Impact of grazing on carbon dioxide flux exchanges in an intensively managed grassland

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1. OBJECTIVES

- To analyze grazing impact on carbon dioxide (CO_2) fluxes (F) measured by eddy covariance over a Belgian meadow,
- To look at both long-term and short-term grazing impact.

2. EXPERIMENTAL SITE

- **Situation**: Belgium, Dorinne Terrestrial Observatory (DTO, l50° 18' 44'' N; 4° 58' 07'' E; 248 m asl.).
- **Climate**: temperate oceanic (TA: 10°C; PPT: 800 mm).
- **Type**: permanent grassland.
- **Surface**: 4.2 ha.
- **Slope**: moderate (1 to 2 %).
- **Ruminant livestock system**: intensive (≈ 2 LU ha^{-1}).
- **Breed of cattle**: Belgian Blue.

3. METHODS

3.1 Long- and short-term effects of grazing

Long-term effects: > biomass consumption by cattle and from cattle effluents modifying **assimilation and respiration fluxes**. This could only be quantified by comparing fluxes before and after grazing periods.

Short-term effects: > **livestock CO_2 emissions ($F_{CO2,livestock}$)** that are part of Total Ecosystem Respiration (TER) and should be measured in its presence in the field.

3.2 Datasets

Dataset I: long-term effects → 2 complete years of eddy covariance measurements made at the DTO (only data from the growing seasons).

Dataset II: short-term effects → livestock confinement experiments.

3.3 Long-term effects

- Analyzing and comparing CO_2 fluxes between grazing and non-grazing periods → dataset I divided into different intervals corresponding to grazing or non-grazing periods:

1) Response of cumulated gap-filled F_{CO2} calculated for each period to grazing intensity,
2) Response of the differences between parameters of interest of the last and first 5-day windows in each grazing or non-grazing period to grazing intensity. Parameters of interest were obtained by fitting a 5-day window F_{CO2} - PPFD relationship on daytime eddy covariance measurements.

3.4 Short-term effects

- **Confinement experiment = 2 successive days:**

1) Cattle day: cattle (≈ 26 LU ha^{-1}) confined in the main wind direction area of the eddy covariance set-up (1.76 ha, Figure 1),
2) No-cattle day: removed from it.

- **3 independent estimations of $F_{CO2,livestock}$:**

1) > nighttime eddy covariance measurements ($F_{CO2,night}$),
2) > daytime eddy covariance measurements ($F_{CO2,day}$),
→ Comparison of filtered half-hourly F_{CO2} measurements made at 24h interval.
→ Similar environmental conditions:

- Air temperature within 3°C,
- Wind speed within 3 m s^{-1},
- Radiation within 75 µmol m^{-2} s^{-1},
- Wind direction within confinement area.

3) > carbon intake measurements:

$$F_{CO2,livestock} = \left(OMD \times C_{intake}\right) - F_{CH4\text{-}C} - F_{product}$$

- OMD (%) = organic matter digestibility,
- C_{intake} (kg C ha^{-1} d^{-1}) = carbon intake,
- $F_{CH4\text{-}C}$ (kg C ha^{-1} d^{-1}) = C lost through methane (CH_4) emissions,
- $F_{product}$ (kg C ha^{-1} d^{-1}) = the lateral organic C fluxes exported as meat.

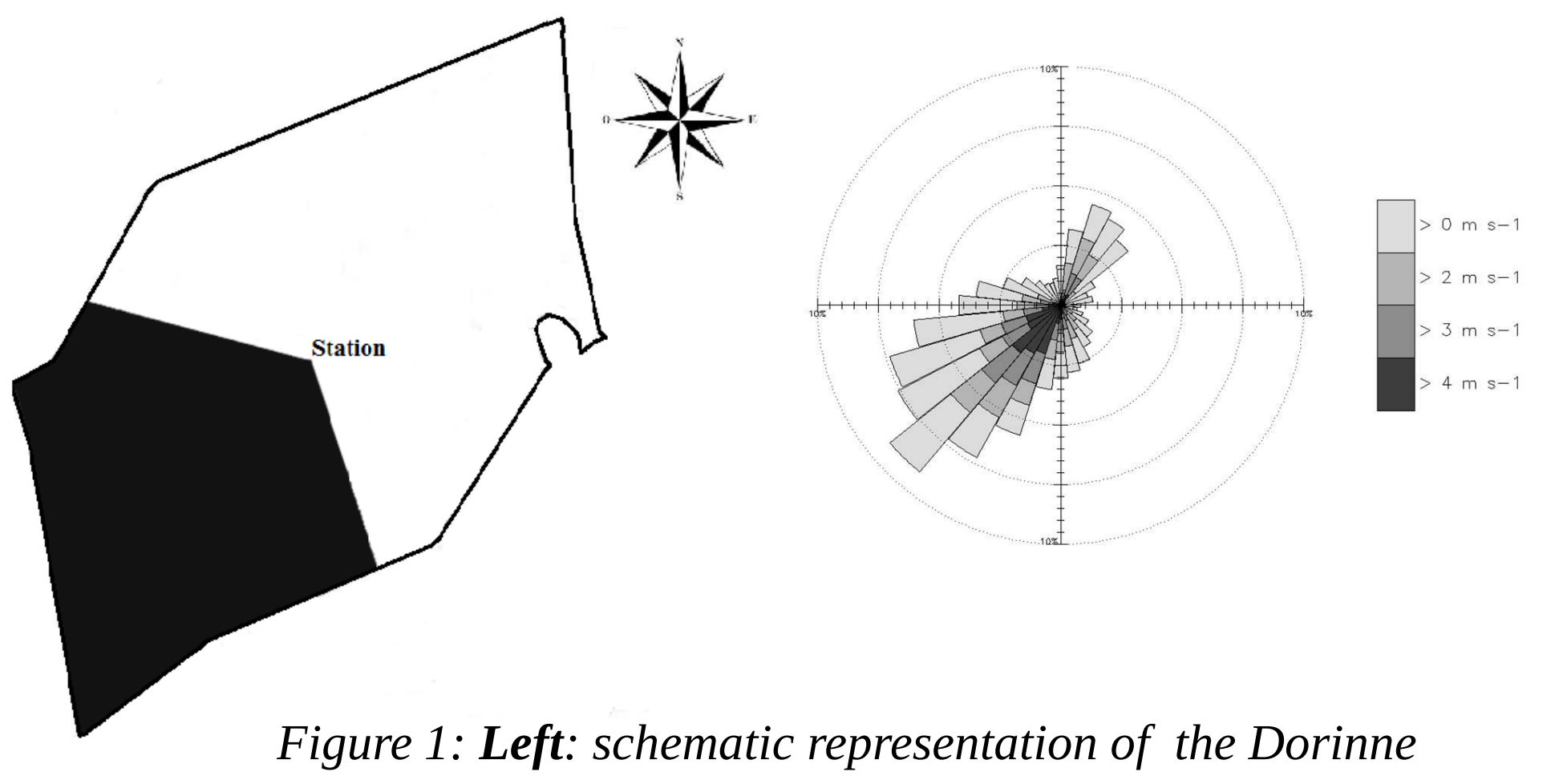

*Figure 1: **Left**: schematic representation of the Dorinne Terrestrial Observatory (DTO). Localization of the micro-meteorological station and eddy-covariance set-up. Black area represents the confinement zone used to analyze short term impacts of grazing on carbon dioxide fluxes. **Right**: wind distribution at the DTO realized with measurements made between 12 May 2010 and 12 May 2012 at the micrometeorological station.*

4. RESULTS

4.1 Long-term effects

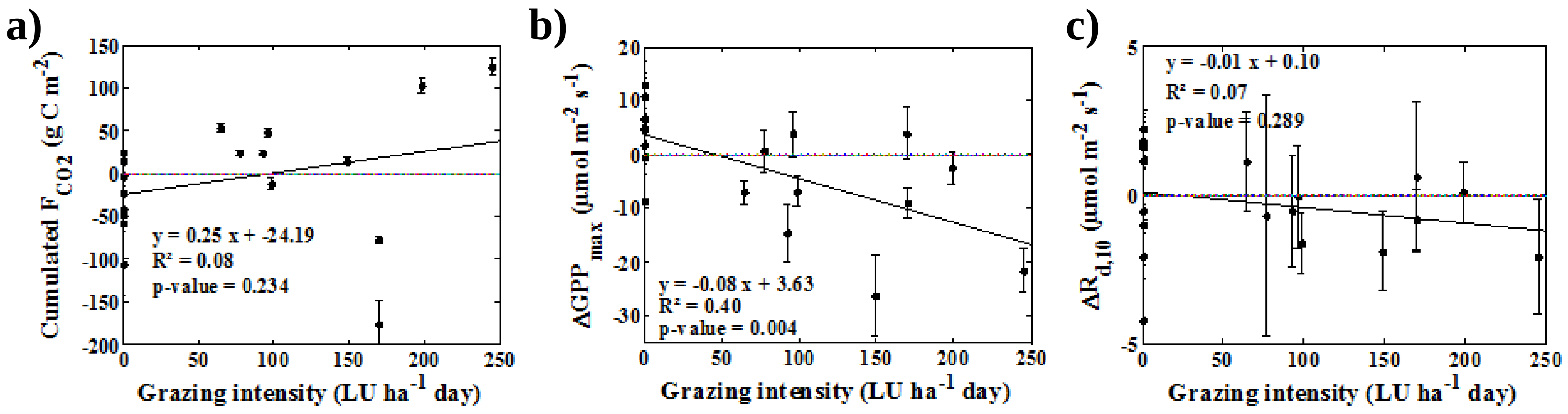

Figure 2: Response of a) cumulated carbon dioxide flux (F_{CO2}), and b) and c) the difference between the last and first 5-day windows regression parameters for grazing and no-grazing periods to grazing intensity.

Analysis:

1) **Figure 2a:** cumulated F_{CO2} ↑ with grazing intensity but the trend was not significant.
2) **Figure 2b:** gross photosynthetic capacity ↓ significantly with grazing intensity, suggesting that the presence of cattle affected grass assimilation capacity.
3) **Figure 2c:** no significant impact of grazing intensity on $R_{d,10}$.

Conclusion:

1) Response blurred by responses to climatic variables: radiation, soil temperature, drought. This suggested that the **grazing cycle effects** on F_{CO2} are **not dramatic** at the ecosystem scale.
2) **Decreases** during grazing periods: > aboveground biomass ↓ due to defoliation by grazing → plant assimilation ↓.
Increases during non-grazing periods : > biomass re-growth.
→ Significant impact of grazing intensity: ΔGPP_{max} ↓ by 0.08 µmol m^{-2} s^{-1} for each LU ha^{-1} day.
3) **No significant $R_{d,10}$ response to grazing intensity** → due to the combination of contradictory effects: ↓ autotrophic plant respiration and ↑ heterotrophic respiration.
→ Discrimination of long-term grazing effects from flux response to climate only possible after gathering and treating two years of measurements taken under various climatic conditions.

4.2 Short-term effects

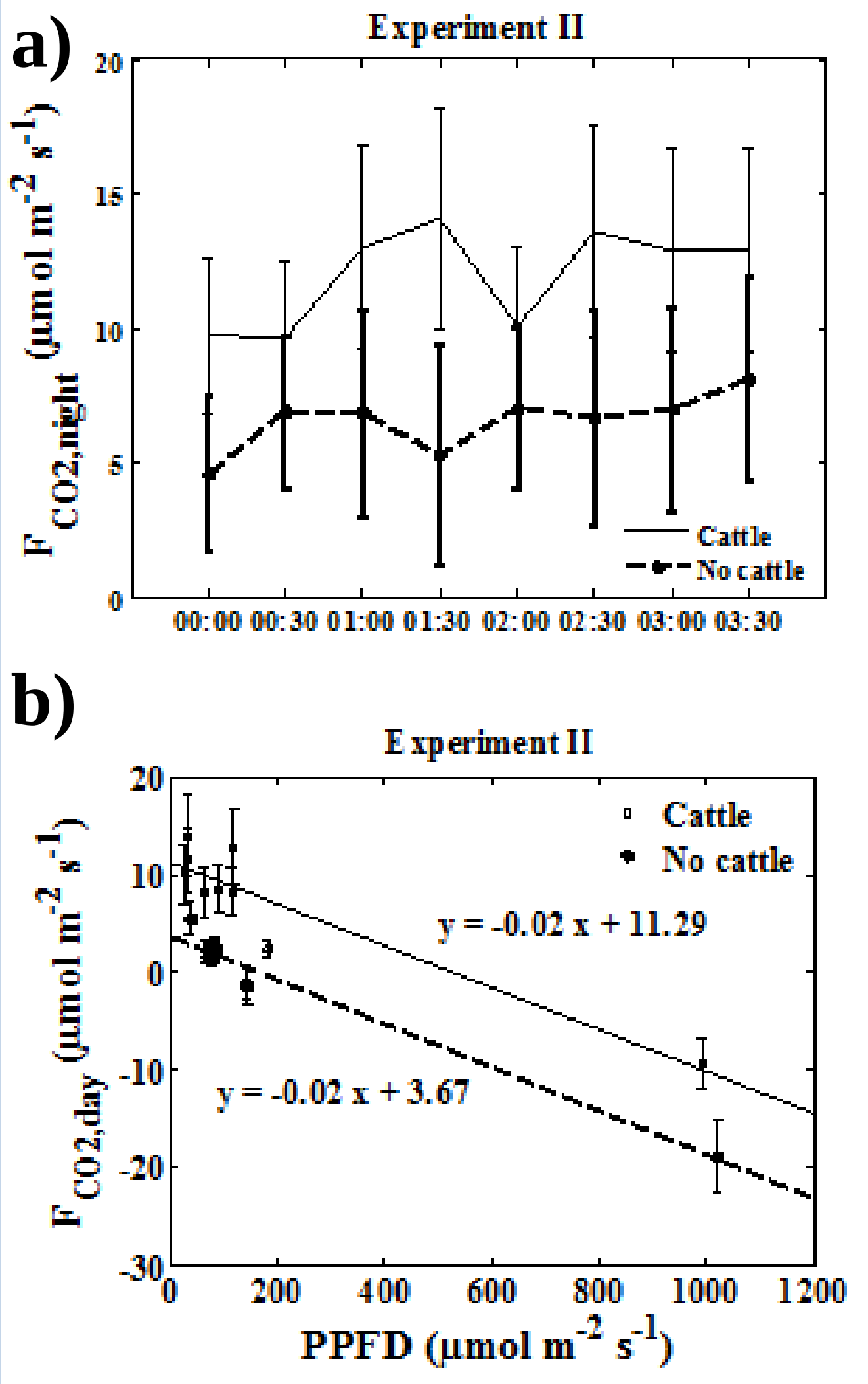

Figure 3: a) Nighttime CO_2 flux evolution, and b) daytime CO_2 flux response to radiation over two successive days with or without cattle confinement in experiments II and III. Average stocking rate for the cattle day was 27 LU ha^{-1}. Dataset II was filtered for u_* and stationarity, and environmental conditions were equivalent over the two successive days. Errors bars are the random error of measurement.

Analysis:

Figures 3, Table 1: fluxes all exhibited the **same coherent pattern** → higher when cattle were present on the plot than when cattle were absent under both nighttime and daytime conditions.
- $F_{CO2,livestock}$ estimations around 2 kg C LU^{-1} d^{-1}
- Values not significantly different between experiments or between daytime and nighttime sets.

Table 1: Results of the confinement experiments.

	Eddy covariance		Herbage mass (HM)
Stocking rate (LU ha^{-1})	Average $F_{CO2,night}$ (µmol m^{-2} s^{-1})	Average $F_{CO2,day}$ (µmol m^{-2} s^{-1})	Average HM (kg dry matter ha^{-1})
Experiment I			
28.6 -	Data not used		942 ± 45 777 ± 45
Difference → $F_{CO2,livestock}$ (kg C LU^{-1} d^{-1})			166 ± 63 1.67 ± 0.69
Experiment II			
26.7 -	12.0 ± 1.3 6.6 ± 0.7	7.4 ± 1.0 -0.6 ± 0.6	639 ± 47 574 ± 48
Difference → $F_{CO2,livestock}$ (kg C LU^{-1} d^{-1})	5.4 ± 1.5 2.10 ± 0.56	8.0 ± 1.1 3.09 ± 0.44	65 ± 67 0.67 ± 0.79
Experiment III			
26.6 -	14.3 ± 1.6 9.1 ± 1.0	7.2 ± 1.0 -0.6 ± 0.7	864 ± 44 655 ± 46
Difference → $F_{CO2,livestock}$ (kg C LU^{-1} d^{-1})	5.3 ± 1.9 2.06 ± 0.74	7.8 ± 1.3 3.03 ± 0.49	209 ± 64 2.28 ± 0.75
Experiment IV			
23.2 -	Data not used		615 ± 47 544 ± 49
Difference → $F_{CO2,livestock}$ (kg C LU^{-1} d^{-1})			71 ± 68 0.84 ± 0.92

- HM decrease during the experiments.
- $F_{CO2,livestock}$ > C intake measurements confirmed partially results of $F_{CO2,livestock}$ > CO_2 flux measurements.

Conclusion:

- Confinement experiments allowed us to evaluate $F_{CO2,livestock}$ directly and to distinguish them from other fluxes.
- Confinement experiments gave reliable results.
- Not possible under normal cattle management because emissions are too small and masked by flux responses to climatic factors.

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