MODELLING CARBON CYCLES AS BASIS OF AN EMISSION INVENTORY IN FARMS – THE EXAMPLE OF AN ORGANIC FARMING SYSTEM

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Abstract

In organic farms, the internal carbon fluxes are of great importance. They are connected with soil fertility (humus contents, biological activity, soil structure) and the yield potential; some C pools (C fixation in humus) and C fluxes (CO_2 and CH_4 emissions) may affect the environment. The approach used in the described model software allows to quantify management related and site dependant C fluxes and also the resulting emissions as starting point for an inventory of emissions from farms. The software was validated on the basis of intensive investigations made in the Experimental Farm Scheyern over many years. The results corresponded well to the measured values and characterize Scheyern as a farming system of intensive ecological shaping.

Introduction

While fully developed systems for the analysis and management of nitrogen cycles are available, no methods are at our disposal for describing carbon cycles on farm level.

In the research sector, activities focus mainly on the analysis of single C fluxes and C pools, generalizing statements for higher system levels (farmscapes, ecosystems) or even global ratings of geochemical C cycles are made (Janzen, 2004). This is surprising because C fluxes are of great importance for farms indeed: An optimal consideration of mass fluxes and recycling processes in farms is a basic principle of organic farming. Above this, some C fluxes and C pools may affect the environment. Analyzing mass and energy fluxes allows to describe farm management systems, assess environmental impacts, disclose bottlenecks in farms and test optimisation strategies. If it were possible to quantify management related and site dependant C emissions with sufficient accuracy and to interrelate them to the N emissions, a step towards an inventory of total farm emissions would be accomplished.

The paper describes an approach to the combined analysis of N and C fluxes on farm level. For this purpose, the underlying environmental management system REPRO (Hülsbergen & Küstermann, 2005) has been supplemented by a module for the description of C fluxes. It includes:

- the considered C fluxes and C pools, methods for their assessment and the coupling of these parameters in a farm balancing model,
- the factors influencing C fluxes and pools,
- the order of magnitude of single C fluxes and pools demonstrated using the example of a farm.

Methodology

REPRO (**Repro**duction of Soil Fertility, Hülsbergen 2003) is a model software for the analysis, evaluation and optimization of farming systems. Mass and energy fluxes are described using the following methods:

- energy balancing (Hülsbergen et al. 2002),
- humus balancing and C/N simulation (Hülsbergen 2003)
- nitrogen balancing and turnover (Abraham 2001).

Balancing inner-farm C fluxes in the system soil – plant – animal required the adaptation of existing modules and supplementation of their parameters and algorithms (for example the C levels in the biomass of plants and animals, organic fertilizer, …). As a new element, a methodical approach to a crop and site specific quantification of C input by root and crop residues has been included. It is based on studies on the root development of relevant crops. The root turnover can be calculated using the ratio between net root development and gross root development (i.e. total root production) in the growth period (Swinnen et al. 1995, Steingrobe et al. 2001). Total root production and C content allow to determine the C input into the soil. Soil conditions, management systems, yield level and/or shoot development are considered by use of correction factors.

C emissions in livestock keeping are handled separately due to the different specific greenhouse potentials of CO_2 and CH_4. CH_4 emissions from enteric fermentation which are estimated on the basis

of feeding with consideration of energy uptake and performance (Hoffmann et al. 1972). CH_4 emissions from manure are quantified with regard to the share of volatile solids and manure management (IPCC 1996, Tier 2-Approach). The direct and indirect CO_2 emissions from production are estimated along with the balancing of the energy input by operating resources and machines. For this purpose, C emission factors are applied. The C source and sink potential of the soil is assessed on the basis of humus balance sheets.
The described model software has been first used in the Experimental Farm Scheyern in the Tertiary Hills of Southern Germany (description of site characteristics and farming system by Auerswald et al. 2000). The farm is one of the most intensely sampled organic farms in Germany. For more than 15 years, a complex measuring programme has been run on its production area. At more than 500 grid points, continuous samplings were made of soil conditions, water regime and yield parameters. The measurements of relevant C and N fluxes and pools (Flessa et al. 2002) provided an important stock of data and thus the basis for validating the model program.

Results and brief discussion

The given farm structure, a legume-based crop rotation, high N inputs into the farming system, intensive management and a high yield level have led to an intensive N cycle in view of the organic management (Hülsbergen & Küstermann 2005).
This intensive N turnover is also mirrored by the carbon cycle. The characteristics of the management system became evident in 2000 (see Fig. 1), when especially high yields pointed to a fixation of atmospheric carbon in the range of nearly 5500 kg ha^{-1}. The C input into the soil reached 4070 kg C ha^{-1}, 49 % thereof in form of crop and root residues as well as rhizodeposition, 16 % as straw and green manure and 34 % as farm yard manure (FYM) from livestock keeping. Altogether, 10 times more carbon was supplied to the soil than was withdrawn from the farming system in form of plant and animal products. Considering the humus demand (crop rotation, soil tillage and cultivation intensity) and the supply of organic matter, the C balance sheet shows a mean accumulation of 200 kg C ha^{-1} a^{-} (= recovery of 734 kg CO_2 ha^{-1} a^{-1}). The increase of the humus level in this order of magnitude after the shift to organic management has been confirmed by measurements (Gutser & Reents 2001). Compared to the C input, only a small quantity has been stored in the soil for a longer time (< 5 % of the C supply). Suggesting a C_{org} steady state, the sum of C supplies would be equal to the total C removal. The organic substances delivered to the soil differ in quality of matter composition and degradability; this was taken into account in the humus balance. Detailed information on the C/N turnover in the soil was furnished by simulation models; several models reflecting soil processes were tested in Scheyern using the farm balancing software REPRO with the target to find a suitable program approach for the given location.
In livestock keeping, 33 % of carbon which is fixed in the plant biomass is used as feedstuff or bedding material. More than 2000 kg C ha^{-1} are fixed in purchased feedstuffs, thus this quantity exceeds on farm production. About 42 % of the carbon supplied in feed and straw is emitted via the metabolism of animals. This corresponds to 6000 kg CO_2 ha^{-1} and 95 kg CH_4 ha^{-1}. These results correspond well to studies by Flessa et al. (2002) undertaken at the same farm.
Beside biological C emissions, mainly technogenic sources in form of direct and indirect C inputs by fossil energy carriers exert influence on the climate. Energy balances in plant production revealed an input of fossil energy in the range of 7.5 GJ ha^{-1} a^{-1}. By use of specific CO_2 emission factors this equals to an emission of 453 kg CO_2 ha^{-1} a^{-1}. A description of all emissions from agricultural production to the environment requires detailed recordings of all technologies and involved methods also in livestock keeping. Currently, the REPRO software is adapted and updated. First runs give numbers for the CO_2 emission of animal husbandry in a range of 250 kg CO_2 ha^{-1} a^{-1}.
Table 1 summarizes the magnitude of the integrated evaluation of farm-specific greenhouse gas emissions. It provides insights into the main sources of greenhouse gas emissions and shows their contribution to the total atmospheric impact, expressed as aggregate CO_2 equivalents. Regarding the numbers, the N_2O and CH_4 emissions are negligible but from the point of view of greenhouse potential they have to be considered because of their high specific greenhouse potential of 21 for methane and 310 for nitrous oxide in relation to CO_2. Those are contributing to the greenhouse effect more than is balanced by the CO_2-sequestration caused by 25 % of lay-crop in the rotation and by manuring.
All emission estimates for the biotic and abiotic processes have considerable uncertainties. This is especially true for N_2O emissions from soils since these emissions may vary by orders of magnitude, both spatially and temporally (Flessa et al. 2002). Measurements are done on certain spots, in general. Results for whole farms are, therefore, derived by emission-factors. For those one might find a broad

range of numbers in the literature (Bouwmann 1996). In the present study, both the well-accepted emission-factors of the IPCC (1996) and of Flessa at al. (2002) which were derived from measurements in Scheyern are used. They result in a broad range of CO_2 equivalents. Implementing the soil-process-model DNDC (Li et al. 2000) within the REPRO is hoped to result in a more precise quantification of soil-borne N_2O emissions at sites where no measurements are performed.

Tab. 1: Total emissions of N_2O. CH_4, CO_2 and CO_2 equivalents in the year 2000

	N_2O kg ha^{-1} a^{-1}	CH_4 kg ha^{-1} a^{-1}	CO_2 kg ha^{-1} a^{-1}	CO_2 equivalents kg ha^{-1} a^{-1}
Plant Production				
• Use of fossil energy	n.d.[a]	n.d.	453	453
Soil (potential of source or sink)				
• arable land	4,6[b] ; 9,4[c]	n.d.	-734	692[b] ; 2180[c]
• pasture land	3,1[b] ; 6,2[c]	n.d.	0	961[b] ; 1922[c]
Animal Production				
• Use of fossil energy	n.d.	n.d.	250	250
• Enteric Fermentation	n.d.	80	n.d.	1680
• Waste management	n.d.	13	n.d.	273

[a]n.d. = not determined, [b]calculated by the emission-factor from IPCC, 1996 (1,25 % of the amount of N applied), [c]calculated by the emission-factor from Flessa et al 2002 (2,53 % of the amount of N applied)

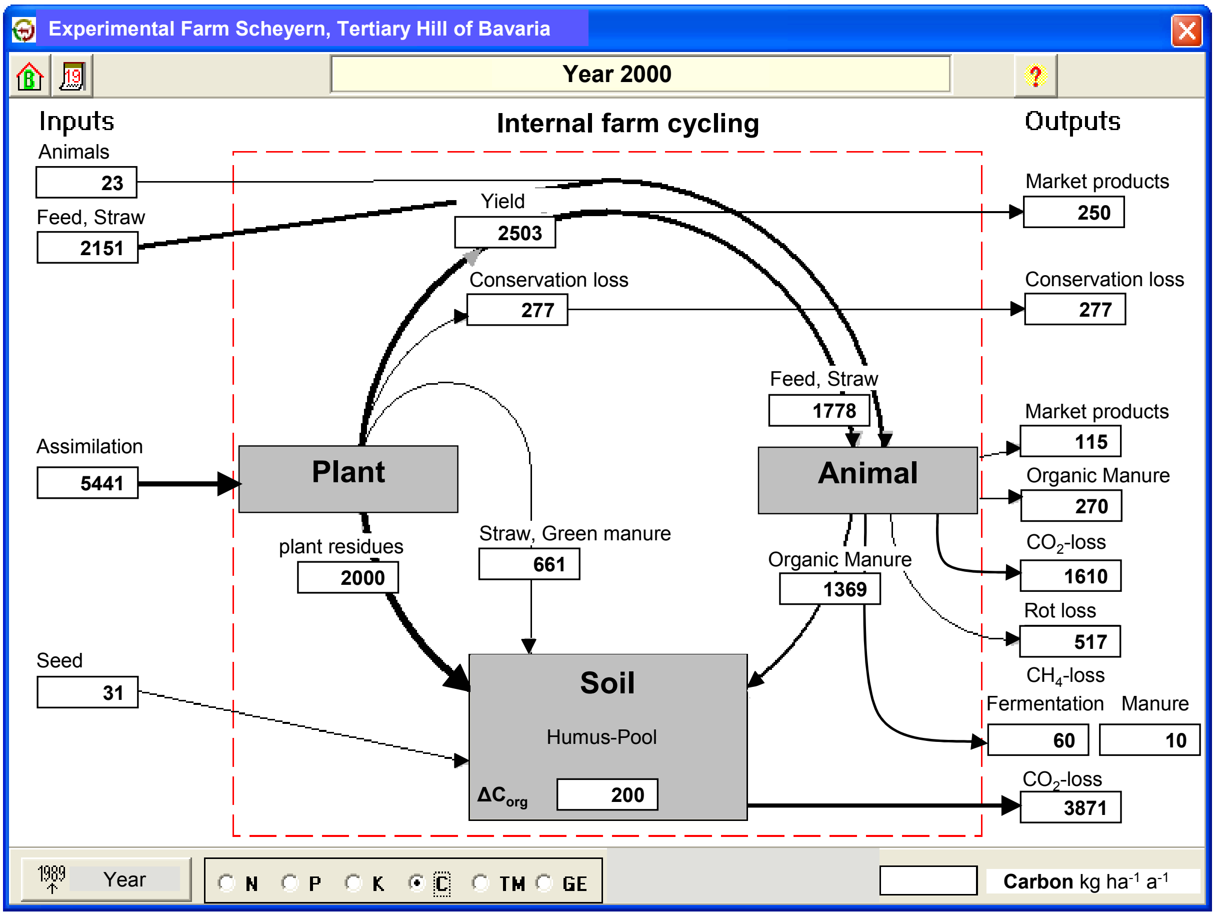

Fig. 1: On-farm carbon cycle 2000

Conclusions

C balances are essential elements in analyses of farm management systems and cannot be neglected when inventories of farm emissions are to be made. The communicated values of C fluxes characterize the management system properly. Significant deviations occurred in single years, due to structural changes, varying yield levels etc. The described C fluxes and C pools correspond well to the order of magnitude of the measured values; the latter, however, show a high variability both at selected places and in defined periods. When using balancing techniques and emission factors, absolute precision is not really claimed. Much more important is the correct display of the magnitude of emissions and the reflection of changes in management.

The described model approach shows analogies to the methodology proposed by Köpke and Haas (1995) for estimating the relationship between climate and organic farming. These authors, however, formulated generalizing statements about organic farming. Our studies focus on real farms. The coupling of C balances with other spheres of the environment (energy, nitrogen, soil fertility…) allows a multiple-purpose optimization of farm management.

New studies concentrate on improving the model approach and to extend the basis of data for validating the software (inclusion of more test sites).

The REPRO model program offers an actual chance for arriving at spatial statements vis-à-vis emission measurements of selected sources and thus for producing overall ratings of farm management systems.

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