Data Article

Data of biomass and N in grass and clover roots, stubbles, and herbage and associated N₂O and CO₂ emissions, inclusive soil air composition, following autumn ploughing – A field study

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A R T I C L E   I N F O

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Keywords:
Denitrification
Decomposition
Nitrous oxide
Crop residue
Low temperature
Freeze-thaw
Snow

A B S T R A C T

This article presents the detailed data of the soil characteristics, field management, amount and N content of below-(roots + crown) and aboveground (stubble and herbage) grass mixture, red clover and red clover grass swards at the end of the 3rd production year, together with fluxes of greenhouse gas emissions (N₂O, CO₂, CH₄) and soil air composition (CO₂, N₂O, CH₄, N₂ and O₂) of a field experiment in Norway. These data supplement the findings presented in the research article “Roots and other residues from ley with or without red clover: quality and effects on N₂O Emission Factor in a partly frozen soil following autumn ploughing” (Bleken et al. 2022). For understanding of the effects of incorporating ley above- and belowground residues on cumulative greenhouse emissions refer to article from this research.

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Specifications Table

| Subject                  | Agricultural Sciences, Agronomy and crop |
|--------------------------|----------------------------------------|
| Specific subject area    | Root biomass, Ley residues and Greenhouse gas emissions from agricultural soils |
| Type of data             | Table                                   |
|                          | Figure                                   |
|                          | Pictures                                 |
| How data were acquired   | Plant and soil material was collected in a field experiment in a silty clay loam (31% clay, 46% silt) from plots of three different forage leys (a grass mixture, a red clover-grass mixture, a red clover in pure stand) at the end of the third production year. Stubble, defined as the biomass present above ground after forage harvest, was collected from representative subplots (60 cm X 60 cm), cutting with a knife at 0–0.5 cm depth. Soil core samples (for collection of crown and roots) were taken with a root auger (ø 8cm) to 30 cm soil depth. Plant crown are defined as belowground organs where stems and roots join each other, but morphologically different from both. Roots and stubbles were carefully washed and cleaned from debris, and dried in a ventilated oven at 40 °C, then analyzed for elemental C and N (Dumas method, Leco CHN628). More quality variables are reported in [1]. Roots and crown amounts were corrected for soil minerals impurities based on the recorded total C concentration and assuming that the correct C content was 45% of the dry biomass. After early autumn ploughing, soil gas fluxes were estimated using manual closed chambers (inner height 19.5 cm) and two fixed aluminum frames per plot (51 × 51 × 20 cm inner size) inserted to 10–15 cm depth in plots with grass mixute and red clover grass-mixture. Chambers were equipped with a 3 mm diameter pressure equilibrium tube and with a sampling tube, assessing the middle of the chamber, ending with a three-way stopcock valve. Gas samples were collected by deploying the chambers on the frames and withdrawing 15 ml gas samples from the chamber headspace with a 20 ml polypropylene syringe at start and 45 minutes later. Before sampling, air in the chamber headspace was mixed by pulling and pushing the plunger of the syringe 3–4 times. The sample was transferred through the three-way valve to He washed, pre-evacuated 12 ml glass vials crimped with butyl rubber septa, causing an over pressure in the vials in order to avoid contamination during sample storage. There were 45 sampling events over 252 days. Sampling frequency varied and was higher when high fluxes could be expected, e.g. immediately after rain and during thawing, and also just before these events in order to identify peak fluxes. The composition of soil air was obtained using probes inserted at 8, 24, 40 cm depth. The probes had an air-permeable cup (pore Ø 100 μm) tightened to PTFE tube (inner Ø 0.97 mm) which runs through a PVC tube (outer Ø 3.3 cm) ending with a three-way stopcock valve (see [2,3] for details). They were installed into pre-augered holes, at a 60° angle to the soil surface. All gas samples were analysed using gas chromatography (GC, model 7890A, Agilent, Santa Clara, CA, USA) using a 30-m wide bore Poraplot Q (0.53 mm) column at 38 °C with back flushing and helium (He) as carrier gas. The GC was equipped with an electron capture detector (ECD), a thermal conductivity detector (TCD) and flame ionization detector (FID). The ECD was run at 375°C with 17 ml min⁻¹ Ar/CH4 (90/10 vol %) as a makeup gas. The GC was connected to an autosampler via a peristaltic pump (Gilson minipuls 3, Middleton, WI, USA), pumping approximately 2.5 ml gas into a 250 μl sampling loop maintained at 1 Atm pressure. The injection system was back-flushed by He 6.0 before each sampling to minimize memory effects. |

(continued on next page)
Soil temperature and moisture were measured using four dataloggers (EM50 datalogger, Decagon Devices, Pullman, WA, USA), connected with temperature and moisture sensors (STTM).

Data format
Analysed
Calculated

Description of data collection
Roots and aboveground residue biomass and qualities were determined in a grass mixture, a red clover in pure stand, and a red clover-grass mixture. Gas soil fluxes were recorded over 252 days in plots of the grass mixture and of the red clover-grass mixture, plunged in at the end of the third productive year. Living grass ley and de-vegetated plots kept were used as controls. Soil air data were collected at 8, 24 and 40 cm depth from selected treatments.

Data source location
Institution: Faculty of Environmental Sciences and Natural Resource Management, NMBU: Norwegian University of Life Sciences
City/Region: Ås, Viken
Country: Norway
Latitude and longitude for collected samples/data: 59°39′47″N, 10°45′42″E

Data accessibility
Repository name: NMBU Open Research Data
https://dataverse.no/dataverse/nmbu
Data identification number:
https://doi.org/10.18710/3JGCCO
Direct URL to data:
https://dataverse.no/dataset.xhtml?persistentId=doi:10.18710/3JGCCO

Related research article
M. A. Bleken, T. Rittl, S. Hansen, S. Nadeem. Roots and other residues from ley with or without red clover: quality and effects on N₂O Emission Factor in a partly frozen soil following autumn ploughing. STOTEN [1]
http://dx.doi.org/10.1016/j.scitotenv.2022.154582

Value of the Data
- The data combine direct measurement of quantity and quality of below- and aboveground residue from different type of forage leys, with sampling of N₂O fluxes after autumn ploughing of the residues in the same field. These data constitute an unique contribution to the assessment of emission factors from non removable crop residues compared to emissions from harvestable residues.
- In addition to N₂O, the dataset also includes CO₂ emissions and CH₄ consumption and data on soil air composition, which are important to decoupling the mechanisms behind the production of soil greenhouse gas emissions.
- Plant residue biomass data and quality are useful for plant physiologist and ecologist.
- These data are relevant for researchers working with modelling of N₂O emission from plant residues, for agronomists and environmental scientists and for stakeholders involved in inventories of greenhouse gas emissions.
- The data can be used to parameterize, calibrate or validate models which estimate the impact of above- and belowground residues on greenhouse gas emissions. The data can also be used in meta-analysis looking for convenient methods to estimate N₂O emission factors from plant residues.

1. Data Description

This article includes the descriptive data (means), analysed and calculated data on the effects of ley type on below- and aboveground plant residues and on greenhouse gas emissions and soil air composition. The data presented here include detailed information of soil characteristics and field management, and data collected in the experiment, whereas the data and statistic of the other parameters were used in the analyses reported in the related article [1]. Replicate data are available in the linked database.

Site description. Table 1 gives a detailed characterization of the plough layer (0–20 cm) and subsoil of an artificially drained Umbric Epistagnic Retisol soil [4] localized in Ås, Norway (59°39′47″N, 10°45′42″E). The treatments were placed in a long-term trial and utilize plots
Table 1
Soil characteristics in the plough layer (0–20 cm) and subsoil. Mean values and (standard deviation). Soil pore distribution and bulk density assessed in summer 2014 when the field was cropped with spring oats.

| Soil characteristics | 0–20 | 20–35 | 35-50 |
|----------------------|------|-------|-------|
| Sand (%)a | 22 (8.7) | 32 (10) | 18 (2.5) |
| Silt (%)a | 46 (6.6) | 39 (6.1) | 50 (2.5) |
| Clay (%)a | 31 (3.7) | 29 (4.9) | 32 (3.4) |
| SOC (%) | 2.81 (0.35) | 0.99 (0.6) | 0.48 (0.2) |
| Total N (%) | 0.25 (0.04) | 0.10 (0.05) | 0.07 (0.02) |
| C:N | 11.14 (0.74) | 9.5 (2.1) | 6.8 (1.5) |

- Plot for gas fluxes and root sampling
- Limed plots, only used for root sampling

| Soil depth (cm), (n ≥ 16, sampled in 2012) |
|------------------------------------------|
| pH\textsubscript{H\textsubscript{2}O}\textsuperscript{b}, 0 -20 cm depth |
| 5.10 (0.18), (n = 14) | 6.05 (0.10), (n = 17) |
| pH\textsubscript{CaCl\textsubscript{2}}\textsuperscript{b}, 0 -20 cm depth |
| 4.70 (0.17), (n = 45) | 5.77 (0.22), (n = 33) |
| Depth of bulk analysis samples (cm) |
| 10 − 15 (n = 23) | 25 − 30 (n = 24) | 40 − 45 (n = 16) |
| Soil bulk density (g soil cm\textsuperscript{−3})c |
| 1.18 (0.08) | 1.51 (0.14) | 1.71 (0.09) |
| Pore volume (% of total soil volume)c |
| 54 (3.4) | 44 (4.9) | 37 (2.9) |
| 0.1 kPa (Field capacity, %)c |
| 36 (2.4) | 35 (3.8) | 29 (3.5) |
| Water filled volume,1 kPa (%c)d |
| 31 (2.0) | 33 (4.0) | 27 (3.6) |
| Water filled volume, 15 kPa |
| (Permanent wilting point, %) |
| 11 (1.4) | 18 (4.8) | 17 (3.8) |
| Air permeability (μm\textsuperscript{2}) |
| 42 (23) | 9 (7) | 3.6 (1.7) |

\textsuperscript{a} Data are from an unpublished study on the same field (Blekken, Børresen and Krogstad), susceptible to minor changes due to recalibration of the methods used.
\textsuperscript{b} Sampled spring 2019. Soil dried at ambient temperature.
\textsuperscript{c} Assessed in a previous cereal crop (2014) during the growing season. In the plough layer the initial porosity is likely underestimated, and so the water content at field capacity is overestimated compared to the conditions shortly after ploughing. This thus not affect the wilting point, which depends on the soil texture and SOM content.
\textsuperscript{d} Lower limit for easily available water

Table 2
Grass mixture seeding proportion (%).

| Name | Short name | % Timothy | % Perennial Ryegrass | % Meadow fescue | % Tall fescue | % Red clover |
|------|------------|-----------|----------------------|-----------------|--------------|-------------|
| Grass mixture | G | 20 | 40 | 20 | 20 | - |
| Red Clover | R | - | - | - | - | 100 |
| Red clover - grass mixture | CG | 16 | 32 | 16 | 16 | 20 |

Table 3
Botanical and cultivar names of the grasses and red clover used in this study.

| Species | Botanical name | Cultivar |
|---------|----------------|----------|
| Timothy | Phleum pretense L. | Grindstad |
| Perennial ryegrass | Lolium perenne L. | Figgio |
| Meadow fescue | Schedonorus pratensis (Huds.) P. | Fure |
| Tall fescue | Schedonorus arundinaceus (Schreb.) Dumort | Swaj |
| Red clover | Trifolium Pratense L. | Lea |

which were nearly uniquely cultivated with annual crops since 1963, before being sown with leys. The leys were ploughed at the end of the 3\textsuperscript{rd} productive year. In May 2015, three different leys were sown: a grass-mixture, a clover grass mixture and a red clover in pure stand. The grass mixture proportion, botanical and cultivar names are given on Tables 2 and 3, respectively. An overview over the field history and timing of the main managements is given in Table 4. Soil moisture and temperature, air temperature and precipitation are shown in Fig. 1.
Fig. 1. Soil moisture (% by volume, upper lines, M), air temperature (°C) and soil temperature (°C, T), and precipitation (mm, right vertical axis). Temperature and soil moisture are hourly averages. M: moisture and T: temperature of P_G: ploughed grass, P_F: ploughed fallow, and of grass ley (M UP_G and T G).
Table 4
Timeline of field management and main operations.

| Year      | Date          | Main field operations                                                                                                                                                                                                                                                                                                                                 |
|-----------|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1953-2013 |               | Spring cereal rotation (barley, wheat, oats) or spring cereals rotation with other annual crops (spring cereals every second year, potatoes, fodder beat, and later mainly field mustard.                                                                                                                                                                    |
| 2014      | September     | Liming: 23 t ha\(^{-1}\) dolomite on randomized plots used in the root study. The dolomite was distributed in two doses, and the soil was ploughed to 20 cm with a moldboard plough after the first application, than harrowed to 10 cm depth after the second application. Gas sampling occurred only on low pH plots (pH 5.10). |
| 2014      | Autumn        | Ploughing; 18-20 cm soil depth after spring oats in 2014                                                                                                                                                                                                                                                                                             |
| 2015      | 12.05.        | Harrowing; 3-5 cm soil depth                                                                                                                                                                                                                                                                                                                        |
| 2015      | 18.05.        | Barley sown; 150 kg seed ha\(^{-1}\) of spring barley sown as cover crop; Fertilization, 100 kg N ha\(^{-1}\).                                                                                                                                                                                                                                          |
| 2015      | 29.05-04.06   | Grass mixture, clover-grass mixture and red clover pure stand sown. Ley type x liming treatments were completely randomized and replicated 4 times; 30 kg seed ha\(^{-1}\).                                                                                                                                 |
| 2016      |               | Fertilized in early spring. after 1st and after 2nd harvest, totally ~140 kg N ha\(^{-1}\) year\(^{-1}\) on CG and ~270 kg N ha\(^{-1}\) year\(^{-1}\) on G, no fertilizer on R. Harvested three times per year, average annual yields were 9.95, 12.7, and 13.3 Mg DM ha\(^{-1}\) year\(^{-1}\) for R, G, and CG, respectively. |
| 2017      | May to       | Area fallowed in 2018 (F) was with low dose N (~140 kg N ha\(^{-1}\) year\(^{-1}\) I in 2016 and 2017, and none in 2018.                                                                                                                                                                                                                               |
| 2018      | September     | Fallow established on previous low-N dose G plots; vegetation including stubble and turf with part of the roots removed; Irrigation 30 mm                                                                                                                                                                                                                 |
| 2018      | 07.05.        | 1\(^{st}\) harvest                                                                                                                                                                                                                                                                                                                                     |
| 2018      | 01.06.        | Fertilization II; 44 kg N ha\(^{-1}\) on CG and 98 kg on G; irrigation 20 mm                                                                                                                                                                                                               |
| 2018      | 06.06.        | Irrigation 20 mm                                                                                                                                                                                                                                                                                                                                     |
| 2018      | 07.06.        | 2\(^{nd}\) harvest                                                                                                                                                                                                                                                                                                                                     |
| 2018      | 11.07.        | Fertilization III; 40 kg N ha\(^{-1}\) on CG and 60 kg N ha\(^{-1}\) on G                                                                                                                                                                                                                                                                             |
| 2018      | 12-13.07.     | Irrigation 15-25 mm                                                                                                                                                                                                                                                                                                                                   |
| 2018      | 05.08.        | Irrigation 30-40 mm, mainly to facilitate sampling of roots                                                                                                                                                                                                                                                                                            |
| 2018      | 27.08.        | 3\(^{rd}\) harvest                                                                                                                                                                                                                                                                                                                                     |
| 2018      | 04.09.        | Sampling of roots and stubble                                                                                                                                                                                                                                                                                                                         |
| 2018      | 06-08.09      | Ploughing                                                                                                                                                                                                                                                                                                                                            |
| 2018      | 17.09.        | Harrowning Frames installed                                                                                                                                                                                                                                                                                                                           |
| 2018      | 18.09.        | First flux sampling event                                                                                                                                                                                                                                                                                                                             |
| 2019      | 19.09.        | Last gas sampling event                                                                                                                                                                                                                                                                                                                              |
| 2019      | 29.05.        |                                                                                                                                                                                                                                                                                                                                                       |

**Plant organs biomass and N amount.** The sums of belowground biomass (crown and roots) and N per ha, their standard deviation and share in % of the belowground biomass are given on Table 5. Roots biomass were sampled after the 3\(^{rd}\) harvest of the swards in 2018, between 6 and 8 September 2018, whashed and crowns were separated from roots (Picture 1). The treatments and the total amount of dry biomass and N in each plant part is presented on Table 6.

**Soil greenhouse gas emissions.** Table 7 presents the mean cumulative N\(_2\)O emission (g N ha\(^{-1}\)) and CO\(_2\) emission (kg C ha\(^{-1}\)) calculated per period and total over 252 days. Means of 4 replicates (± standard deviations) were grouped for different periods: Fall from 19/09/2018 to 28/10/2018; Freeze-Thaw from 29/10/2018 to 5/12/2018; Snow from 6/12/2018 to 11/02/2019; Melting from 12/02/2019 to 24/03/2019; Spring from 25/03/2019 to 29/05/2019. Table 8 shows the cumulative CH\(_4\) emissions for the whole experimental period.

**Soil air content** of N\(_2\)O, CO\(_2\), O\(_2\) and CH\(_4\), in soil air sampled at 8, 24 and 40 cm depth is given as partial pressure (ppm) in Fig. 2.

**Soil Mineral N.** Means of 4 replicates (± standard deviations) of the amount of NH\(_4\) (kg ha\(^{-1}\)) and NO\(_3\) (kg ha\(^{-1}\)) and total soil mineral N (kg ha\(^{-1}\), 0-20 cm depth) measured five times from Spring 2018 (03/09/2018) to Spring 2019 (29/05/2019) in different treatments are given in Table 9.

The pictures show details of field experiment, plant organs and method.
Table 5
Total amount of biomass (DM) and total nitrogen (Tot N) in belowground residues. Averages of low and high pH plots as there was not statically significant difference between them. *n = 8.*

| Depth (cm) | Plant part | Biomass | | | Total N | | |
|---|---|---|---|---|---|---|---|
| | | Grass | Red clover | Clover-grass | Grass | Red clover | Clover-grass |
| | | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 0-15 | Crown | 1.83 | 1.27 | 1.59 | 1.25 | 1.6 | 1.31 | 30.14 | 22.24 | 34.58 | 27.25 | 26.69 | 22.91 |
| | Root | 7.39 | 2.11 | 7.24 | 2.22 | 6.78 | 2.49 | 135.13 | 41.49 | 190.38 | 65.96 | 156.47 | 59.71 |
| 15-23 | Root | 0.98 | 0.29 | 0.86 | 0.33 | 1.31 | 0.31 | 21.36 | 6.13 | 24.1 | 8.89 | 32.37 | 7.88 |
| 23-30 | Root | 0.34 | 0.19 | 0.3 | 0.18 | 0.49 | 0.1 | 6.74 | 4.42 | 8.32 | 5.02 | 12.01 | 2.33 |
| 0-30 cm | Sum | 10.54 | 2.84 | 9.99 | 2.97 | 10.17 | 3.21 | 193.37 | 54.64 | 257.37 | 85.73 | 227.53 | 70.96 |

| Share of total (%) |
|---|---|---|---|---|---|
| 0-15 | Crown | 17 | 16 | 16 | 13 | 12 |
| | Root | 70 | 72 | 67 | 74 | 69 |
| 15-23 | Root | 9 | 9 | 13 | 9 | 14 |
| 23-30 | Root | 3 | 3 | 5 | 3 | 5 |
| 0-15 | Crown + root | 0.87 | 0.88 | 0.82 | 0.85 | 0.87 | 0.80 |
Fig. 2. Partial pressure of $\text{N}_2\text{O}$, $\text{CO}_2$, $\text{O}_2$ and $\text{CH}_4$ in soil air sampled at 8, 24 and 40 cm depth under ploughed grass ley (P_G, in the legend called G) and ploughed red clover-grass ley with the last herbage harvest kept before ploughing (P_CG_M, in the legend called RG). Averages of four replicates. All gas partial pressure in ppm.
Table 6
Total biomass (DM) and nitrogen in the plant residues incorporated after ploughing (P) of a grass (G) or red clover-grass ley (CG) at the end of the 3rd production year, without or with the herbage of the last harvest kept as green manure (M).

| Treatment | Ley mixture          | Ploughed | Residue amounts | Herbage | Stubble | Roots | Total |
|-----------|----------------------|----------|-----------------|---------|---------|-------|-------|
| P.CG      | Red clover-grass     | Yes      | t DM ha⁻¹       | 0       | 5.49    | 10.2  | 15.7  |
|           |                      |          | kg N ha⁻¹       | 0       | 99      | 228   | 327   |
| P.CG_M    | Red clover-grass     | Yes      | t DM ha⁻¹       | 3.45    | 5.49    | 10.2  | 19.1  |
|           |                      |          | kg N ha⁻¹       | 97      | 99      | 228   | 424   |
| P.G       | Grass                | Yes      | t DM ha⁻¹       | 0       | 4.33    | 10.5  | 14.9  |
|           |                      |          | kg N ha⁻¹       | 97      | 99      | 228   | 424   |
| P.G_M     | Grass                | No       | t DM ha⁻¹       | 3.6     | 4.33    | 10.5  | 18.5  |
|           |                      |          | kg N ha⁻¹       | 66      | 60      | 193   | 319   |
| P_fallow  | Grass removed        | Yes      |                |         |         |       |       |
|           | spring 2018          |          | No residue applied, Grass and turf removed spring 2018 | | | | |
| Ley       | Grass                | NO       | No residue applied - | | | | |

Picture 1. Details of the root samples and morphology.

Picture 2. Detail of the frame and chamber used for gas sampling.

Picture 3. Mulching of the herbage in the experimental plot just before ploughing.

Picture 4. Detail of the installation of the probes for soil air sampling.

Picture 5. Soil structure and weather conditions at during the autumn 2018

The dataset named “Replication data for: Roots and other residues from leys with or without red clover; quality and effects on N₂O Emission Factor after ploughing” in the NMBU Open Research Data repository, contains the following files:

- 00_README file.txt: contains the detailed description of the dataset uploaded, i.e. treatments, units, abbreviations, date, etc.
- 01_Gas_Data_field-.txt: Flux data of N₂O, CO₂ and CH₄ from autumn 2018 to spring 2019. Single frames values, 8 frames per treatment distributed pairwise on four plots.
- 02_Gas_Data_Cumulated.txt: Cumulated emission by linear integration of N₂O, CO₂ and CH₄ by period from autumn 2018 to spring 2019 - 8 frames per treatment distributed pairwise on four plots.
- 02_Gas_Data_Cumulated.txt: cumulative emissions of N₂O, CO₂ and CH₄ by period and totally from autumn 2018 to spring 2019 - 8 frames per treatment distributed pairwise on four plots.
- 03_Soil_Moisture_Temperature.txt: Soil moisture (volumetric moisture, %) and temperature of soil (°C) on selected treatments at two depths (cm). Each value is the average of four probes, distributed on four plots. Occasionally a probe did not function, this is not shown in the data.
- 04_Soil_Mineral_Nitrogen.txt: Amount of ammonium-N (NH₄-N) and nitrate-N (NO₃-N) in the soil layer (0-20 cm depth) at selected dates, in kg N per ha, soil bulk density = 1.15. Replicate values, n=4.
- 05_Root_Crown_amounts.txt: Biomass dry weight and amount of total nitrogen (N), nitrate and ammonium, water soluble carbon (C) in roots and crown.
- 06_Quality_roots_crown_stubble_herbage.txt: Concentration of nitrogen, nitrate, ammonium, water soluble carbon, van Soest fractions (NDF: neutral detergent fiber, ADF: acid detergent fiber, ADL: acid detergent lignin) and derived biochemical compounds composition (NS-soluble, Hemicellulose and cellulose) in dry biomass of roots, crown, stubble and herbage used in the field experiment.
- 07_Experimental_design.pdf: schematic plan of main plots and treatments used for root and gas sampling
- 08_Field_position.pdf: position of the field seen aerial photo and placed on map of the NMBU campus
- 09_Pictures.pdf: Photos of field details during different periods
Table 7
Cumulative $N_2O$ emissions (g N ha$^{-1}$) and CO$_2$ emissions (kg C ha$^{-1}$) per period and totally during 252 days after ploughing (P) of a grass (G) or red clover-grass ley (CG) at the end of the 3rd production year, with or without the herbage of the last harvest kept as green manure (M). Means of 4 replicates ($\pm$ standard deviations). Subsequent periods: Fall from 19/09/2018 to 28/10/2018; Freeze-Thaw to 5/12/2018; Snow: to 11/02/2019; Melting: to 24/03/2019; Spring: to 29/05/2019. One or more letters in common indicates no statistically significant difference (LSD-test, $p > 0.05$).

| Treatments        | Fall Mean | SD  | Freez-Thaw Mean | SD  | Snow Mean | SD  | Melting Mean | SD  | Spring Mean | SD  | Total Mean | SD  | Total without melting Mean | SD  |
|-------------------|-----------|-----|------------------|-----|-----------|-----|--------------|-----|-------------|-----|-------------|-----|---------------------------|-----|
|                   |           |     |                  |     |           |     |              |     |             |     |             |     |                           |     |
| P_CG              | 174       | b   | 90               | 44  | 244       | b   | 338          | a   | 85          | a   | 385         | a   | 283          | ab  | 489         | 775 | ab 420       |
| P_CG,M            | 423       | a   | 261              | 74  | 374       | a   | 211          | 91  | b           | 66  | 751         | a   | 1075         | 352 | a 201       | 1991| a 1643       |
| P_CG,M$^a$        | 406       |     | 394              |     |           |     |              |     |             |     | 1646        |     | 824          |     |             |     |             |
| P_G               | 75        | d   | 19               | 49  | 98        | bcd | 40           | 25  | bc          | 31  | 485         | a   | 482          | 288 | a 137       | 970 | b 471       | 486 | bc 180       |
| P_G,M             | 138       | bc  | 51               | bc  | 118       | bc  | 76           | 105 | a           | 77  | 286         | a   | 170          | 326 | a 145       | 970 | ab 272      | 687 | ab 240       |
| P_Fallow          | 91        | cd  | 47               | 68  | cd        | 31  | 9            | c   | 13          | c   | 94          | b   | 97           | 112 | b 62        | 370 | c 129       | 280 | c 85        |
| Ley               | 81        | d   | 29               | 49  | d         | 22  | 38           | ba  | 18          | 19  | c           | 13  | 138         | b   | 127        | 320 | c 177       | 306 | c 174       |

$N_2O$ emission (g N ha$^{-1}$)

| CO$_2$ emission (kg C ha$^{-1}$) |
|----------------------------------|
| P_CG                            | 539     | b   | 126            | c   | 62        | ab  | 43.8         | 79  | a 47.5      | 400 | bc 81       | 1250| c 169       | 1174| 182        |
| P_CG,M                          | 1382    | a   | 914            | b   | 49        | 74  | 25.1         | 132 | a 167.3     | 471 | b 225       | 2320| b 1165      | 2184| 1056       |
| P_CG,M$^a$                      | 815     | a   | 25             |     |           |     |              |     |             |     | 2264        |     | 1051        |     |             |     |             |
| P_G                             | 583     | b   | 159            | bc  | 224       | bc  | 45           | 58  | ab          | 31.9| 133        | 129.9| 381        | bc 108| 1380| c 304       | 1245| 252        |
| P_G,M                           | 835     | a   | 118            | b   | 240       | b   | 62           | 114 | a 67.7      | 78  | a 54.1      | 408 | bc 50       | 1680| cb 159      | 1598| 140        |
| P_Fallow                        | 262     | c   | 59             | 121 | d         | 49  | 35           | b   | 27.1        | 23  | b 28.4      | 303 | c 70        | 740 | d 148       | 721 | 142        |
| Ley                             | 842     | ab  | 220            | 427 | a         | 154 | 104          | a   | 38.0        | 67  | a 19.0      | 2126| a 281       | 3560| a 541       | 3498| 533        |

$^a$: if the single highest emission value observed during melting is considered an outlier and replaced by the average of the other 7 chambers in the same treatment before integration. The results of LSD means comparison during Melting do not change, while for the Total emissions, treatments with ploughed leys are similar to each other and all of them different from each of P_Fallow and Ley, which are similar to each other.
Picture 1. Left: Root core samples upper and lower layer (turned upside-down) collected with a root auger (inner Ø 8 cm). Middle: detailed of the root collected with crown (above the red line, originally below ground surface) in the field. Right: roots dispersed in water for removal of other debris.
Picture 2. Left: chamber used in the field experiment for gas sampling. Right: frame place in the field experiment.
Picture 3. Detail of the plots with green manure.
Picture 4. Left: Inserting the tube probes to sample soil air. Right: probes and gas chamber during winter.
Picture 5. Left: Difference in soil structure in the ploughed soil and fallow, picture taken during a thaw period in between to freezing periods. Right; two Freezing events during autumn in different treatments.
Table 8
Cumulative soil CH$_4$ emission (mg C m$^{-2}$) during 252-day field experiment after ploughing (P) of a grass (G) or red clover-grass ley (CG) at the end of the 3rd production year, without or with the herbage of the last harvest kept as green manure (M). Means of 4 replicates (± standard deviations). One or more letters in common indicates no statistically significant difference (LSD-test, $p > 0.05$).

| Treatments | CH$_4$-C (g C ha$^{-1}$) |
|------------|--------------------------|
| P.CG       | -192 (18.5) a             |
| P.CG.M     | -278 (15.4) ab            |
| P.G        | -130 (9.4) ab             |
| P.G.M      | -170 (16.4) ab            |
| P.Fallow   | -177 (8.7) ab             |
| Ley        | -120 (12.3) b             |

2. Experimental Design, Materials and Methods

2.1. Study Site

A field experiment was conducted from September 2018 to May 2019 in Ås, Norway (59°39'47"N, 10°45'42"E), on an Umbric Epistagnic Retisol soil [4], where the normal (1971–2000) annual mean temperature is 5.7°C and precipitation is 795 mm (NMBU weather station, Ås, 59°39'37.8"N, 10°46'54.5"E). The experiment was established on the previously long-term (1953–2013) crop rotational field trial at a research farm of the Norwegian University of Life Sciences (NMBU) Ås [5]. Plots with similar cultivation history and nearly always annual crops since 1963 were selected for this study. The soil is artificially drained at about 1 m depth. The soil is a silty clay loam (31% clay, 46% silt) in the upper layer plough layer (0–20 cm), with a naturally compacted subsoil below the plough layer. Soil organic carbon (SOC) in the upper soil layer is ~2.8% and decreases rapidly below ploughing depth in connection with a jump in soil bulk density and a drop in the larger pores. The soil pH was low (pH$_{CaCl_2}$ 4.7 in 10 mM CaCl$_2$, pH$_{H_2O}$ 5.1, in spring 2019) due to absence of liming since 1970. In autumn (late September–October) 2014, part of the plots were limed with 23 t ha$^{-1}$ dolomite distributed into two doses, one before ploughing to 20 cm depth and the other before harrowing to 10 cm depth, which raised the soil pH$_{CaCl_2}$ to 5.8 or pH$_{H_2O}$ to 6.05 (limed) in spring 2019 (Table 1). Weather data was collected from the nearby NMBU weather station in Ås as mentioned above.

2.2. Leys Management

Three different leys were sown end of May 2015, only grasses (G), clover-grass mixture (CG) and red clover in pure stand (R) (Tables 2 and 3; dataset file 07). Each ley treatment was replicated 4 times and fully randomized. On both G and CG, each plot was divided longitudinally into two subplot (2.7 m X 10 m), one receiving half (140 kg N ha$^{-1}$) and one receiving normal (270 kg N ha$^{-1}$) N fertilization rate, distributed in early spring (40%), after the 1st harvest (30%) and after the 2nd harvest (30%). Red clover in pure stand (R) did not receive any fertilizer. From 2016 to 2018 the herbage was harvested three times per year (Table 4), at the plant stages recommended for high quality silage, with a Haldrup F-55 grass harvester (J. Haldrup a/s, Denmark). At the beginning of the growing season in 2018 (07 May), a de-vegetated control (fallow) treatment was also established on a subplot (2.5 m x 2.7 m) in each low nitrogen G plots by breaking the sod with a handhold cultivator then removing manually the turf and regularly removing any weed. No fertilizer was applied to these fallow plots in 2018. At the end of 3rd production years (2018), after the 3rd harvest on September 4, all plots were ploughed with a moldboard plough on September 17 to 20 cm depth. However, a 3 m wide area of each plot was left non-ploughed as living ley.
Table 9
Soil Mineral N amount during 252-day field experiment after ploughing (P) of a grass (G) or red clover-grass ley (CG) at the end of the 3rd production year, without or with the herbage of the last harvest kept as green manure (M) SD: standard deviation, n=4, except before ploughing when n = 8.

| Day          | Period      | Treatment | NH₄⁺ | SD  | NO₃⁻ | SD  | TOTAL |
|--------------|-------------|-----------|------|-----|-------|-----|-------|
| 03.09.2018   | Before ploughing | P(CG)     | 7.71 | 4.98| 2.70  | 1.59| 10.41 |
|              |             | P(CG)_M   | 3.40 | 0.52| 0.76  | 0.26| 4.16  |
|              |             | P(G)      | 5.59 | 1.67| 1.10  | 0.94| 6.70  |
|              |             | P(G)_M    | 3.40 | 0.52| 0.76  | 0.26| 4.16  |
| 03.10.2018   | Fall        | P(CG)     | 15.34| 10.88| 10.19 | 3.45| 25.53 |
|              |             | P(CG)_M   | 9.75 | 3.34| 12.36 | 5.06| 22.11 |
|              |             | P(G)      | 6.18 | 1.62| 3.49  | 1.25| 9.68  |
|              |             | P(G)_M    | 8.75 | 4.45| 4.79  | 1.40| 13.55 |
|              |             | P(Fallow) | 5.32 | 1.54| 6.64  | 3.38| 11.96 |
|              |             | Ley       | 4.61 | 1.70| 3.06  | 1.63| 7.67  |
| 07.11.2018   | Freez-Thaw  | P(CG)     | 3.52 | 0.95| 8.20  | 0.96| 11.73 |
|              |             | P(CG)_M   | 2.87 | 0.68| 8.30  | 2.42| 11.17 |
|              |             | P(G)      | 3.06 | 0.91| 2.69  | 0.99| 5.76  |
|              |             | P(G)_M    | 2.44 | 0.78| 4.16  | 1.10| 6.60  |
|              |             | P(Fallow) | 2.12 | 0.29| 5.69  | 1.71| 7.81  |
|              |             | Ley       | 2.24 | 0.76| 1.57  | 0.79| 3.81  |
| 29.03.2019   | Melting*    | P(CG)     | 2.57 | 0.95| 4.17  | 1.22| 6.74  |
|              |             | P(CG)_M   | 1.49 | 0.92| 6.07  | 4.32| 7.56  |
|              |             | P(G)      | 2.71 | 0.63| 3.40  | 0.46| 6.11  |
|              |             | P(G)_M    | 1.70 | 0.77| 4.34  | 1.05| 6.04  |
|              |             | P(Fallow) | 2.12 | 0.93| 4.16  | 0.30| 6.28  |
|              |             | Ley       | 3.89 | 1.84| 3.17  | 1.49| 7.07  |
| 29.05.2019   | Spring      | P(CG)     | 3.50 | 1.27| 16.03 | 7.92| 19.53 |
|              |             | P(CG)_M   | 4.13 | 2.02| 16.86 | 5.72| 21.00 |
|              |             | P(G)      | 2.48 | 0.71| 8.57  | 5.38| 11.05 |
|              |             | P(G)_M    | 3.58 | 2.35| 14.96 | 4.04| 18.53 |
|              |             | P(Fallow) | 3.15 | 1.05| 9.70  | 4.67| 12.85 |
|              |             | Ley       | 4.14 | 1.01| 5.83  | 6.48| 9.98  |

* Sampled 4 days after melting period finished.

2.3. Roots and Stubble Sampling, and N Analysis of Plant Substrates

On 6–8 September 2018, roots samples were taken from grass (G, full dose N), red clover-grass (CG, half dose N) and red clover (R, no N fertilizer) plots, both in non-limed and limed plots (dataset file 07). Two root core samples were collected with a root auger (inner Ø 8 cm) from each of 8 replicate plots (4 on low pH and 4 on limed plots), thus 16 cores per ley type distributed pairwise on the row and in between the plants’ rows. Cores were taken from 0–15 cm, and 15–30 cm soil depth; the latter was divided in 15–23 cm and 23–30 cm soil depth and stored at 1°C until washing in cold water. Visible particles of parts of decomposed dead plant residues were removed and all water used was sieved through a 35 μm sieve to ensure that no root piece was lost. The crown, which here is defined as belowground plant tissues connecting shoots and roots, was kept separate from the roots. Thus, belowground residues include both roots and crowns. Stubbles, here defined as the amount of biomass present aboveground after harvest, were collected from representative areas (60 cm x 60 cm) on 10 September 2018, and washed. Before ploughing, herbage was harvested at 5–7 cm cutting height. All the plant materials, including herbage mentioned later, were dried under strong ventilation at 40 °C to
constant weight. Finely ground samples of roots, crown, stubble and herbage were analyzed for total C and N content (Dumas method, Leco CHN62), water soluble organic C, and KCl extracted ammonium and nitrate at our Soil Science laboratory, NMBU. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined following the Van Soest components method [6,7] at Artemis Laboratories (Janze, France). Based on those analysis, the following biochemical components were calculated in % of ash free dry matter (DM): ND-soluble (100 - NDF %), hemicellulose (NDF % - ADF %), cellulose (ADF % - ADL %) and lignin (= ADL). Root biomass was corrected for soil mineral impurities which remained attach to the root surface using the observed C concentration of the root sample (which was ≤ 45%) and assuming that the correct C concentration in the dry matter was 45%, as observed in a few root samples, and close to that of herbage and stubble (Tables 5 and 6; dataset files 05 and 06).

2.4. Gas Flux Treatments

Only the treatments grass mixture (G, full dose N) and red clover-grass (CG, half dose N) were used for gas flux measurements (dataset file 07). Before ploughing, fresh herbage, taken from adjacent field and similar to that removed at the third harvest, was applied on 2.5 m × 2.75 m subplots (3400 kg DM ha⁻¹ on CG and 3600 kg DM ha⁻¹ on G). This herbage amount resembles a situation when the last harvest is retained as green manure, or regrowth in excess of farm’s demand is left unutilized. By that, 4 treatments were established: the G and CG plots harvested and ploughed (P_G and P_CG), and pairwise adjacent to them those with retained herbage (green manure) and ploughed (P_G-M and P_CG-M). To these, two reference treatments were added: the de-vegetated and ploughed (P_Fallow, sometimes also shortened to P_F), and the part of the G plots kept with undisturbed living ley (Ley). In total there were 24 plots with six treatments (P_G, P_G-M, Ley, P_CG, P_CG-M and P_CG-M) in 4 replicates per treatment.

2.5. Measurements of N₂O, CO₂ and CH₄ fluxes

Gas samples were collected on 45 dates over a period of 252 days, from 19 September 2018 to 29 May 2019, using the closed chamber method. After ploughing on 17 September 2018, the edges of the ridges were smoothened by one pass with a light spring-tooth harrow mounted on a light tractor, to avoid ridges being higher than the metal frames described below. In each selected plot, immediately after harrowing, two micro plots per subplot were established by inserting aluminum frames (51 × 51 × 20 cm inner size) to 10-15 cm depth into the soil, in total 48 permanent frames (6 treatment × 4 replicates × 2 frames/plot), carefully placed on areas undisturbed by the wheel track at harrowing and at minimum 50 cm inside the border of the treatment. The frames upper edge ended with a groove (3 × 3 cm) which remained just above the soil ridges, which was filled with water before deploying the static chamber on it to ensure an air-tight connection [2]. The height from the base of groove to the soil surface was measured on a 28 points grid to calculate the exact volume of frame. The chambers (56 × 56 × 19.5 cm) were equipped with a 3 mm diameter pressure equilibrium tube and with a sampling tube (assessing the middle of the chamber) ending with a three-way stopcock valve. Gas samples were collected by deploying the chambers on the frames, 24 chambers at the time, and withdrawing 15-ml gas samples from the chamber headspace with a 20 ml polypropylene syringe at start and 45 min later. First sample was taken right after the deployment of chamber, while the 2nd sample was taken at 45 min, thus making a total of 96 samples on each single measurement day. Before sampling, air in the chamber headspace was mixed by pulling and pushing the plunger of the syringe 3–4 times. The sample was transferred through the three-way valve to He washed, pre-evacuated 12 ml glass vials crimped with butyl rubber septa resulting in an over pressure in the vials to avoid contamination during sample storage. Gas sampling was completed in two rounds in reverse plot order, one for each of two frames on a plot.
Gas samples were analyzed at our soil biology laboratory (NMBU) using a gas chromatograph (GC, model 7890A, Agilent, Santa Clara, CA, USA) using a 30-m wide bore Poraplot Q (0.53 mm) column at 38°C with back flushing and helium (He) as carrier gas. The GC was equipped with three different detectors, an electron capture detector (ECD, for low concentration of N₂O), a thermal conductivity detector (TCD, for CO₂, N₂O, CH₄, O₂, N₂) and flame ionization detector (FID, for CH₄). The ECD was run at 375°C with 17 ml min⁻¹ ArCH₄ (90/10 vol %) as a makeup gas. The GC was connected to an autosampler via a peristaltic pump (Gilson minipuls 3, Middleton, WI, USA), pumping approximately 2.5 ml gas into a 250 µl sampling loop maintained at 1 Atm pressure. The injection system was back-flushed by He 6.0 before each sampling to minimize memory effects. From the concentration difference between time 0 and 45 min and by considering the headspace volume of chambers and frames, fluxes of N₂O, CO₂ and CH₄ were calculated on a per area basis as:

\[ F = \frac{d/dt \times V_c}{A \times M_n / V_m \times 60} \]

Where \( F \) is the emission flux (µg m⁻² h⁻¹), \( d/dt \) is the rate of change in gas concentration (ppmv min⁻¹) in the chamber headspace, \( V_c \) is the volume of the chamber mounted on the frame (L), \( A \) is the area covered by the frame (m²), \( M_n \) is the molecular mass (g mol⁻¹) of gas (N in N₂O and C in CO₂ and CH₄), and \( V_m \) is the molecular volume of gas at chamber temperature (L mol⁻¹) (Tables 7 and 8; dataset files 01 and 02).

Out of a total 2160 fluxes measures, 15 were missing due to mistake or removed due to suspect gas leakage as suggested by negative CO₂ emission values. Eight of the suspected leakages were on November 28th, under windy and icing forhold, during the second measurement round when no water was added in the grooves to avoid ice formation (freezing). After that date, when the snowpack was high, and the frames under it were not visible, chambers were placed directly on the snow. Out of 2145 valid flux measurements, 223 were negative. The lowest was -5.74 (µg m⁻² h⁻¹) and their average -1.18 (µg m⁻² h⁻¹). Occasionally they were accompanied by similarly small negative CO₂ fluxes. These values were included in the calculation of cumulative fluxes, assuming that they were fluctuations around zero emissions, and at times also real but small N₂O consumption. Cumulative gas fluxes were calculated by linear interpolation between the two sampling dates.

2.6. Composition of Soil Air and Accumulation of N₂O in the soil

Probes for sampling soil air were inserted at 8, 24 and 40 cm depth in each P_G and P.CG.M plot. The probes had an air-permeable cup (pore Ø 100 µm) tightened to PTFE tube (inner Ø 0.97 mm) which runs through a PVC tube (outer Ø 3.3 cm) ending with a three-way stopcock valve (see [2,3] for details). They were installed into pre-augered holes, at a 60° angle to the soil surface in order to minimize preferential water flow along the tubes. At each sampling, 10–15 ml gas sample were withdrawn using a 20 ml plastic syringe and transferred into 12 ml pre-evacuated glass vials. Occasionally it was not possible to extract an air sample due to high water content which enter the probe, or because there was no sufficient air flux. Soil air samples were analyzed as described above for CO₂, N₂O, CH₄, N₂ and O₂ gas concentrations. N₂O concentrations (ppm) were converted to N mass assuming equilibrium between gaseous and dissolved N₂O at the given soil temperature. The soil volume was divided into three layers, 0-20 cm; 20–30 cm and 30–45 cm soil depth, centre around the probes (inserted at different depths), and the soil air sampled was assumed to be representative for the whole layer.

2.7. Soil Mineral N and pH

Soil samples for determination of NH₄⁺ and NO₃⁻ content were taken from the plough layer (0-20 cm) before ploughing and at four dates during the experimental period (Table 9, dataset
file 04). Eight soil cores per sample were taken from each G or CG plot before ploughing, there-
after four cores per sample, one core between the two frames and the other three randomly
around the frames in the plot. Sieved samples (< 2mm) were partitioned into 30-35 g samples
and frozen (-20°C) on the day of collection. Before extraction the frozen samples were placed
overnight at +3°C, then each sample was added 120 ml 1M KCl, shaken for 1 hour at 125 rpm
at room temperature. Supernatants were allowed to settle down for 10 minutes and 1ml of super-
natant was transferred to 1.5ml eppendorf tube and centrifuged at 10,000 g for 15 minutes
at 4°C. NO₃⁻ and NH₄⁺ concentration in the supernatant were determined colorimetrically by
using a plate reader (Infinite F50, TECAN Austria GmbH), using the Berthelot reaction [8] for
NH₄⁺, and the Griess reaction [9] for NO₃⁻. The presence of NO₂⁻ was checked before reduc-
tion of NO₃⁻ to NO₂⁻ through vanadium chloride [10].
In spring 2019 composite soil samples were taken from all plots at 0-20 cm depth, air dried,
and analyzed for pH in 10 mM CaCl₂, and a subset was analyzed for pH in water (Table 1).

3. Soil Temperature and Moisture

Four dataloggers (EM50 datalogger, Decagon Devices, Pullman, WA, USA), one per each repli-
cate, were installed on 25 September 2018. Each logger was connected with temperature and moisture sensors (5TM), two placed at 5 cm depth (one in P_G and one in G_Ley) and three installed at 45° angle from 18 cm depth (under P_G, G_Ley and P_Fallow), (Dataset file 03). Precipitation and air temperature data were retrieved from a nearby weather station at NMBU (59°39’37.8”N, 10°46’54.5”E, 93. a.s.l.)

Ethics statements

The authors declare that there are no ethical issues with the data presented and the methods used

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which have or could be perceived to have influenced the work reported in this article.

Data Availability

Replicate data on: Roots and other residues from leys with or without red clover; quality and effects on N2O Emission Factor after ploughing (Original data) (DataverseNO).

CRediT Author Statement

Marina Azzaroli Bleken: Conceptualization, Investigation, Methodology, Formal analysis, Writing – review & editing, Visualization, Project administration, Funding acquisition; Tatiana F. Rittl: Data curation, Writing – original draft, Visualization; Sandhya Karki: Investigation, Data curation; Shahid Nadeem: Investigation, Data curation, Writing – review & editing.
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