (June-September) with the lowest value on September (Fig. 4). Furthermore, variation of CO_2 emission dependence on vegetation period could best be described using cubic polynomial empirical model ($y=0.0373x^3 - 0.6831x^2 + 4.2765x - 2.1434$; $R^2=0.59$). A strong correlation (r=0.7) confirmed both climatic factors (temperature, humidity, soil pH) and fertilizing had equally strong influence.

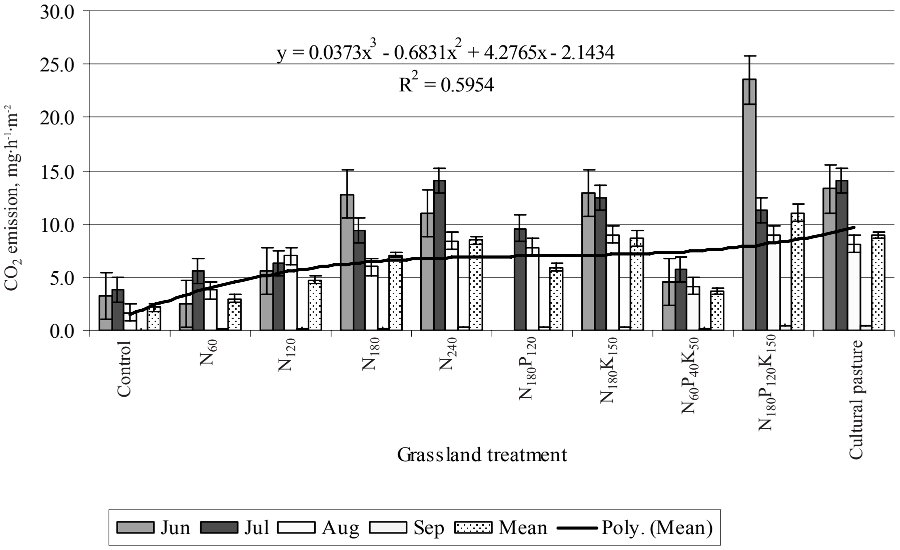

Fig. 4. Fertilizing impact on CO_2 emissions in semi-natural grassland during vegetation period ($p<0.05$; mean±SE).

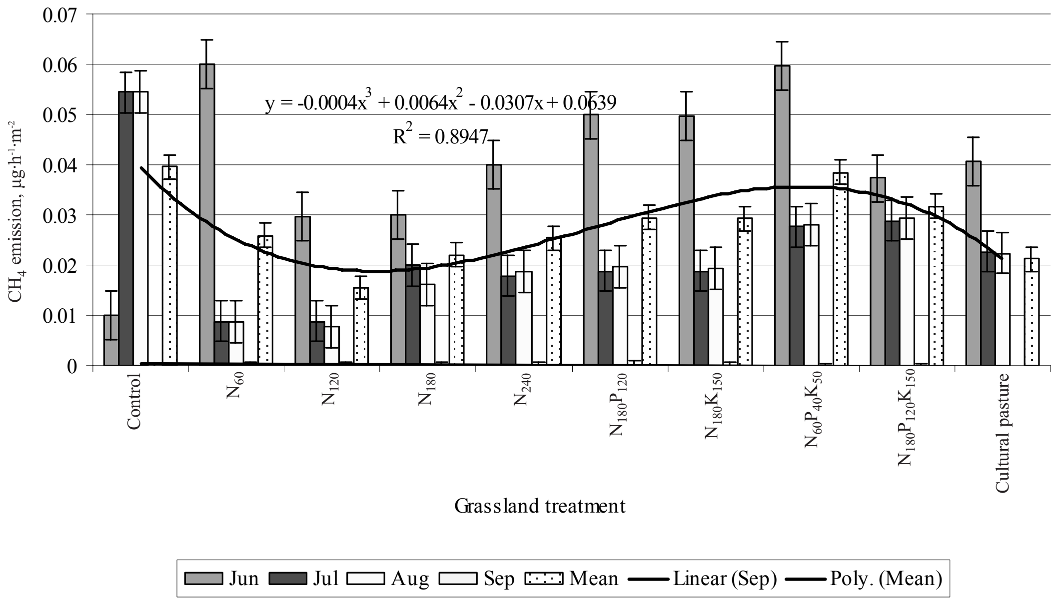

Fig. 5. CH_4 emission in semi-natural grassland ($p<0.05$; mean±SE).

Despite the highest harvest in $N_{180}P_{120}K_{150}$ treatment (Table 1), the semi-natural grassland fertilizing with monomial and multiple fertilizers containing higher than N_{120} rate economically and ecologically is disadvantageous [38]. In order to keep CO_2 emissions to the atmosphere, it would be sufficient to fertilize abandoned grasslands with $N_{60}P_{40}K_{50}$. Also, such grasslands could be used for small (goat, sheep) or undemanding wild cattle to protect agricultural land from afforestation in a moderate climate zone.

CH_4 Emission

According to Houghton et al. references [39], methane follows the CO_2 in order of importance with 23 times higher warming effect. Nonetheless, significantly high CH_4 content could be observed in anaerobic conditions [40]. CH_4 formation in well-drained soils also is performed by aerobic microorganisms, but there methane is oxidized by methanotrophic and nitrifying bacteria so that higher content does not accumulate in these soils [30, 41]. Due to this reason, very low CH_4 emission was observed in all investigated grasslands positioned in well-drained soils of the Training farm (Fig. 5). Measured CH_4 emission was negligible and ranged between 0.01-0.06 µg·h^{-1}·m^{-2} in fertilized grassland ($r=0.9$).

In accordance with Perälä et al. [42], CH_4 emission change was observed in well-aerated grassland soil with stronger dependence on monomial nitrogen fertilizer ($r=0.6$, Fig. 3), than on multiple fertilizer ($r=0.9$), soil pH ($r=0.4$) and humidity ($r=0.4$). Therefore, management of mineral, partially nitrogen, fertilizers may be considered as a potential factor that could lead to possible reduction of CH_4 emissions in an agro ecosystem [43]. Higher CH_4 emission rates evaluated at the beginning of vegetation period confirms the role of humidity content to maintenance of suitable conditions that stimulated anaerobic methanogenic microorganisms in soil. Natural diminishing of CH_4 emission rates occurred in July and September due to a decrease of soil moisture (HTC=1.6 and 0.9).

Conclusions

Application of different rates of monomial nitrogen and multiple fertilizers impacted GHG emissions. Given that fertilizing is an easily controlled factor, fertilizing management may therefore be important when diminishing emissions in grasslands. Climatic conditions, namely temperature and humidity, strongly ($R=0.9$) impacted the rates of GHG emissions during vegetation. The lowest CH_4 emission was observed in grasslands, probably due to well drained soil conditions. The highest GHG emission (0.045 mg·h^{-1}·m^{-2} N_2O, 23.49 mg·h^{-1}·m^{-2} CO_2, and 0.06 µg·h^{-1}·m^{-2} CH_4) was observed in June in semi-natural grassland. Nonetheless, lower emissions were observed in cultural grassland. This finding can possibly be justified by the fact that species peculiar to cultural grasslands exercise higher physiological potential to assimilate fertilizers when forming yield. A gradual decline of GHG fluxes was observed during vegetation, in accordance with decreasing supply of environmental components encompassing organic substrates, fertilizers, and activity of microorganisms, as well as their interaction with humidity and temperature. There was strong correlation observed between mean N_2O, CO_2, and CH_4 emissions during vegetation period on the one hand, and NPK ($r=0.9$, 0.8, and 0.9) with monomial nitrogen fertilizers ($r=0.8$ and 0.6) on the other. Therefore, an appropriate fertilizing rate for supporting soil fertility should not exceed $N_{60}P_{40}K_{50}$. Furthermore, grasslands employment with undemanding cattle (sheep, goat) should be considered in order to prevent abandoned semi-natural grassland from forestation.

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