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GREENHOUSE GAS FLUXES IN AN AGRICULTURAL FIELD IN ICELAND UNDER DIFFERENT FERTILIZATION SCHEMES

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ABSTRACT

The effects of different fertilisation treatments on CO_2 and CH_4 fluxes and on soil organic carbon (SOC), total nitrogen (TN), C/N ratios and pH were investigated in two long-term fertiliser experiments at Hvanneyri, Iceland. One experiment tested the depravation of certain nutrients (299-70), the other tested the long-term effect of sheep manure application (437-77). Flux measurement was done using a LI-COR 7810 attached to a soil CO_2 flux chamber. C and N were measured via elemental analysis on soil samples randomly taken from each treatment plot. Soil pH was tested in deionised water. There were significant differences ($p < 0.05$) in CO_2 fluxes of different fertiliser treatments in experiment 299-70 but not in experiment 437-77 ($p = 0.67$). CH_4 flux from the treatments in both experiments 299-70 ($p = 0.30$) and 437-77 ($p = 0.20$) was not statistically significant from each other. There were significant differences ($p < 0.001$) between SOC of different treatments in both experiments, ($P < 0.01$) for TN in both experiments, and ($p < 0.001$) for pH in both experiments. There was no significant difference ($p > 0.63$) in C/N ratio between fertiliser treatments in experiment 299-70, but the difference in experiment 437-77 was statistically significant ($p < 0.01$). The study showed that continuous application of fertilisers, particularly N-based, leads to the emission of GHG and decreases soil pH. Treatments with sheep dung had higher pH values. Treatments with higher N and K increased SOC, TN, and C/N ratio.

Key words: greenhouse gas, fertilisation, experiments, soil fertility, Iceland

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ABBREVIATIONS

ANOVA	:	Analysis of variance
C	:	Carbon
CH_4	:	Methane
CO_2	:	Carbon dioxide
C/N	:	Carbon-to-Nitrogen ratio
DM	:	Dry matter
GHG	:	Greenhouse gases
H2O	:	Water
IPCC	:	Intergovernmental Panel on Climate Change
K	:	Potassium
N	:	Nitrogen
OF-CEAS	:	Optical feedback cavity enhanced absorption spectroscopy
P	:	Phosphorus
SOC	:	Soil organic carbon
SOM	:	Soil organic matter
TN	:	Total Nitrogen

1. INTRODUCTION

Human existence on Earth is largely dependent on land, which is a vital resource for survival. Land and land use systems are under stress because of the rapidly urbanising world and the ever-growing population, leading to the reduction in the resilience of land and consequently reducing its potential to optimally support production (IPCC 2007).

Iceland's agriculture is largely focused on livestock production and available productive grasslands are used to cultivate silage to feed the livestock (Gudmundsson et al. 2004). Commercial cultivation of arable crops is not prevalent due to unstable weather conditions, which affect yield and hence make yield computation difficult. Fertilisation and pesticide use in grass fields are very limited in Iceland as compared to other developed countries (Jóhannesson 2010).

In Ghana, agriculture is largely crop-based and in the past was carried out by individual subsistence farmers (Martey et al. 2014). Traditionally, farmers had always fallowed their lands to regain their vigour after years of continuous cultivation. Population increase has, however, affected this practice, as there is now a reduction in the availability of arable land. This has seen farmers resorting to the use of synthetic fertilisers to improve soil conditions and increase their production since the land has been mined off its nutrients (Atakora & Kwakye 2016). The Ghanaian government is aware of the crucial role that fertiliser application practises play in soil health and boosting agricultural output hence the initiation of programmes aimed at increasing fertiliser usage by subsidizing fertiliser importation (Martey et al. 2014; Atakora & Kwakye 2016; Donkor et al. 2019).

Fertilisation results in improved soil health and higher crop yields and have contributed significantly to the agricultural revolution that took place at the end of the 19th century (Sabry 2015). Even though the use of synthetic fertilisers has helped increase yield to meet the growing food demand that comes because of rapid population growth and global food shortage, its negative implications nonetheless cannot be underscored. The continuous application of fertilisers has the potential to alter the soil pH, cause underground water pollution due to leaching, loss of humus because of the absence of beneficial microbes required to decompose soil litter and the potential to emit greenhouse gases (GHG) (Pahalvi et al. 2021; Rivera & Chará 2021).

GHG are a group of gases including carbon dioxide (CO_2) and methane (CH_4) that warm the troposphere by trapping infrared and near infrared radiation (IPCC 2007). After fossil fuels, agriculture is by far the main origin of GHG (Janzen 2005; Maljanen et al. 2010). The relative abundance of these gases in the atmospheric pool is on the rise and this can be attributed to some activities of human activity in the form of industrialisation and the conversion of forests for agriculture purposes.

Understanding the long-term implications of fertilisation with respect to its impact on GHG emissions and on soil health can be used to track changes in soil quality caused by various fertilisation strategies, forecast fertiliser needs for crops, and study interactions between the soil and the environment. This would contribute towards attaining sustainable development goal 13: "Take urgent action to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy". Consequently, the outcome of this research will serve as a basis for further research towards designing and formulating climate smart fertiliser use systems for sustainable agriculture practices especially in developing countries like Ghana.

The study specifically sought to:

1. Determine the effects of different fertilisation doses on CO_2 and CH_4 fluxes in an agricultural field in Hvanneyri, Iceland.
2. Determine the carbon, nitrogen, and C/N ratio of soils under different fertilisation regimes, including different fertilisation doses and different times since the beginning of the fertilisations.

2. LITERATURE REVIEW

2.1 Greenhouse gases

GHG including carbon dioxide (CO_2) and methane (CH_4) are gases that warm the troposphere by trapping infrared and near infrared radiation (Solomon et al. 2007). After the burning of fossil fuels, the principal source of CH_4 and CO_2 is agriculture (Rivera & Chará 2021). The relative abundance of these gases in the atmosphere is on the rise. Anthropogenic activities such as conversion of forests into arable lands (Lynch et al. 2021), are seen to increase the concentration of these gases in the atmospheric pool, hence contribute to the rise in global temperatures (Janzen 2005; Maljanen et al. 2010). Mooney et al. (1987) and Lashoff (1989) indicated that to understand the impact of GHG on global warming, all biological factors and processes that contribute towards their relative abundance should be explored.

2.1.1 CH_4 and CH_4 flux measurements

The atmosphere contains CH_4, a naturally occurring gas whose molecular weight is less than that of air hence the tendency to rise. It has 25 times more potential to contribute to global warming than CO_2 (Solomon et al. 2007). CH_4 is generated by microbes during a process of methanogenesis which happens during anaerobic decomposition of organic matter (Villegas et al. 2014).

Segers (1998) and Hendriks et al. (2010) indicated that the availability of suitable substrate, increasing soil temperature and the redox value of the soil-root interface are some factors that affect CH_4 fluxes in the soil. Hence it is safe to infer that CH_4 fluxes are highly influenced by management practices such as fertilisation and ploughing carried out on the soil (Naser et al. 2018; Paustian et al. 2019).

CH_4 fluxes increases with increasing soil moisture. This is because air pores are taken up by water creating and oxygen deficient environment that increases the activities of methanogens hence increased CH_4 production (Chai et al. 2020). In contrast, in well aerated soil where there is enough oxygen, methanotrophs oxidise CH_4 hence low CH_4 emissions (Ho et al. 2015).

2.1.2 CO_2 and CO_2 flux measurement

The carbon cycle is one of the pathways through which CO_2 occurs in the atmosphere (Hanafiah et al. 2021). A recent study by Friedlingstein et al. (2022) indicates that CO_2 levels have exceeded pre-industrial levels by 51%, and the current level as of August 15, 2023, was 418.65 ppm (https://gml.noaa.gov/ccgg/trends/monthly.html). Analysing the trends in the natural carbon cycle while accounting for variations in these trends is vital to understanding

an ecosystem's resilience to CO_2 imbalance and how to offset it by measuring natural sinks of CO_2 to mitigate climate change (Hooper et al. 2002; Canadell et al. 2023).

CO_2 and CH_4 fluxes and the moisture level and temperature of the soil are correlated (Davidson & Janssens 2006; Fang et al. 2010). In dry or low soil moisture condition, soil microbial and enzymatic activities are reduced hence CO_2 flux is low (Praeg et al. 2017).

2.2 Soil emissions

Soil is a source although it can sometimes act as a sink of GHG (Oertel et al. 2016). It plays the role of a source of CO_2 by being the origin from which soil microbes and plant roots respire and of the organic matter decomposition by heterophytes (Oertel et al. 2016). It acts as a sink for CO_2, when the organic matter content of the soil is increased (Wachiye et al. 2020).

The presence or absence of oxygen affect the activities of methanotrophs in the soil. In the case of CH_4 however, soil is a source under anaerobic environment such as during methanogenesis and a sink during aerobic settings such as the utilisation of CH_4 by methanotrophic bacteria (Hanson & Hanson 1996; Serrano-silva et al. 2014). The soil physicochemical properties and the environmental factors such as soil moisture and temperature are crucial to the production and emission of GHG in the soil (Davidson & Janssens 2006; Bezyk et al. 2023). The type of vegetation cover on the soil also, to an extent, influences the microclimate, thereby affecting the GHG fluxes from the soil.

2.3 Soils of Ghana

Most soil types in Ghana are highly weathered and are savannah Ochrosols, forest Ochrosols, and Oxysols (Brammer 1962). These soils have mostly been impacted by the significant climatic variations that have led to two significant and well-defined vegetation belts: the forest and savannah. Based on the amount of organic matter in the top horizon, the soils of the forest and savannah belts can be easily distinguished from one another. Forest soils have higher organic matter (OM) content due to rich and increased litter, whereas savannah belts have grass as the predominant flora (Obeng-Koranteng et al. 2017). This has impacted Ghana's soil characteristics and fertility condition along with human activity.

2.4 Soil Carbon, Nitrogen, and Carbon-to-Nitrogen ratio

Soil organic carbon (SOC) is directly correlated with soil total nitrogen (TN); hence, their relative abundance in the soil is a vital indicator of soil fertility and GHG emissions (FAO 2017). The C/N ratio is indicative of the ability of the soil to serve as a nutrient repository (Doran & Jones 1997).

The C/N ratio of the organic matter (OM) in the top layer of an arable land typically ranges from 8:1 to 15:1, with 12:1 being very near to the optimum (Brady & Weil 2013). However, climatic conditions (Burke et al. 2004), the type of vegetation on the topmost layer (Lal 2007), soil quality parameters such as soil pH and soil particle size (Cao et al. 2021) and management practices like crop rotation, compost, and fertiliser application (Dala et al. 2011; Liang et al. 2011) are all crucial contributors that affect the C/N ratio of the soil. SOM contains on average 58% OC hence it is often used as an indicator for SOC (Motsara & Roy 2008). The SOM concentration can also indicate the availability of N and the capacity of the soil to provide N to plants.

2.5 Fertilisers

Fertiliser is any substance that is added to the soil with the express intention of providing developing plants with their nutritional needs (FAO 2019). One of the important practices in agronomy is fertilisation, mostly with nitrogen based chemical fertilisers which are aimed at improving soil health and increasing productivity (Liang 2022). The application of fertilisers by farmers does not only increase their lots, improve the living conditions of farmers and farming households, but also benefits all actors along the entire food and fertiliser value chain (Donkor et al. 2019; Martey et al. 2019).

Organic fertilisers are fertilisers whose principal materials are solely from plants, animals and/or both. A distinguishing feature of these fertilisers is the slow rate at which their components are released since mineralisation precedes absorption by plants (Stewart 2023). These materials generally enhance overall soil health as they contain a wide variety of nutrients though in low concentrations, often a substantial amount of organically bound carbon (Ontl & Schulte 2012).

Synthetic fertilisers are fertilisers that are synthetically combined with the sole purpose of increasing soil nutrients for plant uptake. The key is that mineral fertilisers contain, as the name states, the nutrients in an ionic/mineralised state, which makes them so easily absorbable by plants. Even though synthetic fertilisers produce positive results when applied on small-scale on in commercial production, uncontrolled use can result in fertiliser pollution (Sabry 2015).

3. METHODS

3.1 Site description

The experiment is situated at Hvanneyri in West Iceland 64°34'N, 21°44'W, as shown in Figure 1 below. The soil type on the field is histosol. About 1% of Icelandic soils are histosols (Arnalds 2008). A characteristic of this soil is its high organic carbon content >20 %, a bulk density of 0.15-0.4 high moisture, a pH between 4 and 5.5 (Arnalds 2004). These soils are mostly found in wetlands.

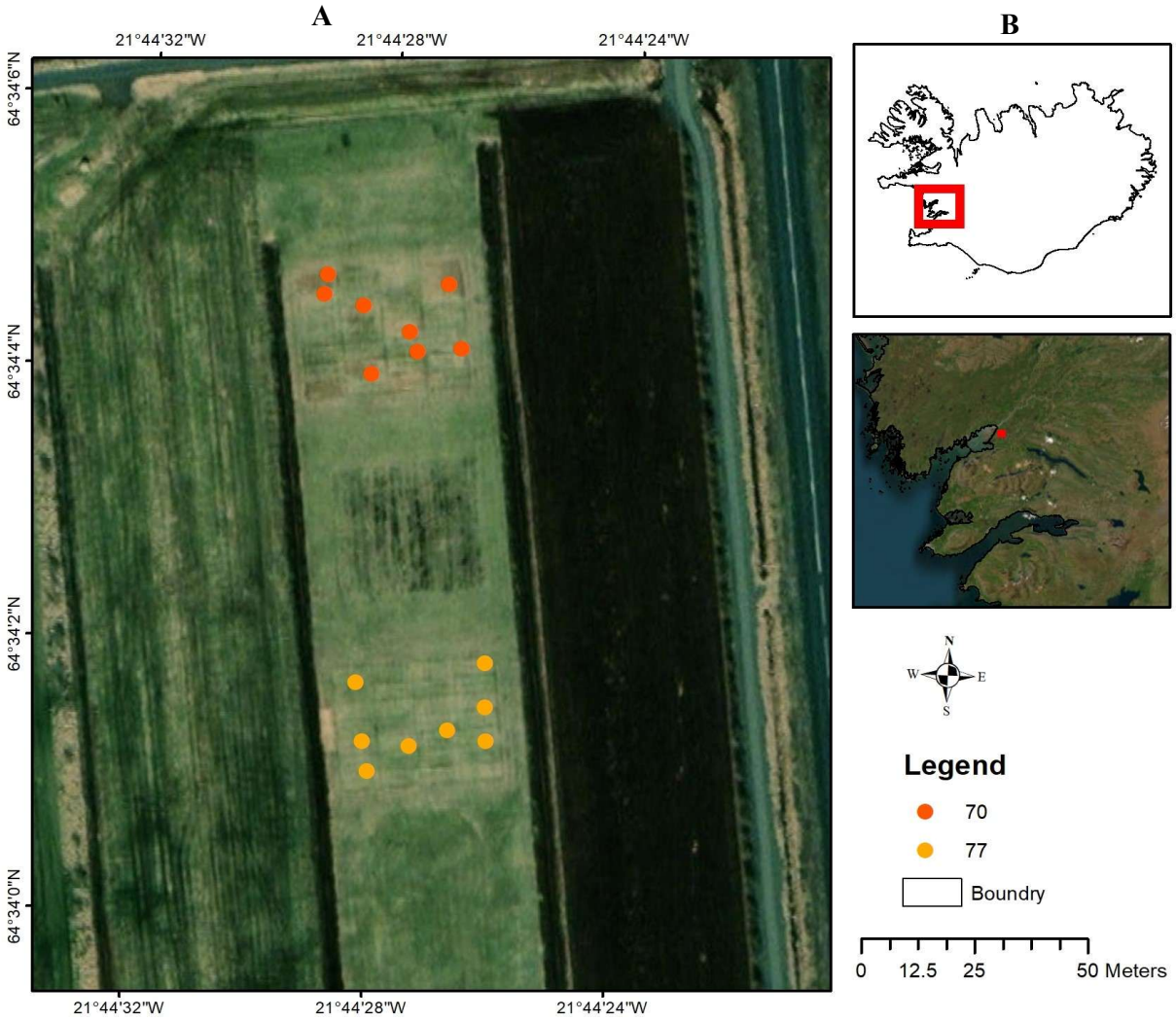

Figure 3A**.** Experimental site at Hvanneyri (Red dots is 299-70) and (Orange dots is 437-77)
Figure 1B, map of Iceland indicating the site of the experiments.
(Source: Esri, Maxar, Earthstar Geographics, and the GIS user community).

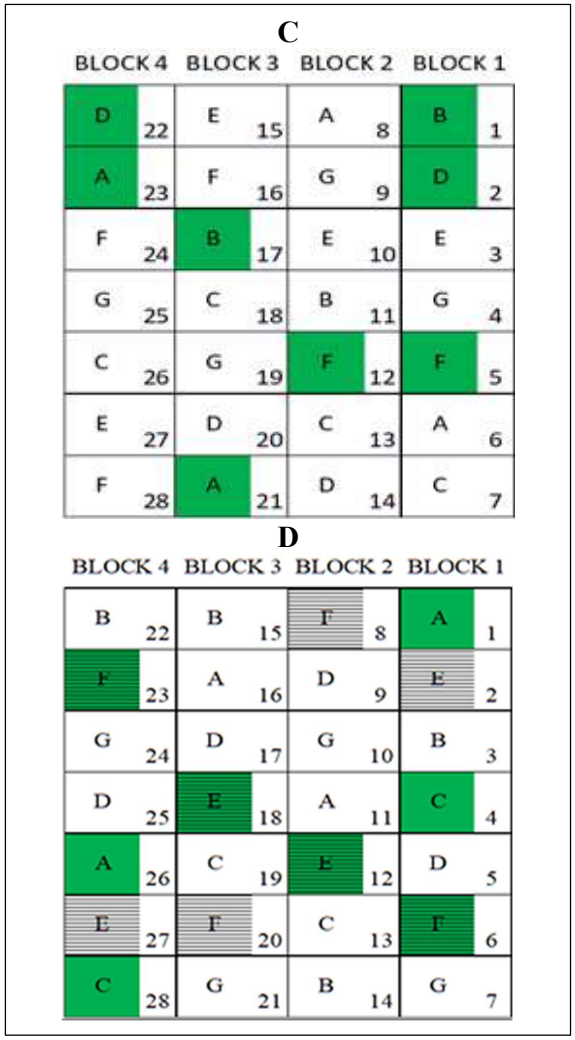

Figure 1C. Layout of experiment 299-70 (flux taken in green area)
Figure 2D. Layout of experiment 437-77 (flux taken in green area)

3.1.1 Experimental set up

Two long term experiments have been laid out 200 m apart on the same field. The treatments for these two experiments are uniquely combined and do not have any treatment in common. They also vary from each other by time. The initial intent of the experiment was not for long term purposes. Over the years however, it has served as a visible learning field for farmers and students to appreciate the effects of nitrogen (N), phosphorus (P), potassium (K) deficiencies and also demonstrate practically the laying out of field trials are laid out (Christensen et al. 2008).

Each experiment is randomly laid with seven treatments which are then replicated four times in blocks. This gives a total experimental unit of 56 (7 treatments*4 replications) *2 experiments). The size of each plot is 4*9 m^2.

The soil of experiment 299-70 was drained in 1969, sowed and fertilised the following year. This is a depravation experiment where treatments are combined such that one or more individual nutrients are limited. The combination of individual nutrients to constitute a treatment for experiment 299-70 and the layout of the treatments on the field are shown in Table 1 below and Figure 2 below.

Table 1. Fertiliser treatment combination used for experiments 299-70 and 437-77. This treatment combination has been adopted since the establishment of the trial, with modifications made over the years, especially in experiment 437-77. Source:(Christensen et al. 2008).

Experiment 299-70				Experiment 437-77			
Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)
A	0	30	100	M	60	30	60
B	50	0	100	N	100	30	80
C	50	30	0	O	140	30	100
D	100	0	100	P	180	30	120
E	100	30	0	Q	-	15 t sheep dung	-
F	100	30	100	R	40	15 t sheep dung +	-
G	100	30	100 + Calcium	S	100	30	80 (since 1993)

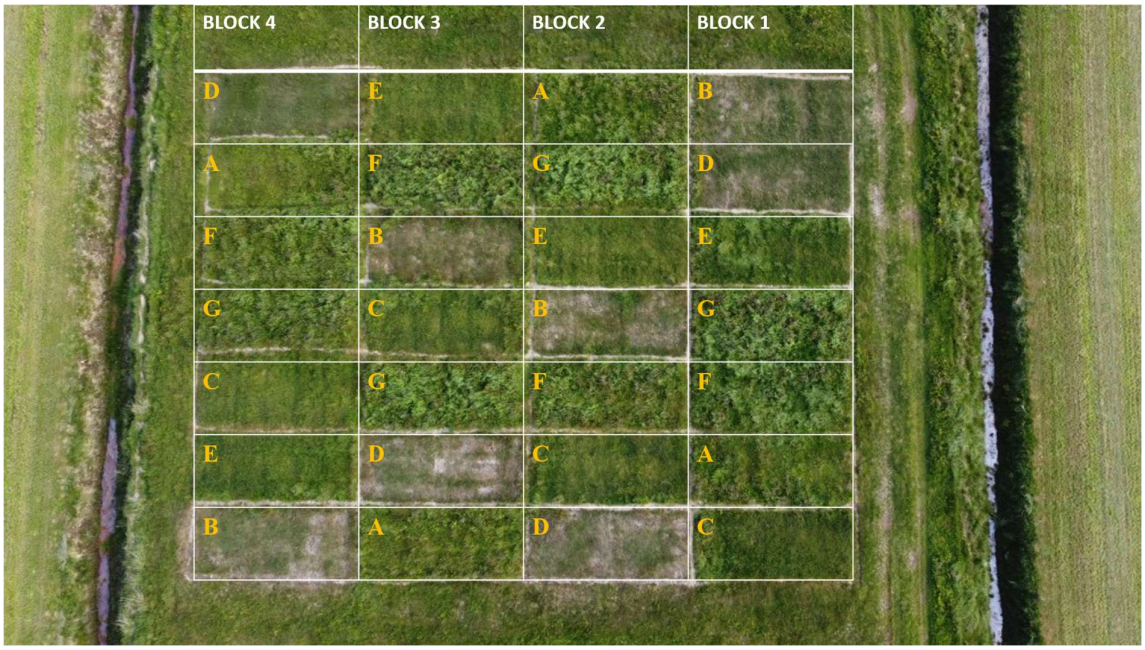

Figure 4. Pictorial view of experiment 299-70 with fertiliser treatments laid out on the field. (Source: Drone picture captured by Friederike Dima Danneil, 6.7.2023).

Experiment 437-77 (77) was established to test the effects of increasing levels of N and K and compare the incorporation of mineral fertiliser with sheep manure. This experiment was set up in 1977, seven (7) years after experiment 299-70. The combination of individual nutrients to constitute the treatments in Table 1 above and the layout of the treatments on the field is shown in Figure 3 below.



Figure 5. Pictorial view of experiment 437-77 with treatment layout on the field. (Source: Drone captured image by Friederike Dima Danneil, 6.7.2023).

3.2 Measurements

3.2.1 Soil sampling and sample preparation

Soil sampling for the experiments was done on the 10th of November 2022. Plots to be sampled were diagonally mapped out for four (4) sampling points. Using a soil auger at a depth of 12 cm, the top two (2) cm, which was mainly plant litter, was scraped off, leaving about 10 cm of soil. The samples were thoroughly mixed to obtain a single composite sample per plot. The soil was passed through a 2 mm sieve after drying at 40°C. The samples were stored in paper bags under room temperature.

3.2.2 Flux measurement using gas analyzer

A total of eight plastic rings (9 cm in diameter) were struck into the soil leaving about two cm above the soil surface in 8 randomly selected plots. The rings (plots filled green in Figures 1 C and 1D above) served as stands on which the enclosed chamber-based laser instrument which uses the OF-CEAS patented technology was placed. The LI-7810 $CH_4/CO_2/H_2O$ trace gas analyser instrument was used to measure the spatial variations in CH_4 and CO_2 fluxes. The fundamental idea behind this method is to enclose a specified amount of soil in a closed chamber that permits gas exchange between the chamber headspace and the soil below. Quantifying and converting the change in gas concentration over time in the chamber headspace into a flux rate, which represents the flux into or out of the soil (Zaman et al. 2021).

Rainy and windy weather during flux sampling made it difficult to take measurements hence the data was augmented with supplementary data from the experiment manager in order that meaningful conclusions could be made.



Figure 6. Flux measurement in the field using the LI-COR 7810 with a closed chamber. (Source: Alejandro Salazar).

3.2.3 Soil C, N and C/ N ratio

Dried and sieved soil was ball-milled using the Retsch PM 400 ball miller and stored in airtight containers. Prior to analysis, samples were weighed and wrapped with tin foils and then compressed into pills with a special press. The aim of the tin foil wrap was to contain and maintain sample integrity during combustion. The samples were weighed again after wrapping and pressing to account for the weight added by the tin foil. The pill samples were then loaded onto a labelled auto sampler for analysis. The SOC, and TN were determined by the a high-temperature combustion with high purity oxygen in a high purity Helium carrier as described in the Elementar varioMACRO cube (CHNS) methodology (Elementar Analysensysteme GmbH 2017). The final C, and N results were then calculated on a dry matter (DM) basis to correct for any moisture in the samples. C/N was then calculated using the C and N values. DM was calculated as the difference between the soil weight taken from the same ball milled sample used for the measurement before and after drying in an oven (salvisLAB Thermocenter) at 105ºC for 24 hours.

DM = dry sample weight/wet sample weight

Corrected % C, N and C: N values = output results from analyser * DM

3.2.4 Soil pH

The pH of the soil was measured using the method described by Blakemore et al (1987) but modified/ or adjusted where necessary. 5 g dry soil was weighed using a sensitive scale (PB602-S) into 50 ml tubes with lids.

25 ml of deionized water was added to the soil sample in replicate. In each batch of 20 samples, a reference sample was added to serve as a quality control check. Samples were shaken for 2 hours on a mechanical shaker (Heidolph multi-reax vortex mixer). The samples were read after the pH meter (OAKTON pH 550) was calibrated with buffers 4, 7 and 10.



Figure 7. pH measurement in the lab. (Source: Alejandro Salazar, 27.06.2023).

3.3 Data analysis

An ANOVA analysis was conducted to make comparisons between categorical variables and a linear regression approach was employed to analyse potential relationships between continuous variables. All statistical analyses were conducted in R, after cleaning and sorting of data in Microsoft Excel.

4. RESULTS

4.1 Fluxes

4.1.1 CO_2

The effects of different fertilisers on CO_2 flux were evaluated using a one-way ANOVA. There was a difference ($p < 0.05$) between CO_2 fluxes emitted from plots under different fertilisation schemes in experiment 299-70. In 20.07.2023, CO_2 emissions from treatment F (100 kg N/ha; 30 kg P/ha; 11 kg K/ha) were ca. 2 CO_2 µmol/m^2/s, which was more than double the emissions from treatments A, B and D (Figure 6).

In experiment 77, however, there was no statistical difference between the treatments ($p = 0.674$).

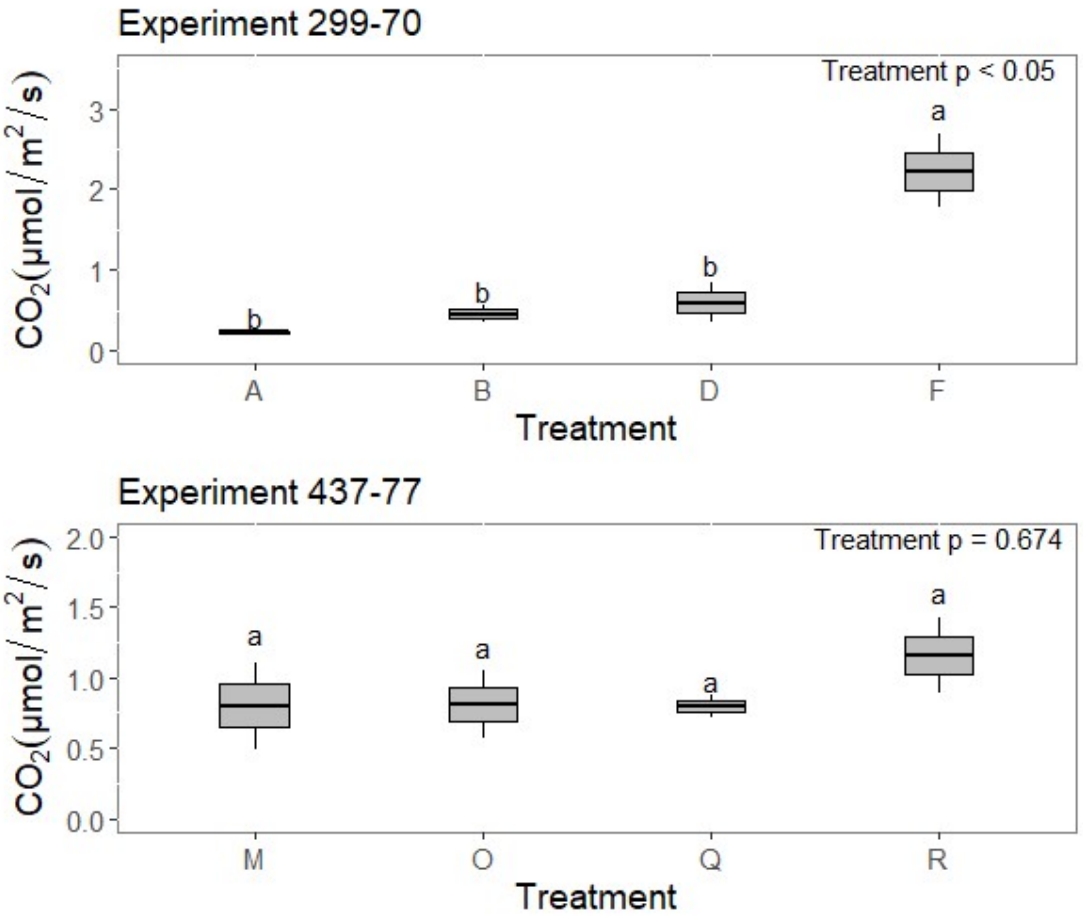

Figure 8. CO2 fluxes from different fertiliser treatments. Treatments with the same letter are not statistically different from each other.

4.1.2 CH_4

The one-way analysis of variance of CH_4 fluxes showed that there were no statistical differences in treatments for both experiments 299-70 and 437-77 in 20.07.2023.

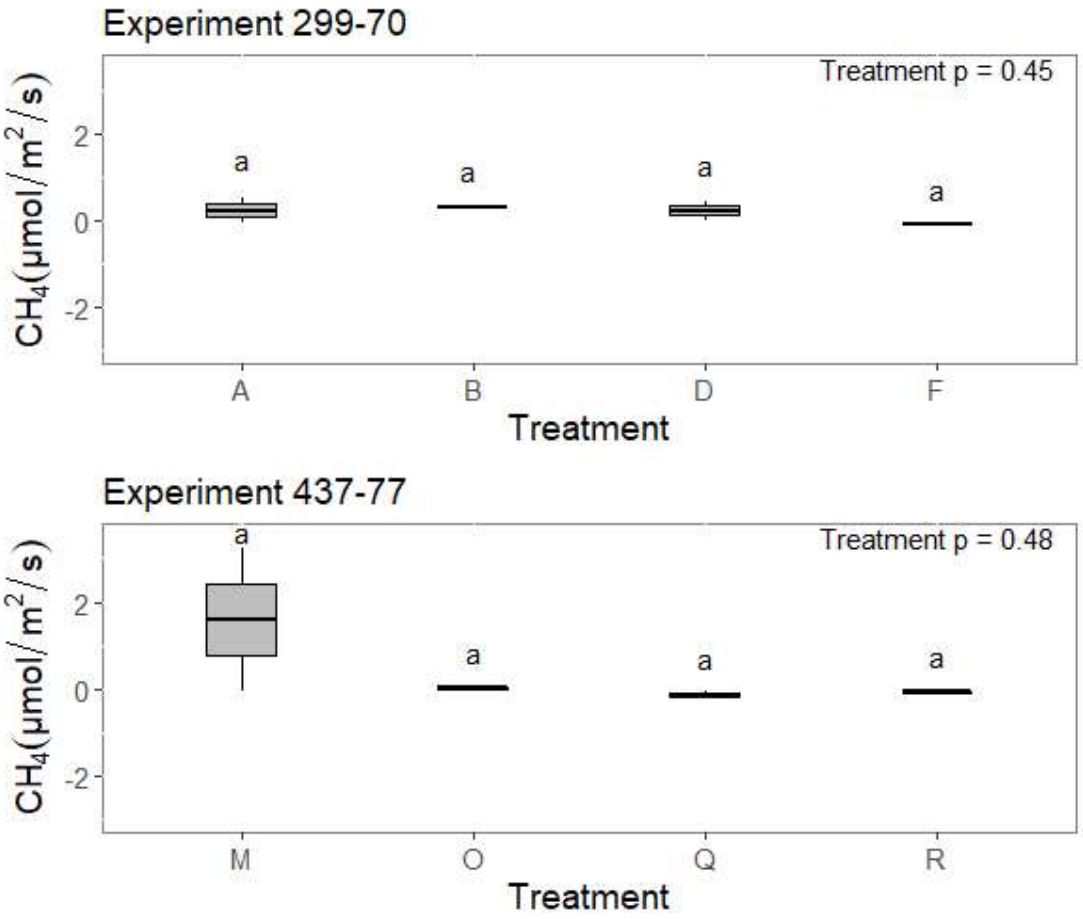

Figure 9.CH4 fluxes from different fertiliser treatments. Treatments with the same letters indicate no significant difference between treatments.

4.1.3 Soil organic carbon

There were significant detectable differences between some of the treatments. SOC in treatment D was significantly different from A and C. All other treatments were not statistically significantly different from each other. The fertilisation treatments had an effect on SOC in experiment 437-77 between most of the treatments too. SOC was highest in treatment P (180 kg N/ha; 30 kg P/ha; 120 kg K/ha) than in treatments M, N and R (Figure 8).

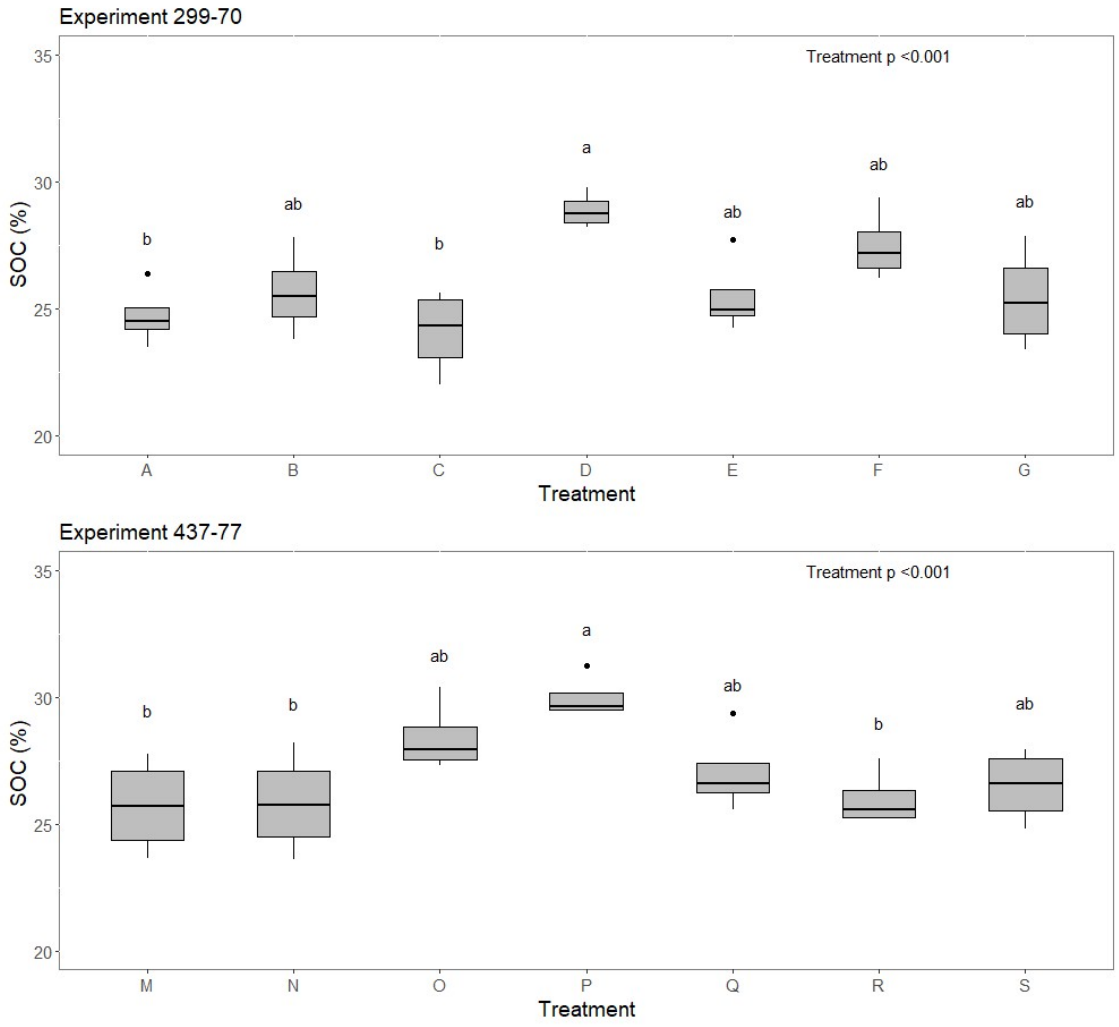

Figure 10. Soil organic carbon for different fertiliser treatments. Treatments with the same letters are not different statistically from each other.

4.1.4 Total nitrogen

From Figure 9, treatment D gave the highest value of %TN while C gave the least value of %TN. In experiment 299-70, treatment D was significantly different from A, C. The differences between treatments F, A and C were also significant.

In experiments 437-77, there was statistically significant difference between treatments P, M and N. From Figure 9 below, it was realised that the %TN values were generally lower in experiment 299-70. In experiment 437-77, treatment combinations with 100 kg/ha K, had higher %TN values. There was also a trend of increasing %TN with treatments with higher N content in the treatment combination.

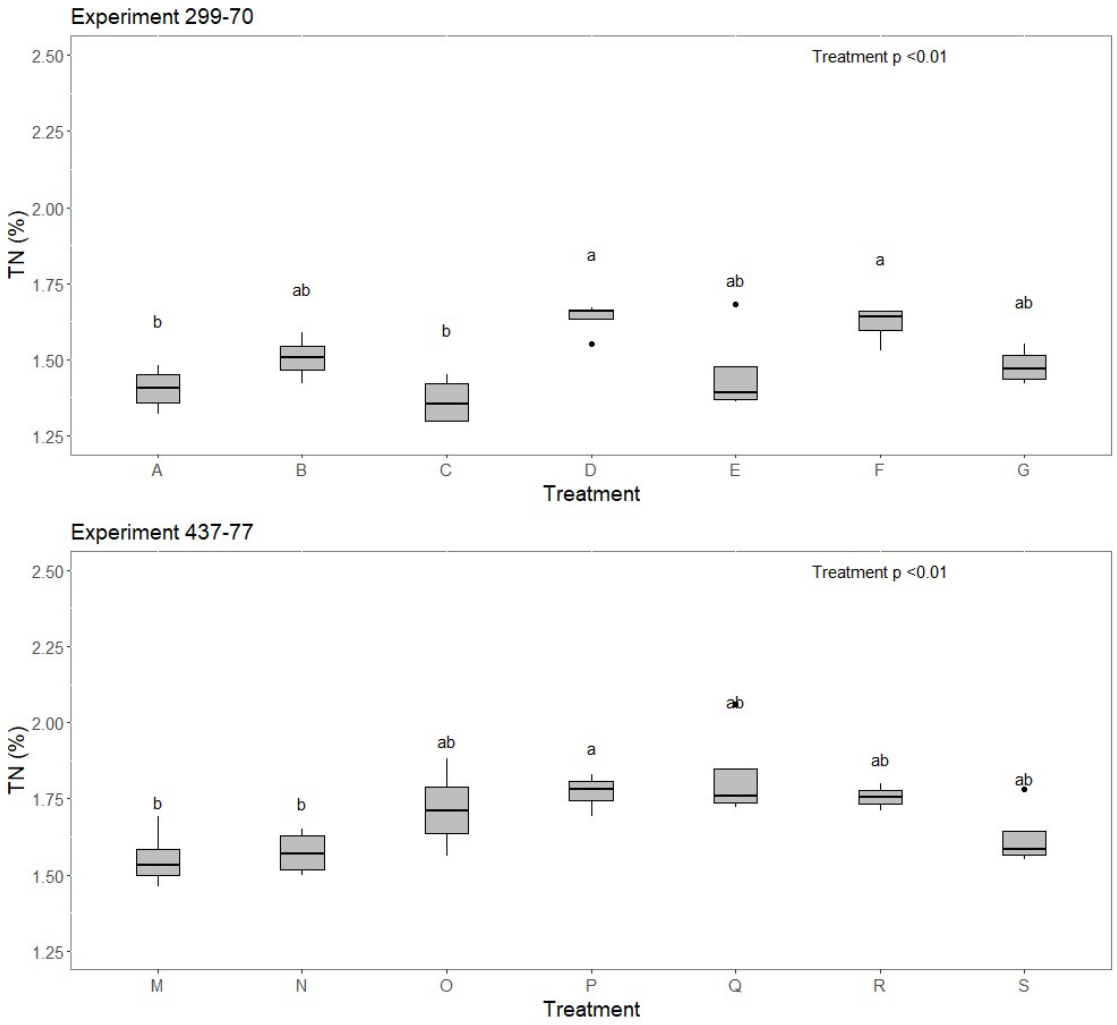

Figure 11. Percentage soil nitrogen for the different fertiliser treatments. Treatments different letters indicates statistical significance between such treatments.

4.1.5 Carbon nitrogen ratio

The analysis of the results for C/N revealed that there was statistical difference between some treatments under each experiment ($p < 0.01$). The results revealed that, C/N ratio of treatments in experiment 299-70 were generally higher.

In experiment 437-77, treatments Q and R had the least C/N ratio as shown in Figure 10 below.

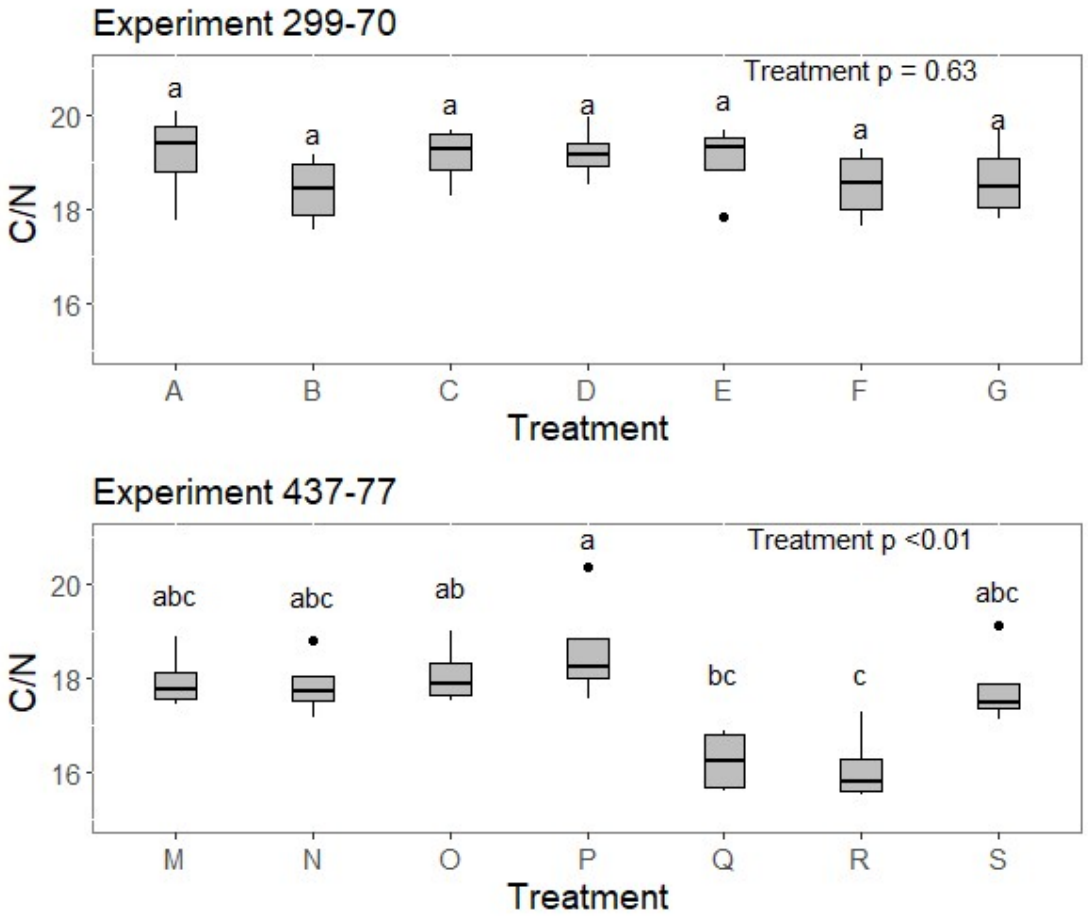

Figure 12**.** Percentage C/N ratio for treatments in different experiments.

4.2 Soil pH

An ANOVA was performed to analyse the effects of different fertilisation treatments on soil pH. The results showed that there were highly significant differences between different fertiliser treatments ($p < 0.001$). From experiment 299-70, the pH of treatment B was the highest while the soil in treatment F gave the least pH value. In experiment 437-77, pH in treatments Q and R were higher than the rest of the other treatments with treatment P recording the least pH value as shown in Figure 11 below.

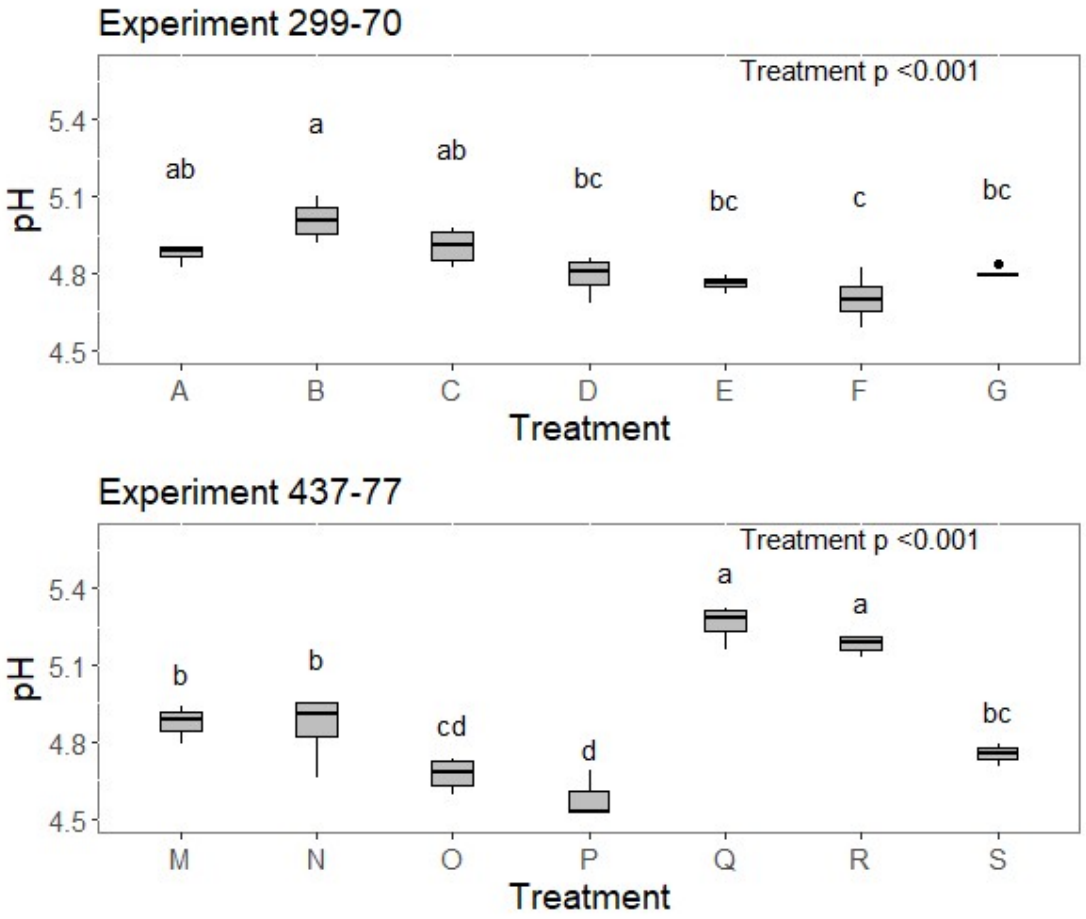

Figure 13. The effects of different fertiliser treatments on soil pH for experiment 299-70 and 437-77.

5. DISCUSSION

5.1 Fluxes

5.1.1 CO_2 emission

The outcome of the research has provided insight into the effects of different fertilisers on CO_2 emissions. The results, even though not conclusive, are due to several other factors that affect CO_2 emissions from an ecosystem. The results from this research support other works that state that the type of fertiliser applied to the soil affects the GHG emissions. Fertilisers serve as a food source for soil microbial activities. Increased substrate implies higher microbial respiration, hence increased CO_2 flux (Wang et al. 2022).

5.1.2 CH_4

The moisture on 20.07.2023, was low (data not included in this report). In soil where water is limiting, there are a lot of pores where air exchange with the soil air can take up oxygen from the air above ground. The enzymatic and microbial oxidation of CH_4 produced by methanogens

is minimal. The activities of methane-oxidising bacteria increase, hence, CH_4 emission is low (Ho et al. 2015).

5.2 Soil chemical properties

5.2.1 Total nitrogen

In experiment 299-70, it was observed that treatment A which had 0% of N during treatment formulation had higher %N than treatments C and E. It is speculated that the increased % K in treatment A contributed to it outperforming treatments C and E which had 0% K. Treatments with full %K (100 kg/ha) had relatively higher %TN compared with those treatments with 0 kg/ha K. Low amounts of K in the soil (Ullah Chaudhry & Khalid Malik 2000) affects the ability of crops to fully utilise N fertiliser (Akhtar et al. 2022). The above could explain the positive relationship observed between N and K during treatment formulation as treatments with higher K had higher %N.

One of the objectives of experiment 437-77 was to test the effect of increasing rate of N and K on grass growth (Christensen et al. 2008). The increasing trend in % N across treatment could be due to N accumulation and increasing levels of K as already indicated above.

5.2.2 Soil organic carbon

The observation made in %SOC for both experiments were similar to the % N observed above. SOC content increased with increasing N. A study conducted on a long-term implication of fertilisation revealed that the addition of soil amendments increased the concentration of nutrients in the soil (Christensen et al. 2008; Ge et al. 2018).

5.2.3 C/ N ratio

Treatments in experiment 299-70 generally recorded higher C:N ratios. This is observed in the % N values which are low. C:N ratio of 10 is optimum (Doran & Jones 1997). Higher ratios result in microbial immobilisation hence low soil N for plants use.

The low amount of C:N ratio observed in treatment and R in experiment 437-77 could be attributed to the application of sheep dung. This implies that there is likely more mineralisation of N for plant use. This is true as these two treatments recorded higher %N in Figure 6. Rasmussen et al (1980) noted a similar outcome of decreased C:N ratio in soils treated with manure.

5.3 Soil pH

The soil pH in general for both experiments was below 7 (acidic) and there were detectable differences between them. This could be attributed to the geology of Icelandic soils. The soil on which these experiments were established is histosol and a characteristic of this soil is low pH (Arnalds 2008). The reason why the effect of Ca was not seen in treatment D could be because liming with Ca was done in the year of establishment (1970) and this year (2023) hence the buffering effect of the first liming might have worn off over the years. The soil samples for pH analysis were taken in 2022, hence the effect of the 2023 application was not reflected. This is confirmed in a report published by (Christensen et al. 2008), where they indicated that the initial pH of treatment G after liming was 5.8 in 1971.

There was not much grass growth in treatment B of 70 hence the high pH value could be because of less redox activity in the rhizosphere.

In experiment 77, treatments Q and R had higher pH values, and this could be due to the additional nutrient component of the sheep dung, especially for Q where there was no added chemical nutrient. The lowest pH value for P could be because it had the highest N composition during the formulation of the treatment. The excess N could have been converted to ammonia hence the low pH recorded.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study showed that different fertilisers can result in different rates of GHG emissions. Fertilisers with higher rates of nutrients (treatment F), for example, resulted in higher CO_2 emissions.

The study also found that treatment D resulted in higher SOC, TN, and C/N ratio for experiment 299-70. The outcome is indicative that increasing fertilisation with NPK increases SOC and TN content of the soil. The pH values of treatments with higher N were generally lower in both experiments. Sheep dung-treated plots had higher pH values than other treatments in experiment 437-77. The effect of Ca was not seen to play a significant role in treatment G, probably due to the long time that had passed since the last application.

The pH values of treatments with higher N decreased soil pH in both experiments. Sheep dung-treated plots had higher pH values than other treatments in experiment 437-77. The use of sheep dung increased the buffering capacity of the soil hence plots treated with sheep manure had increased pH. The effect of Ca was not seen to play a significant role in treatment G, probably due to the long time that had passed since the last application.

6.2 Recommendations

Global climate change is eminent, and the most important step now is to ensure that efforts are taken towards adopting measures that will mitigate its impact. From the findings of this study, it is recommended that:

- There is the need for stakeholder engagement between governments, researchers, and all actors along the fertiliser value chain on promoting integrated and smart fertiliser use system. This will ensure that fertilisers with minimal emissions of GHG are promoted for use by farmers.

- The incorporation of animal manure can increase the buffer capacity of the soil, hence increasing soil pH.
- The CSIR-SARI could consider establishing long-term fertiliser trials in its mandate areas to assess the long-term impact of the different fertilisers available on the Ghanaian market on GHG emissions and on global climate change and long-term impact on soil fertility. Long-term experiments are of scientific interests to researchers

globally as they create an avenue to track soil quality over time forecast crop fertiliser requirement and the potential relationships that exist between the soil and the environment (Ge et al. 2018). This would strategically place it to recommend climate smart fertilizer use system for the country.

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APPENDICES

Appendix 1
Fluxes measurement

Date	Expt	Treatment	Technical Rep	CO_2	CH_4	Temp	Moisture
5/4/2023	70	A	1	0.2122575	-0.1321775	6.9975	0.9495
5/4/2023	70	A	2	0.0212175	0.1023275	7.35	0.355
5/4/2023	70	B	1	0.03159	0.023483333	8.06666667	0.95
5/4/2023	70	B	2	0.062035	0.2770975	7.16	0.554375
5/4/2023	70	D	1	0.16645	0.135063333	7.67666667	0.72878333
5/4/2023	70	D	2	-0.004855	-0.1453975	7.625	0.372325
5/4/2023	70	F	1	0.18501333	-0.02849	7.15	0.95
5/4/2023	70	F	2	0.117125	-0.2176475	6.85	0.59025
5/3/2023	77	A	1	0.18751	-0.013293333	14.3666667	0.493
5/3/2023	77	A	2	0.156525	0.1191225	13.24	0.65
5/3/2023	77	C	1	0.24105667	-0.033576667	13.4	0.82266667
5/3/2023	77	C	2	0.23299	0.129576667	13.4666667	0.52433333
5/3/2023	77	E	1	0.25361	-0.0663	13.0966667	0.412
5/3/2023	77	E	2	0.23821667	-0.05483	13.2766667	0.5156
5/3/2023	77	F	1	0.19861333	-0.031693333	13.4	0.71106667
5/3/2023	77	F	2	0.13420333	-0.00557	14.5233333	0.7629
5/16/2023	70	A	1	0.26611333	-0.02049	13.2333333	0.75566667
5/16/2023	70	A	2	0.17282	-0.032756667	13.3716667	0.6022
5/16/2023	70	B	1	-0.5782933	-2.138886667	15.2233333	0.53956667
5/16/2023	70	B	2	0.34688667	-0.021993333	13.6666667	0.55833333
5/16/2023	70	D	1	0.21703333	0.163193333	14.3	0.766
5/16/2023	70	D	2	0.33173	0.002366667	13.9666667	0.40923333
5/16/2023	70	F	1	0.21802333	-0.01154	13.9883333	0.95
5/16/2023	70	F	2	0.22589667	-0.045606667	13.46	0.9192
5/16/2023	77	A	1	0.18065333	-0.031106667	12.2666667	0.567
5/16/2023	77	A	2	0.16557	0.14738	10.0333333	0.657
5/16/2023	77	C	1	0.35948667	-0.015016667	11.5	0.47833333
5/16/2023	77	C	2	0.1653	-0.005246667	10.7	0.95
5/16/2023	77	E	1	0.30736	-0.059386667	8.9	0.454
5/16/2023	77	E	2	0.28883333	-0.06079	8.97666667	0.66173333
5/16/2023	77	F	1	0.26439333	0.052756667	9.33333333	0.95
5/16/2023	77	F	2	0.20979333	-0.028836667	8.84	0.37835
5/25/2023	70	A	1	0.07717667	-0.012393333	11.7666667	0.82633333
5/25/2023	70	A	2	0.12435667	-0.024876667	12.6	0.60533333
5/25/2023	70	B	1	0.18608	0.344156667	11.6333333	0.53633333
5/25/2023	70	B	2	0.0661975	-0.00812	11.825	0.524
5/25/2023	70	D	1	0.26007	0.0116325	11.775	0.8105
5/25/2023	70	D	2	0.318485	-0.01897	12.09625	0.496575
5/25/2023	70	F	1	0.21026667	-0.006946667	12.3	0.37826667

Date	Expt	Treatment	Technical Rep	CO_2	CH_4	Temp	Moisture
5/25/2023	70	F	2	0.17611	-0.004926667	11.7583333	0.44483333
5/25/2023	77	A	1	0.04680667	-0.022643333	11.8333333	0.65876667
5/25/2023	77	A	2	0.13470333	0.016711111	11.3866667	0.95
5/25/2023	77	C	1	0.09319	-0.003186667	11.5833333	0.279
5/25/2023	77	C	2	0.12734333	-0.008216667	10.9466667	0.88666667
5/25/2023	77	E	1	0.1636025	-0.0250125	11.8	0.4707625
5/25/2023	77	E	2	0.27584	0.002266667	12.0333333	0.907
5/25/2023	77	F	1	0.16045667	0.001316667	11.6666667	0.773
5/25/2023	77	F	2	0.22668333	0.003383333	11.9	0.7125
6/12/2023	70	A	1	0.31969	0.03916667	12.73	0.435
6/12/2023	70	A	2	-0.5492167	-2.7378667	15.43	0.44
6/12/2023	70	B	1	0.18593333	2.37922	12.17	0.334
6/12/2023	70	B	2	0.21144	-0.0089033	14.7	0.439
6/12/2023	70	D	1	0.37351	0.14830333	12.37	0.435
6/12/2023	70	D	2	-0.5492167	-2.7378667	17.28	0.563
6/12/2023	70	F	1	0.98146667	-0.0128533	13.14	0.509
6/12/2023	70	F	2	0.43839	-0.0099167	13.89	0.329
6/12/2023	77	A	1	0.800656667	-0.018766667	11.5983333	0.45503333
6/12/2023	77	A	2	0.4879325	-0.1954575	11.79	0
6/12/2023	77	C	1	0.281053333	0.003586667	11.6	0.50166667
6/12/2023	77	C	2	0.21316	-0.004076667	11.56375	0.44375
6/12/2023	77	E	1	0.328776667	-0.0431	11.6733333	0.37875
6/12/2023	77	E	2	0.841625	0.0379325	12.3	0.26875
6/12/2023	77	F	1	1.129563333	-0.025916667	11.6333333	0.5416
6/12/2023	77	F	2	0.448516667	0.041636667	13.0333333	0.601
6/25/2023	70	A	1	0.072666667	-0.013	11.76666667	0.823333333
6/25/2023	70	A	2	0.113666667	-0.025	12.6	0.906666667
6/25/2023	70	B	1	0.193666667	0.344666667	11.63333333	0.8
6/25/2023	70	B	2	0.05275	-0.005	11.9	0.52
6/25/2023	70	D	1	0.217	0.011333333	11.93333333	0.86
6/25/2023	70	D	2	0.195666667	0.001666667	12.23333333	0.56
6/25/2023	70	F	1	0.216	-0.004	12.3	0.45
6/25/2023	70	F	2	0.187	-0.005	11.73333333	0.44
6/25/2023	77	A	1	0.06	-0.014333333	11.83333333	0.65
6/25/2023	77	A	2	0.282666667	0.001333333	11.96666667	0.923333333
6/25/2023	77	C	1	0.114333333	-0.009333333	11.6	0.59
6/25/2023	77	C	2	0.124	0.072333333	11.56666667	0.95
6/25/2023	77	E	1	0.16175	-0.013	11.925	0.625
6/25/2023	77	E	2	0.282666667	0.001333333	11.96666667	0.923333333
6/25/2023	77	F	1	0.116	-0.019666667	11.86666667	0.53
6/25/2023	77	F	2	0.124	0.072333333	11.56666667	0.95
20/07/2023	70	A	1	0.18000333	0.51329667	20.9	0.459
20/07/2023	70	A	2	0.26037667	-0.0605233	21.71	0.23323333

Date	Expt	Treatment	Technical Rep	CO_2	CH_4	Temp	Moisture
20/07/2023	70	B	1	0.55424	6.80446667	21.2733333	0.2807
20/07/2023	70	B	2	0.34039	0.29522333	21.1666667	0.17533333
20/07/2023	70	D	1	0.83903667	0.43874333	21.3	0.27833333
20/07/2023	70	D	2	0.34593	-0.0020233	21.9	0.32233333
20/07/2023	70	F	1	2.68361	-0.09912	21.3666667	0.22933333
20/07/2023	70	F	2	1.76788	-0.0588633	21.3666667	0.40433333
20/07/2023	77	A	1	0.49499	-0.0832	21.1666667	0.19533333
20/07/2023	77	A	2	1.10623667	3.2253	19.62	0.2963
20/07/2023	77	C	1	0.56834	-0.023656667	20.5466667	0.20426667
20/07/2023	77	C	2	1.04968333	0.051466667	19.9666667	0.164
20/07/2023	77	E	1	0.71495667	-0.243836667	19.9	0.38666667
20/07/2023	77	E	2	0.87486667	-0.08143	19.9	0.299
20/07/2023	77	F	1	1.42459333	-0.12188	20.2333333	0.24266667
20/07/2023	77	F	2	0.88902	-0.04593	18.98	0.23856667
26/07/2023	70	A	1	0.22822333	1.2765	13.3	0.27533333
26/07/2023	70	A	2	0.16730333	-0.0357967	13.2333333	0.34233333
26/07/2023	70	B	1	-0.78154	0	14.4333333	0.3338
26/07/2023	70	B	2	0.18260333	0.03791667	13.1730167	0.00654
26/07/2023	70	D	1	0.31980667	0.06144	14.0666667	0.33956667
26/07/2023	70	D	2	1.04544667	0.03548	13.1	0.36133333
26/07/2023	70	F	1	0.31356333	-0.11456	13.7633333	0.17363333
26/07/2023	70	F	2	1.06836	-0.0269267	13.4666667	0.264
26/07/2023	77	A	1	0.4832	0.78276	13.5516667	0.09806667
26/07/2023	77	A	2	0.63105333	-0.0729633	18.895	0.0178
26/07/2023	77	C	1	0.46737667	0.12365667	13.9333333	0.366
26/07/2023	77	C	2	1.01617667	-0.04801	19.5	0.332
26/07/2023	77	E	1	1.26151667	-0.27375	14.3333333	0.24273333
26/07/2023	77	E	2	1.38339667	-0.19976	15.0333333	0.31366667
26/07/2023	77	F	1	0.64018333	0.41145667	13.3	0.256
26/07/2023	77	F	2	0.90874	-0.1364067	18.9	0.2122

Appendix II
Output of chemical analysis after DM calculation.

Expt	Treatment	Rep	N%	C%	C/N%
70	A	1	1.482229258	24.44332751	17.7533821
70	B	1	1.420014625	23.79626325	18.01429909
70	C	1	1.411613963	25.6475729	19.69342423
70	D	1	1.669453826	29.76850923	19.23681319
70	E	1	1.677834452	27.73494855	17.83001029
70	F	1	1.531428571	26.77333333	19.02770068

Expt	Treatment	Rep	N%	C%	C/N%
70	G	1	1.501223529	26.17995294	18.88056471
70	A	2	1.37046723	24.57404651	19.6679055
70	B	2	1.58512931	27.81465517	18.90711207
70	C	2	1.447898048	25.2361974	19.01918286
70	D	2	1.662231293	29.05196372	19.05927052
70	E	2	1.361230769	24.88446154	19.684
70	F	2	1.65689011	27.59489011	18.11297473
70	G	2	1.438602763	24.23028843	18.11789447
70	A	3	1.324437956	23.47690511	19.14180146
70	B	3	1.529429719	24.95628916	17.56508594
70	C	3	1.29834507	22.03307746	18.28414648
70	D	3	1.66119708	28.21418978	18.51787835
70	E	3	1.369513185	24.2388641	19.20248479
70	F	3	1.620261628	26.19259302	17.63826628
70	G	3	1.418581443	23.38228454	17.80897732
70	A	4	1.435329193	26.39125466	20.09428075
70	B	4	1.484943478	26.0051	19.15467739
70	C	4	1.300528455	23.42364837	19.58730691
70	D	4	1.546883249	28.44787817	19.97923553
70	E	4	1.40672093	25.07723256	19.48904186
70	F	4	1.662405034	29.38516476	19.30038055
70	G	4	1.547443645	27.84193046	19.71500192
77	A	1	1.548398467	26.86683525	18.88436782
77	B	1	1.645360825	28.22232577	18.80899711
77	C	1	1.560612903	27.29606452	18.99886022
77	D	1	1.685853604	31.26342568	20.34190225
77	E	1	1.736716981	26.74128302	16.84910943
77	F	1	1.742469307	27.60128119	17.27783248
77	G	1	1.569106942	27.47411257	19.12312233
77	A	2	1.51209854	24.57837591	17.61383431
77	B	2	1.624940206	26.71319588	17.75852206
77	C	2	1.656681529	27.60593418	18.07518747
77	D	2	1.797285714	29.79704762	18.15554286
77	E	2	1.718390144	26.43769405	16.77349405
77	F	2	1.804965753	25.91104452	15.61121404
77	G	2	1.603525483	25.75757996	17.47418506
77	A	3	1.463193676	23.64525296	17.43865731
77	B	3	1.524730435	24.78962087	17.64606887
77	C	3	1.761298246	28.28976316	17.50279232
77	D	3	1.760792453	29.51215094	18.33949057
77	E	3	1.781404669	25.56500584	15.60295156
77	F	3	1.772212598	25.25620669	15.51110571

Expt	Treatment	Rep	N%	C%	C/N%
77	G	3	1.552858896	24.8086135	17.44312638
77	A	4	1.692298729	27.73689619	17.88272034
77	B	4	1.501547445	23.58717153	17.14775912
77	C	4	1.877729258	30.41157205	17.68406114
77	D	4	1.828976864	29.46309512	17.56264679
77	E	4	2.056626747	29.36247106	15.69899082
77	F	4	1.714178506	25.18615665	15.94750528
77	G	4	1.781776573	27.93995879	17.10865575

Appendix III
Average soilpH

Expt	Treatment	Rep	pH (H2O)
70	A	1	4.82
70	B	1	5.035
70	C	1	4.855
70	D	1	4.68
70	E	1	4.79
70	F	1	4.665
70	G	1	4.79
70	A	2	4.875
70	B	2	4.915
70	C	2	4.815
70	D	2	4.775
70	E	2	4.765
70	F	2	4.585
70	G	2	4.79
70	A	3	4.895
70	B	3	4.97
70	C	3	4.96
70	D	3	4.835
70	E	3	4.72
70	F	3	4.725
70	G	3	4.835
70	A	4	4.895
70	B	4	5.1
70	C	4	4.975
70	D	4	4.86
70	E	4	4.76
70	F	4	4.82
70	G	4	4.785
77	A	1	4.91
77	B	1	4.865
77	C	1	4.585

Expt	Treatment	Rep	pH (H2O)
77	D	1	4.52
77	E	1	5.155
77	F	1	5.125
77	G	1	4.735
77	A	2	4.79
77	B	2	4.655
77	C	2	4.635
77	D	2	4.475
77	E	2	5.255
77	F	2	5.17
77	G	2	4.7
77	A	3	4.935
77	B	3	4.95
77	C	3	4.725
77	D	3	4.53
77	E	3	5.31
77	F	3	5.205
77	G	3	4.785
77	A	4	4.855
77	B	4	4.95
77	C	4	4.72
77	D	4	4.685
77	E	4	5.315
77	F	4	5.205
77	G	4	4.765

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