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## Water, carbon and nitrogen cycling in a rendzina soil cropped with winter oilseed rape: the Châlons Oilseed Rape Database

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**Abstract** – The Châlons Oilseed Rape Database holds the results of a comprehensive experiment on the dynamic fluxes of water, carbon and nitrogen within a soil–crop system at the field-scale, conducted in the Champagne region in France. The Châlons experiment started with the sowing of a rapeseed crop (*Brassica napus* L.) in September 1994, and stopped at its harvest in July 1995. It involved three fertilizer N treatments and a bare control. The soil was a rendzina overlying a subsoil of mixed compact and cryoturbed chalk. The variables monitored were: crop biomass, C and N content, soil matric potential, water and mineral N contents, actual evapotranspiration, nitrous oxide emissions, and ammonia volatilization, along with the usual meteorological data. Mass-balance estimates of water drainage and NO<sub>3</sub> leaching below the root-zone, along with <sup>15</sup>N balances accounting for the short-term dynamics of fertilizer N are also available. The data are accessible on the Internet through a World Wide Web server by means of a specific front-end, and may be used to test or calibrate soil–crop models. (© Inra/Elsevier, Paris.)

**Internet database / nitrogen cycle / rendzina / oilseed rape**

**Résumé** – Une base de données sur les cycles des éléments eau, carbone et azote dans un sol de rendzine sous culture de colza. La base de données CORD (Châlons Oilseed Rape Database) archive les résultats d'une expérience intensive conduite en région Champagne sur la dynamique des flux d'eau, de carbone et d'azote dans un système sol-plante, à l'échelle de la parcelle agricole. L'expérience a débuté au semis d'une culture de colza (*Brassica napus* L.) en sep-

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tembre 1994, et a duré jusqu'à la récolte de celui-ci en juillet 1995. Trois traitements azotés, ainsi qu'un témoin en sol nu ont été suivis, et le sol était une rendzine sur craie à poches de cryoturbation. Les variables mesurées comprennent : biomasse et contenu en carbone et azote de la culture, profils de potentiel matriciel, d'humidité et d'azote minéral du sol, évapotranspiration réelle, émissions d'oxyde nitreux et volatilisation d'ammoniac, ainsi que les variables climatiques usuelles. De plus, le drainage et le lessivage de nitrate sous la zone racinaire ont été estimés par défaut de bilan. Enfin des bilans à l'azote marqué ont permis de rendre compte du devenir de l'engrais sur des pas de temps courts. Les données sont accessibles sur un serveur internet par l'intermédiaire d'une interface spécifique, et peuvent par exemple servir au test ou au calage de modèles de simulation des systèmes sol-culture. (© Inra/Elsevier, Paris.)

**base de données internet / cycle de l'azote / rendzine / colza**

## 1. INTRODUCTION

Within the European Union, the recent implementation of the reformed Common Agricultural Policy prompted cultivation of oilseed rape (OSR) for biofuel production on set-aside land. Because of the large fertilizer requirements of OSR, in particular of nitrogen (N), concerns were raised as to the environmental impacts of such a practice which could be expected to lead to substantial N losses either to groundwater through  $\text{NO}_3$  leaching, or to the atmosphere as ammonia ( $\text{NH}_3$ ) or nitrous oxide ( $\text{N}_2\text{O}$ ). However, data on such N budgets are scant for OSR, because direct measurements are time-consuming and expensive, especially concerning gaseous losses.

Deterministic models of the water, carbon (C) and N cycles within the soil-crop system offer an attractive alternative to analyse these pollution fluxes. They may provide estimates of the risks associated with climate variability, allowing us to test various crop management options when run on a long-term series of past or generated weather data. However, the accuracy of their predictions relies primarily on the range of experimental data against which they have been calibrated, and the data often do not provide sufficient information to test separately the simulation of each process involved in the N cycle.

With the objectives of i) measuring dynamic water, C and N budgets for an OSR crop subjected to different levels of fertilizer N, and ii) testing several soil-crop models against a comprehensive data set, we set up a 1-year experiment near Châlons-en-Champagne (48.50 N; 2.15 E) in north-eastern

France. Monitored variables included: profiles of soil hydraulic suction, water and N contents in 30 cm layers down to 120 cm, dry matter (DM) and C-N contents of the main plant parts (roots, stems, leaves, pods and grains), rooting dynamics, and  $^{15}\text{N}$  balances following the application of labelled fertilizer N in microplots, along with basic climatic data. Soil parameters such as microbial biomass, bulk density, hydraulic conductivity and water retention curves were also measured. Compared to other similar data sets (albeit for wheat [2, 4]), ours also includes field-measurements of  $\text{NH}_3$  volatilization and  $\text{N}_2\text{O}$  emissions, using chamber or micrometeorological techniques. The data were organized into the Châlons Oilseed Rape Database (CORD), for which an HTML-based interface was developed, and made accessible through the Internet on a dedicated Web site.

## 2. DESCRIPTION AND QUALITY OF THE DATA

The N treatments were: no fertilizer (N0), split spring application of  $135 \text{ kg N ha}^{-1}$  (N1), and spring and autumn application of  $270 \text{ kg N ha}^{-1}$  (N2), along with a bare control soil. They were established on  $30 \text{ m} \times 30 \text{ m}$  blocks arranged in a split-plot design with three replicates, and also on 1-ha plots dedicated to the micrometeorological measurements. Crops were sown on 9 September 1994, and harvested on 11 July 1995. The soil was a grey rendzina, consisting of a 30-cm deep loamy-textured calcareous topsoil overlying a 60-cm thick zone of cryoturbated chalk, lying in turn over a

bedrock made of layered horizontal chalk plaques. *Table I* lists the available properties for this soil.

*Table II* lists the dynamic variables measured, along with the timing of their measurement and the methods employed. These are further detailed in refs. [16] and [11].

Soil cores were taken for water and mineral N analyses using an automatic auger (Hydrocare, MCL2, Geonor, Norway) with a diameter of 15 mm. In each block, eight 120-cm-deep cores were collected every metre along a straight line and divided into four 30-cm layers. For each layer, the eight replicate samples were pooled before analysis. Surface soil moisture was also continuously monitored using sets of time domain reflectometry (TDR) probes wired to a datalogger (CR 10, Campbell Sci., UK). Probes were horizontally placed at depths of 5, 10, 20 and 45 cm, and calibrated against gravimetric measurements on hand-collected soil samples coupled with bulk density values obtained using a gamma densitometer (LPC-Inra, Angers, France) on the same spot. The datalogger also recorded the soil suction values given by sets of tensiometers on a hourly basis, during the winter drainage period. Two of the four TDR probes were paired with tensiometers, which allowed us to determine the retention curves in the rendzina (–20 cm) and in the chalky zone underneath (–45 cm). The saturated hydraulic conductivity in the rendzina was measured at two depths (–10

and –20 cm) using a Guelph infiltrometer (Soil Moisture, Santa Barbara, USA).

Total denitrification was not directly measured, but its magnitude appeared to be limited. First, the levels of N<sub>2</sub>O emissions recorded were very low (less than 2 g N-N<sub>2</sub>O ha<sup>-1</sup> day<sup>-1</sup>), and the continuous monitoring of surface soil water showed that the water-filled pore space rarely exceeded the threshold value of 60 % that is generally considered conducive to denitrification [14]. Second, the semi-deterministic denitrification model NEMIS [13] gave an estimate of 1 kg N ha<sup>-1</sup> year<sup>-1</sup> for total denitrification over the growing season. NEMIS was run on a daily basis with the measured surface (0–30 cm) soil water, temperature and NO<sub>3</sub> content as inputs. The model was also provided with a potential denitrification rate which had been measured in the laboratory on undisturbed topsoil cores injected with acetylene.

Lastly, as regards gaseous losses, the micrometeorological campaigns were carried out for 2–3 weeks after fertilizer spreading.

Replicate micro-plots (0.36 m<sup>2</sup> in area) labelled with <sup>15</sup>N at 3.2 atom % excess were also set up for the N<sub>2</sub> treatment, and dynamically sampled 3–4 times after each fertilizer application. The following fractions were analysed for isotopic excess: soil inorganic N (NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup>), soil organic N, with four layers down to 90 cm, and plant N (with a breakdown into the main parts at harvest).

**Table I.** Measured soil properties available in the CORD, for each soil layer. Layers are numbered from 1 to 4, starting from the surface downwards in 30-cm increments.

Property and Unit	Available for layer(s)	Method
Bulk Density (g cm <sup>-3</sup> )	1–4	gravimetric
Hydraulic conductivity (m s <sup>-1</sup> )	1–2	Guelph infiltrometer
Soil retention curve	1–2	tensiometers coupled with TDR probes
Microbial biomass (C, mg kg <sup>-1</sup> )	1	fumigation–extraction
Residues in soil at sowing (t C ha <sup>-1</sup> )	1	fractionation and floatation (≥ 80 μm)
Particle-size distribution ( %)	1–4	measured after removal of carbonates
Field-capacity content ( %)	1–4	pressure plates*
Soil C, N, CaCO <sub>3</sub> , pH	1–4	+Afnor standards NF X 31-109, 31-111, 31-105, and 31-103

\* For layers 2–4, field-capacity estimates for similar soils were used.

+Association Française de Normalisation, Tour Europe, cedex 7, 92080 Paris-la-Défense

**Table II.** Dynamic measurements conducted in the Châlons experiment: type, method and timing. Timing includes the duration and the frequency of the measurements.

Measurement and unit	Timing	Method
<b>• Meteorological and soil temperature data</b>		
Rainfall	hourly	automatic tipping bucket gauge
Air temperature	hourly	thermocouples
Wind speed	hourly	opto-electronic cup anemometer
Water vapour pressure	hourly	capacitive moisture probe
<b>• Soil N balance</b>		
Soil mineral N ( $\text{NO}_3^-$ and $\text{NH}_4^+$ ) (mg N $\text{kg}^{-1}$ soil)	every 2–3 weeks 9/94–7/95	soil core sampling + auto-analyser (Skalar, Breda, NL)
$\text{N}_2\text{O}$ emissions (g N $\text{ha}^{-1}$ day $^{-1}$ )	every 1–3 weeks 9/94–7/95	0.2-m $^2$ static chambers + gas chromatography (Varian 3400Cx)
$\text{NH}_3$ volatilization (g N $\text{ha}^{-1}$ day $^{-1}$ )	hourly 15–27/9/94, 15–28/2/95, 14–27/3/95	micrometeorological gradient technique chemo-luminescence $\text{NH}_3$ analyser (NH30M, Environnement SA, Poissy, F)
$\text{NO}_3^-$ leaching (kg N $\text{ha}^{-1}$ day $^{-1}$ )	every 1–3 weeks 9/94–7/95	estimates obtained by multiplying water drainage with $\text{NO}_3^-$ concentration in bottom layer of soil
<b>• <math>^{15}\text{N}</math> balances</b>		
Soil N:	every week for 4 weeks after fertilizer application	
– total N kg $^{15}\text{N}$ $\text{ha}^{-1}$		flash combustion (C-N analyser ANA 1500) + mass spectrometry (VG SIRA 9)
– inorganic N kg $^{15}\text{N}$ $\text{ha}^{-1}$		extraction with 1M KCl, steam distillation + mass spectrometry
Plant N kg $^{15}\text{N}$ $\text{ha}^{-1}$	every week for 4 weeks after fertilizer application	flash combustion (C-N analyser ANA 1500) + mass spectrometry
<b>• Soil water balance</b>		
Water content (g $\text{g}^{-1}$ soil) ( $\text{cm}^3\text{cm}^{-3}$ soil)	every 2–3 weeks 9/94–7/95 hourly 9/94–6/95	soil core sampling + oven-drying time domain reflectometry (Tektronix, USA)
Matric suction (cm water)	hourly 11/94–5/95	tensiometers + pressure transducers (Soil Moisture, Santa Barbara, USA)
Actual évapo-transpiration (AET, mm $\text{h}^{-1}$ )	hourly 15–27/9/94, 15–28/2/95, 14–27/3/95*	energy balance + gradient technique
<b>• Crop C–N balance</b>		
Dry matter ( $\text{t ha}^{-1}$ )	every 2–3 weeks 9/94–7/95	sampling of 1.5-m $^2$ plots + separation into main parts + oven-drying (80 °C)
C-N concentration (g N $\text{g}^{-1}$ DM)	every 2–3 weeks 9/94–7/95	Dumas method in dried tissues (ANA 1500, Carlo-Erba, It.)
Leaf and pod area indices (m $^2$ m $^{-2}$ )	every 2–3 weeks 9/94–7/95	optical planimeter (Licor 5000, USA)
Rooting depth (cm)	every month 9/94–7/95	in situ root mapping through a 2-cm-mesh grid
Frequency of root occupation (%)	every month 9/94–7/95	in situ mapping of root

\* Daily AET data for the 9/94–7/95 period were interpolated using Ritchie's model [17].

The root length density, which is a common parameter in models of crop water transpiration and N uptake, was not directly measured. However, it may be related to the frequency of lateral occupation by the roots cited in *table II* [9]. Indirect estimates of water drainage and  $\text{NO}_3$  leaching below the root zone, and of net N mineralization are available in the database as calculated from mass balances [16]. In the crop budget, the return of N to the soil as leaf litter resulting from senescence appeared to be an important item, as estimated by frequently sampling the dead material on plastic grids placed on the soil surface at the base of the canopy.

As to the accuracy of the data, most of the replicated measurements presented in *table II* had acceptable standard deviations with typical coefficients of variation of 10 % for soil moisture, and 15 % for the soil inorganic N or plant biomass and N. The confidence intervals were somewhat larger for the statistics on rooting dynamics derived from root mapping, although these were performed over nine planting rows, because of subsoil heterogeneity. The static  $\text{N}_2\text{O}$  measurements were also quite variable, essentially due to the weak values of the fluxes, but the high number of replicates (eight) enabled us to detect a significant effect of fertilization on the  $\text{N}_2\text{O}$  emissions.

### 3. EXAMPLES OF USE

As stated in the introductory objectives, the CORD first provided figures to quantify the effect of N fertilization on N losses from OSR crops during the growing season [8]. It has also proved to be a unique data set for testing the various components of soil-crop models, such as a modified version of the CERES model [10], the mechanistic DAISY model [12] and the Rothamsted C-N model SUNDIAL [1]. The CORD made it possible to screen the weaknesses and strengths in these models, and to identify potential improvements to them [6]. Given the range of measured soil parameters, different parameterization scenarios could also be implemented to analyse model sensitivity to the level of information available for the simulation [5]. In gen-

eral, it appears that a wide range of soil-crop models could be tested on this data set with benefits as regards the simulation of separate processes. As a global validation data set the CORD is somewhat limited because it relates only to one soil and covers less than a year. However, its time span should soon be extended with the addition of results from an extra 8-month experiment following the harvest of OSR from the same field. During this period, soil cover consisted of OSR volunteers and bare soil, and measurements of OSR residue decomposition and soil microbial respiration were also carried out.

From the point of view of crop modelling, the CORD was used to develop a CERES-type model for OSR, including the processes of leaf senescence and the effect of a limited soil N supply on photosynthesis and leaf and pod elongation [3, 7]. The resulting model, CERES-Rape, is scheduled to be integrated into the international decision support system DSSAT [15]. The effect of N nutrition on the radiation use efficiency of the canopy is also under investigation on the basis of additional chemical analyses of plant composition.

### 4. DATA ACCESS

Data in CORD may be searched, extracted and downloaded on a dedicated Internet World Wide Web server, whose address is:

<http://www-bioclim.grignon.inra.fr/ecobilan/base/accueil.html>

After connecting to this site, the user may select the data required using either a Hypertext menu-driven interface, which also provides a few information pages about the CORD, or a version of the database developed under the statistical software 'Splus', which features additional statistical and graphical outputs. The latter may be remotely used in a telnet session, or locally after downloading as described on the Web pages.

In both versions, data are sorted in a tree structure that starts from main classes such as soil water, meteorological data or gaseous fluxes, and progressively narrows down to an ultimate class of data (e.g. grain N content), for which various statistics

are proposed prior to downloading. Hypertext buttons then offer two formats: a text-like ASCII format that can be imported into many spreadsheet softwares, or a binary Splus file. Clicking either button launches a file transfer protocol (FTP) procedure that will transfer the selected data onto the user's computer, in a file whose location and name are to be defined in a pop-up FTP window.

Lastly, an ASCII version of the CORD on disk may be obtained from the corresponding author for researchers who cannot access the database on the Internet.

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