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Modelling long term effects of cropping and managements systems on soil organic matter, C/N dynamics and crop growth

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Abstract/Executive summary

While simulation of cropping systems over a few years might reflect well the short term effects of management and cultivation, long term effects on soil properties and their consequences for crop growth and matter fluxes are not captured. Especially the effect on soil carbon sequestration/depletion is addressed by this task. Simulations of an ensemble of crop models are performed as transient runs over a period of 120 year using observed weather from three stations in Czech Republic (1961-2010) and transient long time climate change scenarios (2011-2080) from five GCM of the CMIP5 ensemble to assess the effect of different cropping and management systems on carbon sequestration, matter fluxes and crop production in an integrative way. Two cropping systems are regarded comprising two times winter wheat, silage maize, spring barley and oilseed rape. Crop rotations differ regarding their organic input from crop residues, nitrogen fertilization and implementation of catch crops. Models are applied for two soil types with different water holding capacity. Cultivation and nutrient management is adapted using management rules related to weather and soil conditions. Data of phenology and crop yield from the region of the regarded crops were provided to calibrate the models for crops of the rotations. Twelve models were calibrated in this first step. For the transient long term runs results of four models were submitted so far. Outputs are crop yields, nitrogen uptake, soil water and mineral nitrogen contents, as well as water and nitrogen fluxes to the atmosphere and groundwater. Changes in the carbon stocks and the consequences for nitrogen mineralisation, N fertilization and emissions also considered.

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Introduction

Crop growth models are frequently used to assess the impact of changing climatic conditions on crop production. However, most climate impact studies on crop production focus methodologically on simulating single years and single crops (Asseng et al., 2013; Bassu et al., 2014; Palosuo et al., 2011; Rötter et al., 2012), although in situ crop performance depends strongly on the crop's position within the sequence of crops (Sieling et al. 2005). To consider the complex inter-annual interactions, the application of crop growth models for complete crop rotations is necessary (Kollas et al. 2015). Only such simulations enable the estimation of the long-term influence of a particular farming approach, previous crops or catch crops on soil properties, production and emissions in relation to climate variables. Moreover, changing crop rotations are seen as an important option to adapt to changing climatic conditions (Olesen et al. 2011). Cropping systems and their management also determine sequestration or depletion of soil organic stocks. Since carbon sequestration is one measure to mitigate global warming, the effect of crop rotations and residue management require a stronger focus in agro-ecosystem modelling. In the present model study we focused on simulating effect of climate change on "real" crop rotations. In this way e.g. the ability of soils (in connection with climatic conditions and selected farming approach) to be source or sink of CO_2 due to sequestration could be assessed. Simultaneously, expected trends of soil water and nitrogen management and their effects on soil quality or soil water reserves should be assessed. Also expected yields (level and variability), above ground and root biomass are estimated. The data, visualization methods and the whole chain of simulation results post-processing was developed and tested in the pilot study with HERMES model (e.g. Hlavinka et al., 2015). Using an ensemble of different climate and crop models will provide information on the uncertainty of predictions.

Methods

Study locations and climate scenarios

Simulations will be conducted at three locations (Fig. 1) within the Czech Republic: Lednice, Věrovany and Domanínek. Table 1 provides the main climatic characteristics of the past situation and future projections. Two typical, but contrasting soils were defined for all sites, a loamy Chernozem with 270 mm water holding capacity, and a loamy-sandy Cambisol with 94 mm water holding capacity in the root zone.

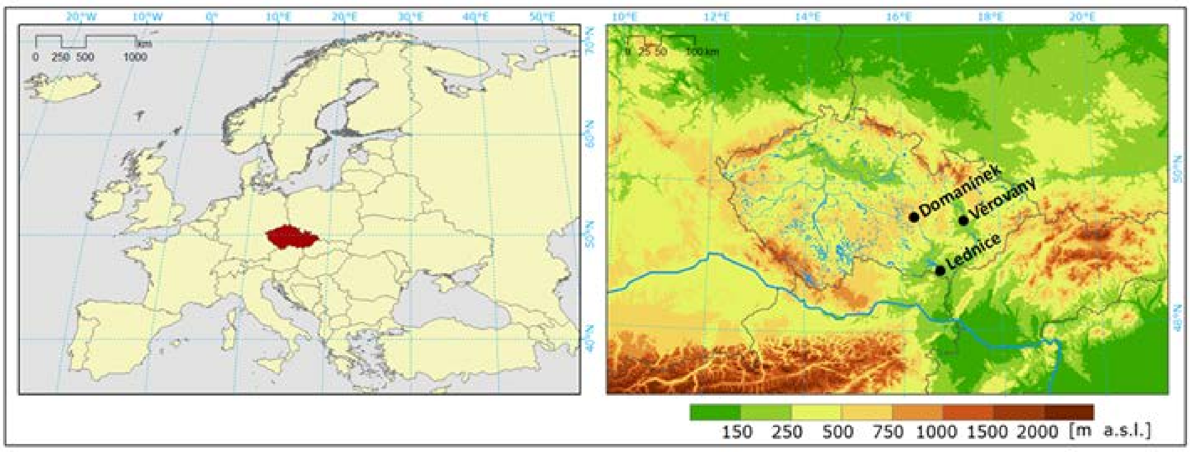

Fig. 1: Location of the study sites within Europe and Czech Republic

Table 1: List of the stations, their coordinates, altitudes, average annual temperatures and precipitation totals (±standard deviations).

Stations	Long (°)	Lat (°)	Alt (m asl)	Air temperature (°C) 1961-1990	1981-2010	2061-2080 BNU-ESM	CNRM	HadGEM2	IPSL	CGCM3	Precipitation totals (mm) 1961-1990	1981-2010	2061-2080 BNU-ESM	CNRM	HadGEM2	IPSL	CGCM3
Lednice	16°46′	48°48′	170	9.4±0.6	9.9±0.5	13.4±0.6	13.5±0.6	14.3±0.6	13.6±0.6	12.5±0.6	491±81	514±74	503±75	619±89	504±72	503±70	575±83
Věrovany	17°16′	49°28′	215	8.4±0.7	9.0±0.6	12.6±0.7	12.6±0.7	13.4±0.7	12.8±0.7	11.8±0.6	563±90	542±68	525±66	650±84	538±66	513±63	603±75
Domanínek	16°15′	49°32′	572	6.6±0.7	7.2±0.5	10.7±0.6	10.8±0.6	11.5±0.7	10.9±0.6	9.9±0.6	591±84	612±73	592±71	734±90	611±72	592±69	662±78

Weather will be represented by series for 1961-2080 containing daily solar radiation (MJ/m^2/day), maximum and minimum temperature (°C), relative air humidity (%), wind speed (m/s), precipitation in (mm) and CO_2 concentration (ppm) at the beginning of each year) generated by M&Rfi weather generator. The period 1961-2010 is represented by observed data. The period 2011-2080 is constructed using 5 scenarios based on 5 GCMs. Moreover variant “now” and “naw” will be prepared (now – means 1961-2010 measured, 2011-2080 the same statistical characteristics of climate data as 1981-2010 with increasing CO_2; naw - means 1961-2010 measured, 2011-2080 the same statistical characteristics of climate data as 1981-2010 with increasing CO_2 up to 2010 and after 2010 CO_2 is constant). Each scenario (series 2011-2080) will be represented by 20 realizations.
For all prepared weather series two types of meteorological files will be distributed: “no_snow_cover_assumed” as it based directly on measurements and results of weather generator and “snow_cover_assumed” – in this case moreover the SnowMAUS model (Trnka et al., 2010) is used to modify weather data due to expected influence of possible snow cover. If there is expected snow cover, temperature and precipitation (assuming snow cover forming and snow melting) were modified. For these two types of weather series separate folders will be used (see the example of distributed data). Snow cover should be assumed for all simulation a) by the crop model itself, or b) using weather data modified by SnowMAUS (Trnka et al. 2010).
For the climate projections 5 GCMs from the CMIP5 ensemble (MRI-CGCM3, IPSL_CM5A_MR, HADGEM2_ES, CNRM-CM5 and BNU-ESM) were selected to provide climate scenarios for the RCP 8.5.

Model calibration
For calibration local appropriate soils, weather and crop data from the three locations were provided. The goal was to adjust model parameters for individual crops to fit as much as possible to local yield levels and agronomy practice. Calibration was not meant to compare the model performance, but to adjust models properties to the local condition using protocols that each modelling group routinely uses. Combination of each defined year, crop and location was simulated as a separate run. Data for 118 calibration runs were available:
Winter wheat (cult. Samanta), 3 stations included, harvest years 1992-2008 (total of 50 runs)
Spring barley (cult. Tolar), 3 stations included, harvest years 1997-2007 (total of 29 runs)
Silage maize (cult. Cefran: Lednice 1999-2009, Věrovany 2002-2009; cult. Cingaro: Domaninek 2002-2009) (total of 26 runs)
Winter rape (cult. Artus – for Domanínek 1999-2007, for Lednice 1999-2006, for Věrovany not available) (total of 13 runs)

Long term simulations
The crop rotation itself based on cultivars and adjustment from Step A will be conducted as 30 years spin up (1961-1990) uninterrupted rotations (for spin up period 2nd crop rotation should be used exclusively) and 90 year runs (1991-2080) using initial conditions (soil Corg pools, soil Nmin, soil moisture) from the end of the spin up period. Two types of crop rotation (Fig. 2) will be simulated from 1991: one showing "biomass intensive" (i.e. 1st crop rotation) and other "best-practice" (2nd crop rotation). Former tries to maximize

short term gain by taking most of the biomass out of the field, while the second tries to preserves soil organic matter or even increase it. Each crop model performed a continuous run with both crop rotation types for the RCP 8.5 scenarios of all GCM projections.
The two crop rotations (CR 1 and CR 2) have the same duration (5 years cycle) and the same sequence of main crops: spring barley – silage maize – winter wheat – winter oil seed rape – winter wheat. In the case of CR 1, there are no assumed catch crops between the main crops; only mineral fertilization used and 80% of the crop residues are exported from the field after harvest (except silage maize and winter rape). For CR 2, the sequence of the main crops is the same as for CR 1, but between winter wheat and spring barley and between spring barley and maize, catch crops (abbreviated as WRC) should be simulated. The catch crop parameters should be adjusted to resemble the properties of vegetation (especially water consumption and biomass production) similar to those of oil-seed rape. In the case of CR 2, all the crop residues after harvest remained on the field. In addition to nitrogen mineral fertilizer, 40 tons of cattle manure is applied after the main crops (except after winter rape). After the harvest of all the crops, tillage up to 20 cm was performed to incorporate the crop residues for both CR 1 and CR 2. Fig. 2 shows the scheme of both crop rotations which were simulated in five replications with an annual shift (different starting crop).

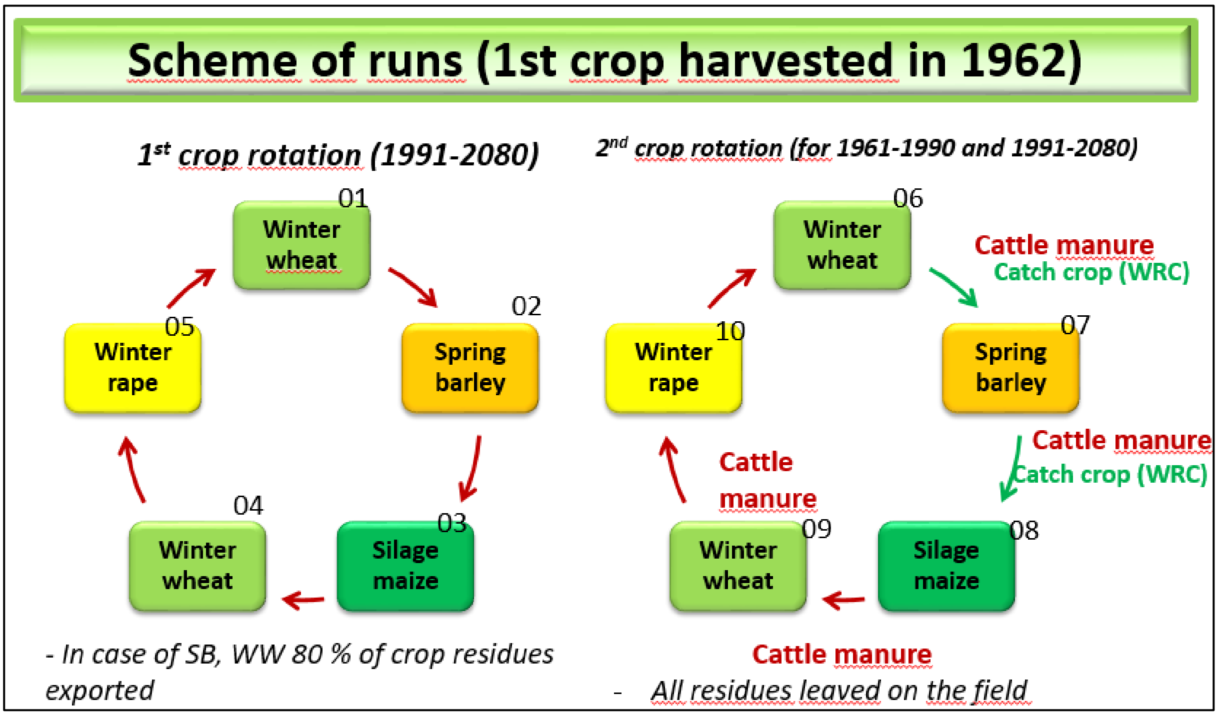

Fig. 2: Crop rotations for the long term simulations. Crop rotations are replicated with one year shift. The numbers 01-10 indicate the starting crop of each crop rotation (1st crop rotation - CR1 = 01-05; 2nd rotation = CR2: 06-10). Each first main crop is harvested in 1962.

Results

Model calibration was performed by twelve different modelling groups for HERMES, MONICA, AGROTOOL, DSSAT (separately calculated by three groups of modellers), DAISY (separately calculated by two groups of modellers), CROPSYST, FASET, APSIM and AQUACROP. However, modelling of all combinations of climate scenarios and crop rotation configurations was challenging for the modelling groups. Therefore, we have so far received model results from four out of twelve models (APSIM, CROPSYST, HERMES and MONICA). Further submissions are expected during June 2017.

Since the study has not yet been accomplished no output results of target variables are presented here yet. However, since adaptation of crop management was previously simulated by the HERMES model to be used for the simulations of the other models some of the provided outputs can be presented here.

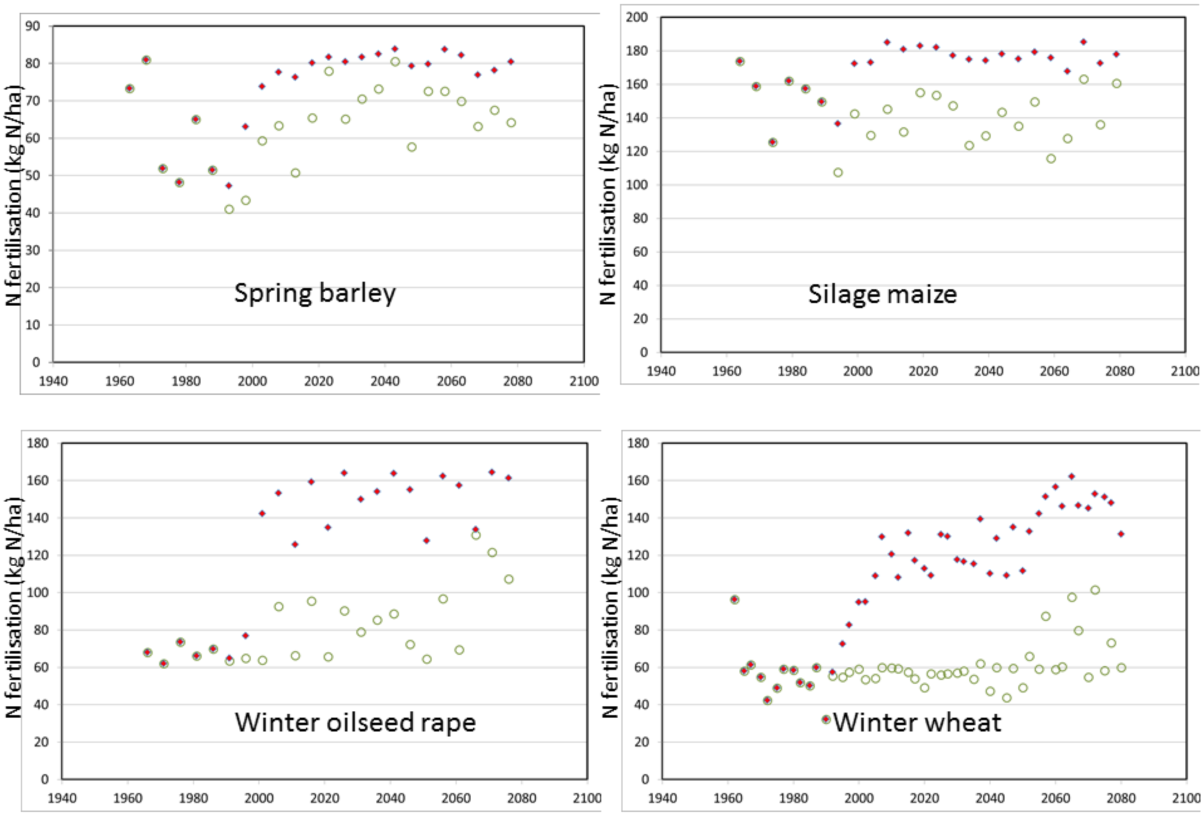

Fig. 3: Simulated adaptation of nitrogen fertilization by the HERMES model for a crop rotation with low (C1, red filled dots) and a crop rotation with high organic input (C2, green circles). C2 was applied in both cases during the spin-off (1961-1990).

Fig. 3 shows an example of one climate scenario (BNU-ESM) simulated for the two crop rotations at Domaninec on Chernozem. During the spin-off period (1961-1990) the crop rotation C2 was used. During this time N fertilization showed a decreasing trend due to the accumulation of organic matter caused by the relative high input of organic material. However, after switching to crop rotation C2, where most residues were removed, the required nitrogen fertilization increased significantly compared to the continued rotation C2. After 2060 required N fertilization increased also for the C2 rotation indicating either a lower mineralization of soil organic matter or a decreasing nitrogen use efficiency due to more frequent dry periods. Especially for winter wheat the inter-annual variability during the last two decades increased in correspondence to higher yield variability.

Discussion

Presently only preliminary results are shown here since the model output of several participating models is still outstanding. However, the results for the adapted nitrogen fertilisation indicate already some distinct effects of the selected crop rotations, but also the effect of climate change. Since the calculated amount of nitrogen fertilizer is based on available soil mineral nitrogen, it is an indicator which summarizes various processes involved in the complex soil-crop-atmosphere interactions. However, a detailed interpretation requires a closer look at other soil and crop variables in parallel to analyse the effects. The required model outputs will enable a detailed analysis of the complex interactions and will provide insights regarding the causes of differences in the behaviour of the participating models. It is expected to finalize the study by July and to submit a paper to a peer reviewed journal by autumn 2017.

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