Experimental and simulated data for crop and grassland production and carbon-nitrogen fluxes

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Abstract: Multi-year datasets from field experiments and simulations at five agricultural sites in the Northern Hemisphere were developed for three cropland sites in Ottawa (Canada), Grignon (France) and Delhi (India) and two grassland sites at Laqueuille

(France) and Easter Bush (UK). The cropland sites have rotations with wheat, triticale, maize, rapeseed, soybean, phacelia and rice, as well as periods of bare fallow. Cattle (Laqueuille) or mixed cattle and sheep (Easter Bush) graze in the two grassland sites. Field data were collected between 2003 and 2012 for three to eight years, including grain yield/above-ground net primary productivity, nitrous oxide emissions, carbon fluxes (gross primary production, net ecosystem exchange, ecosystem respiration), together with daily weather data (solar radiation, maximum and minimum temperatures, precipitation, wind speed, relative humidity, vapour pressure), soil properties, and records of crop and grassland management. Simulated outputs are from 23 models: 11 crop models, eight grassland models and four models simulating both systems.

Keywords: cropland, grassland, modelling, observation, simulations

1 INTRODUCTION: The main purpose of the modelling in this study was to simulate carbon and nitrogen fluxes across different cropland and grassland ecosystems under different climatic and management conditions. The selected field experiments provided robust datasets on soil properties, crop and pasture yields, and greenhouse gas emissions (especially CO_2 and N_2O), which are essential for parameterising models focused on carbon-nitrogen dynamics. These data, combined with site-specific climate and management information, allowed for detailed multi-model simulations to improve our understanding of ecosystem fluxes.
The field trials at the cropland and grassland sites were pre-existing long-term experiments designed to assess ecosystem responses to different management practices and climatic conditions. These trials were selected for the modelling study because of their extensive datasets on carbon-nitrogen fluxes, which were consistent with the purpose of this multi-model comparison. Although not originally designed for modelling purposes, these experiments were selected for their suitability for evaluating biogeochemical fluxes. The observational data are from two long-term grazing sites (G3, G4) and three cropland sites (C1, C2, C3), covering a variety of soil types, climatic conditions and farming practices in the United Kingdom, France (two sites), Canada and India (Table 1).

Table 1: *Cropland and grassland sites, and years of available data. Cropland sites used different crop sequences, including cereals (spring and winter wheat [W], triticale [T], maize [M] and rice [R]), legumes (soybean [S]), rapeseeds (canola and mustard [C]), borages (phacelia, F) and fallow intercrop periods [I].*

Site	Country	Location	Years of available data (simulation period)	Land use	Reference
C1: Ottawa	Canada	45.29 N, 75.77 W, 94 m a.s.l.	2007-2012	W/S/C/M/W/C	Sansoulet et al. (2014)
C2: Grignon	France	48.85 N, 01.95 E, 125 m a.s.l.	2008-2012	C/M/W/T/P/M/W/I	Laville et al. (2011)
C3: Delhi	India	28.60 N, 78.22 E, 233 m a.s.l.	2006-2009	W/R/W/R/W	Bhatia et al. (2012)
G3: Laqueuille	France	45.64 N, 2.74 E, 1040 m a.s.l.	2003-2012	Permanent grassland	Klumpp et al. (2011)
G4: Easter Bush	United Kingdom	55.52 N, 3.33 W, 190 m a.s.l.	2002-2010	Permanent grassland	Skiba et al. (2013)

The selected cropping systems covered a range of climates, from continental (C1, Canada), oceanic (C2, France) to subtropical (C3, India). All croplands had rotations with at least one wheat crop (six growing seasons), while maize was present in C1 and C2 (three growing seasons), and rice was only grown in C3 (two growing seasons), for a total of 18 growing seasons (including fallow intercrops). INRAE organised the model inter-comparison study and collated experimental and simulated data. They served as the basis for studies (Sándor et al., 2016, 2020, 2023; Ehrhardt et al., 2018), coordinated by the Integrative Research Group of the Global Research Alliance on Agricultural Greenhouse Gases, supported by five research projects (CN-MIP, Models4Pastures, MACSUR, COMET-Global and MAGGNET), which received funding by a multi-partner call of the Joint Programming Initiative 'FACCE' on Agriculture, Food Security and Climate Change through national financing agencies.

2 MODEL CALIBRATION AND EVALUATION: We produced multi-year daily model outputs, obtained from 23 crop and grassland simulation models/versions (Sándor et al., 2020):

- 11 crop models: Agro-C 1.0, APSIM 7.5, CERES-EGC, DNDC95 Canada, EPIC 810, INFOCROP, STICS v.8.2, APSIM 7.6, DailyDayCent, SALUS, FASSET;
- eight grassland models: APSIM+GRAZPLAN, APSIM-SoilWater, PaSim, DairyMod v5.3.1, LPJmL v.3.5.003, CenW, APSIM-SWIM 7.6, SpacSys;
- four crop and grassland models: Daily Daycent v.2010, DAYCENT v.4.5 2006, DAYCENT v.4.5 2010, DAYCENT v.4.5 2013, Landscape DNDC.

Model names were anonymised in the reporting of simulation results using model codes from M01 to M28, from the initial list of 28 models in Ehrhardt et al. (2018).
The modelling approach was based on a multi-model study, where all participating teams were given the same data and asked to return simulated outputs for the same conditions using their usual calibration techniques. The models were run independently at each site in five stages, with gradual access to site data from blind modelling (S1) to partial (S2 to S4) and full (S5) calibrations (Table 2) to inform and parameterise the models.

Table 2: Stages of the model runs (after Ehrhardt et al., 2018).

Modelling stage		Description
S1	blind without calibration and initialisation data	Basic data covering the simulation period of the experimental measurements (climate, initial soil properties and site management information, crop rotation/grazing configuration, fertilisation and irrigation)
S2	initialisation with historical management and climate	Site-specific historical climate and management data allowing for long-term initialisation periods, and regional statistics on crop yields and pasture productivity based on expert estimates
S3	calibration with vegetation data	Site-specific phenological data, crop/pasture vegetation development (e.g. leaf area index), observed grain yields, monthly estimated grassland offtake (biomass removed by mowing or animal intake)
S4	calibration with vegetation and soil data together	Dynamic soil process data (temperature, humidity, mineral nitrogen dynamics)
S5	calibration by adding C and N fluxes from the surface to the atmosphere	C-N emissions and changes in soil organic C stocks

3 DATA ACCESS AND RETRIEVAL: The data "Ensemble modelling of carbon-nitrogen fluxes in grasslands and croplands" (parent folder) has four levels of navigation. The parent folder contains a text file with the input and output variables of the dataset and their units. The data are grouped into two main folders (first level): one for cropland data and one for grassland data. Within each main folder, for each site (second folder level), input and output data are given (third folder level). Daily weather (dew-point, mean, maximum and minimum temperatures, precipitation, global solar radiation, wind speed, vapour pressure) from local weather stations situated either on-site or nearby, management data from detailed site records, and site and land-use information, including soil samples taken on-site at the start of the experimental period, are included in the input folders. In the daily weather files, 1 indicates the years prior to the simulation period (Table 1), used for initialisation purposes (S2), and 2 indicates the simulated years. The output data (both observed and simulated from the different models) are provided as daily values. They start on 1 January of the specified year and are organised in as individual spreadsheet files for each output within the output folders. These files are arranged by modelling step, which is the fourth folder level. Individual output files are provided for: gross primary production (GPP, g C m^{-2} yr^{-1}); ecosystem respiration (RECO, g C m^{-2} yr^{-1}); net ecosystem exchange of CO_2 (NEE, g C m^{-2} yr^{-1}); nitrous oxide emissions (N_2O, µg N_2O-N m^{-2} yr^{-1}); annual grain yield of arable crops or annual above-ground net primary productivity for grasslands (Yield, kg DM m^{-2} yr^{-1}). The simulated data are organised by columns (one column per model) in these site-specific files. Missing data (NA) are indicated as data values that were not provided by either the modellers or the experimentalists on the output variable of interest.

4 DATA LIMITATIONS AND FUTURE RESEARCH: Although the dataset for this study is extensive and robust, some limitations should be acknowledged. A key limitation is the lack of detailed environmental context beyond geographic coordinates. While the exact location of each site is provided, additional information on the surrounding landscape - such as proximity to natural features (e.g. rivers, forests) or human influences (e.g. urban areas, roads) - is lacking. This can limit the ability to fully assess the impact of external environmental factors on ecosystem processes, particularly where landscape features interact with management practices or influence carbon and nitrogen dynamics (Chiaffarelli et al., 2024).

In addition, soil data are limited to initial characterisation, with details such as soil depth, bulk density and water holding capacity inconsistently available across sites. These factors are important for understanding soil carbon storage and plant growth, and their absence introduces uncertainty when assessing the impact of management practices on soil dynamics (Reilly et al., 2023). In addition, topographic features such as slope and aspect, which influence microclimates, runoff and soil erosion, have not been systematically included (Patton et al., 2019).

A significant source of uncertainty also arises from how modellers use this dataset during model calibration and validation. While all modellers in ensemble studies start with a common dataset, their experience and approaches to weighting and selecting variables can vary considerably, affecting the final model results. For example, discrepancies in how important input variables - such as fertiliser rates, irrigation regimes and soil properties - are valued at different calibration stages lead to inconsistencies. The subjective decisions made by modellers, influenced by their experience and incremental access to input data, highlight the complexity and potential biases in model interpretation beyond the technical aspects of the model itself (Albanito et al., 2022).

There are also modelling uncertainties in extrapolating results to regions with different environmental conditions. Models calibrated for specific ecosystems may not perform as well in areas with different climates, soils or topography, potentially leading to biased results when applied more widely (Kirchner et al., 2021).

To overcome these limitations, the integration of remote sensing technologies and spatial datasets can provide more dynamic insights into how ecosystems respond to changing environmental and management conditions (Zhu et al., 2022). Long-term monitoring is also essential to capture temporal variation and improve our understanding of ecosystem evolution over time. In addition, a more standardised approach to model calibration, with a focus on reducing subjective biases, could improve the reliability and comparability of future modelling efforts (Knapp et al., 2012).

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