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EPIC model based search of agronomic strategies for increasing SOC (case study)

Mikuláš Madaras[1,2] *, Juraj Balkovič*[1]*, Rastislav Skalský*[1]

[1)] International Institute for Applied Systems Analysis, Ecosystem Services & Management Program, Laxenburg, Austria
[2)] Crop Research Institute, Prague, the Czech Republic

Introduction

In the Czech Republic, the Trutnov district, due to its prevailing mountain character, is among the regions with the smallest proportion of arable land. Arable land makes 21% of the total district area, compared to the country average of 38%. The majority of farmers still employ conventional soil cultivation methods, such as deep tillage. In last two decades, the livestock sector has been struggling, and in plant cultivation a definite shift from fodder crops toward cereals and industrial crops has been occurring. An abandonment of regular manure applications and fodder crop production leads to SOC loss in arable soils, and in the consequence — to the reduction of their structural stability followed by other negative effects. Due to low acreage of the arable land, soil conservation in the district is an urgent issue.

We used the process-based cropping systems EPIC model as a tool to search for and valuate possible strategies for SOC balance improvement. The EPIC model incorporates a wide spectrum of soil processes (including organic matter transformation ones derived from the Century model) together with thoroughly verified crop growth routines. A local-scale instance of EPIC model was run using data from a long-term field experiment located near the Trutnov town (430 m a.s.l.). Correct SOC modelling is not possible without plausible estimates of plant residue and root biomass inputs. For this reason, calibration and validation of the model was performed with respect to both crop yields and SOC. Below, we present some preliminary results of our research with the aim of (1) describing the basic steps of site model building and (2) providing examples of modelling applications based on a selection of real-world or artificial fertilization and management scenarios.

Long-term experiment

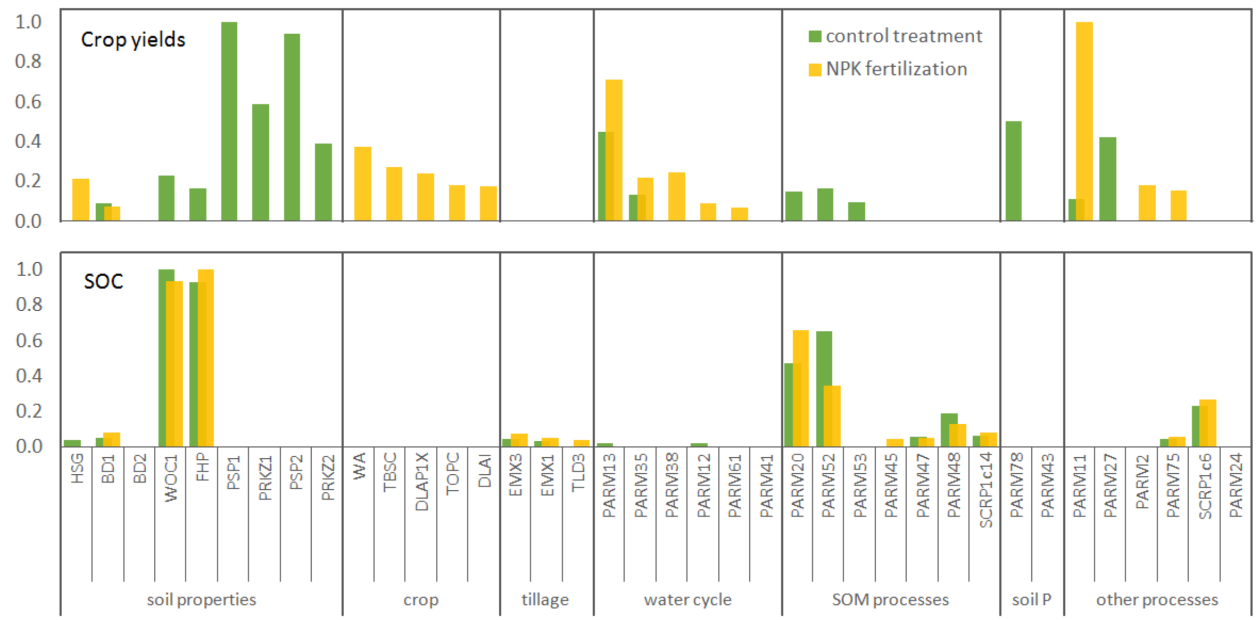
The Trutnov field experiment was running between 1965 and 2009. Its original aim was to compare the effect of organic fertilization with either farmyard manure (FYM) or cereal straw supplemented with mineral N (Straw N) on crop yields and soil fertility. FYM was applied each 4th year at the rate of 30 t/ha. In the same years straw was applied after harvest of cereals. Mineral N fertilizer was added at the rate of 1 kg N per 100 kg straw. Mean C inputs at the FYM and StrawN plots were similar, and, respectively, amounted to 1.51 and 1.24 t C/ha year. In 1965, there were already farms undergoing gradual abandonment of livestock-based farming, thus from the very beginning, the issues addressed by the research project were viewed as important. In addition, the experiment included applications of N, P, and K mineral fertilizers in different combinations, resulting in a total of eighteen treatments (4-times replicated). In this study, we used these treatments: non-fertilized treatment (Nil+Nil), only mineral ferilization (NPK+Nil), only organic fertilization (Nil+FYM, Nil+StrawN) and combination of mineral and organic fertilization (NPK+FYM, NPK+StrawN).

The eight-year crop rotation consisted of cereals (50%), potato (25%), and a fodder crop (clover; 25%). Conventional soil cultivation was maintained, including ploughing to the depth of 25–30 cm. At the experiment initiation, SOC content was about 1.15% by weight. After 40 years, the SOC content in respect to the treatments amounted to 1.03% (Nil+Nil), 1.14% (NPK+Nil), 1.17% (Nil+StrawN), 1.19% (NPK+StrawN), 1.17% (Nil+FYM), and 1.38% (NPK+FYM). The results clearly show that FYM manuring cannot be fully replaced by mineral-N-enhanced straw applications involving roughly equivalent doses of C inputs.

Initiation, calibration and validation

The EPIC modelling was performed in several steps that are commonly found in model building in general. The model relies on several hundred input parameters. For this reason, a *sensitivity analysis* (SA) was performed with the aim to identify those with the biggest influence on the model output variables of interest — crop yields and SOC in our case. We used a variance-based global SA according to Sobol (1993). Sobol's total order sensitivity index (S_T) was used for parameter ranking. Higher S_T values indicate higher model sensitivity toward a parameter. From 121 parameters covered by SA, not more than 15 occurred to have a substantial influence on crop yields, and even fewer on SOC (Fig. 1).

Figure 1. Normalized Sobol's total order sensitivity indices ($S_{T\,rel}$) in crop yield and SOC modelling obtained under two distinct fertilization regimes, with parameters grouped according to a process. For the meanings of the abbreviations consult the text or the EPIC manual at http://epicapex.tamu.edu/manuals-and-publications/.



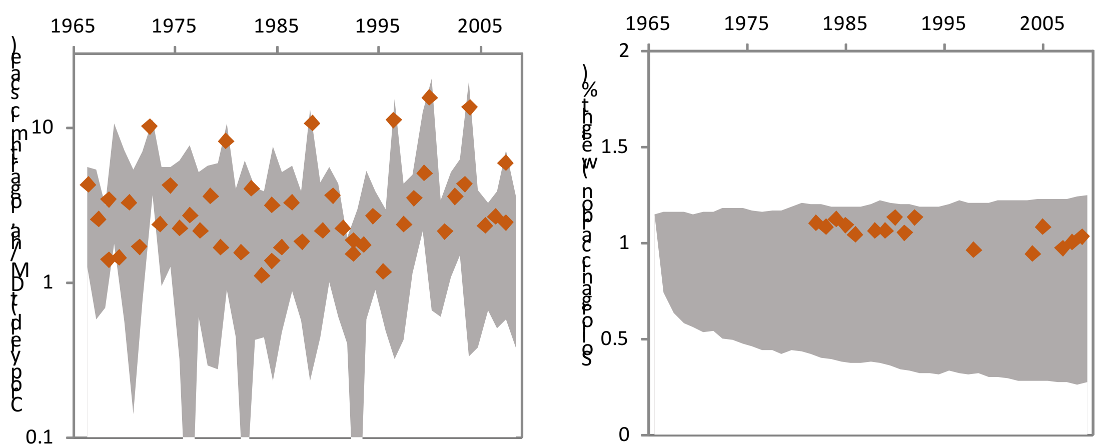
According to the sensitivity analysis, sensitivity of parameters was to a large degree determined by fertilization. In case of the crop yields modelling, only four of the fifteen most sensitive parameters occurred to be important for both non-fertilized (Nil+Nil) and fully fertilized (NPK+Nil) treatments: initial topsoil bulk density (BD1) and three parameters related to soil water status or crop response to water deficit. Soil properties related to SOC (WOC1, FHP), soil P (PSP, PRKZ), and SOC transformation processes at the beginning of the trial were highly relevant for the Nil+Nil treatment, whereas in case of NPK+Nil, parameters describing crop growth and water cycle occurred to have much bigger influence on yields. This discrepancy is linked to differing limiting factors. P-deficiency limited crop growth in the Nil+Nil treatment; therefore initial soil P pools (both mineral and organic) and P-release processes played dominant role in determining crop yields. In the NPK+Nil treatment, the major crop-growth limiting factor was water deficit; thus the most important parameters were the ones related to water-cycling and crop growth in non-stressed conditions processes.

As for the SA for SOC modelling, we found out that highly-influential parameters were common for both treatments. These were: initial SOC content in topsoil (WOC1), the fraction of organic C in a passive pool (FHP), and several parameters describing SOC transformation processes. Their relative importance varied slightly among the fertilization regimes. The influence of parameters related to soil cultivation was much lower; however, they occurred to be quite important for the model calibration procedure. To our surprise, crop and water-cycle parameters played a small role in determination of SOC levels. Apparently, variation in biomass input was masked by more influential variables — for instance, those related to residue and humus microbial transformation processes.

Uncertainty analysis (UA) was aimed at a determination of crop yields and SOC predictions reliability in a way accounting for various sources of uncertainty in input parameter values. It was based on a set of eighteen parameters whose S_T values for yield and SOC obtained in the course of SA were the highest. Other parameters whose values had been known at the start of the experiment, could be inputed with a sufficient precision, or were default in EPIC (e.g. cultivar-specific crop growth parameters) were not included. In the next step, 10,000 sets of input parameter values were randomly generated. The values of each of the eighteen parameters were set to vary in the ranges that are found in the real world or are recommended by the EPIC manual. The values of the remaining parameters were kept constant. EPIC modelling was performed for each set and for both NPK+Nil and Nil+Nil treatments. The modelling results were then pooled in order to obtain uncertainty ranges, i.e. ranges of each of the output variables across the generated sets. The ranges were then compared with reported yields and SOC measurements.

Nearly all of the measurements occurred to lie within the uncertainty range (Fig. 2), thus it can be said that the model plasticity was sufficient for matching measured yields and SOC contents. The only exception was clover (the highest dry matter yield in the crop yield graph), in case of which the yields predicted by the model were systematically lower than measured ones. This systematic shift can be amended by tuning of specific crop growth parameters of the model.

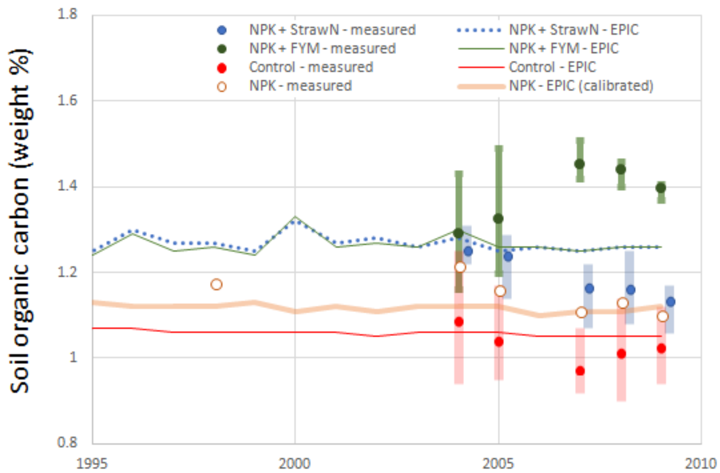
Figure 2. Measured crop yields and SOC contents (dots) and model uncertainty range (min - max interval of modelled values) for the Nil+Nil treatment.



Model calibration was performed using the data from the NPK+Nil treatment. For each of the 10,000 model runs, the sum of normalized root-mean-square errors pertaining to the difference between the predicted and reported crop yields ($NRMSE_{yield}$) and SOC contents ($NRMSE_{soc}$) were calculated ($NRMSE_{tot} = NRMSE_{yield} + NRMSE_{soc}$). The model runs were then ranked according to the obtained $NRMSE_{tot}$ values. Of the best twenty runs, i.e. the ones with the lowest $NRMSE_{tot}$, the run with the lowest $NRMSE_{soc}$ was identified. The parameter set of the run became a basis for the calibrated site model.

Subsequent *model validation* was performed using the measurements from the remaining treatments: Nil+Nil, NPK+StrawN, and NPK+FYM. The model predictions of SOC development in the Nil+Nil treatment were very accurate; however, less so in case of the treatments with external organic matter input (Fig. 3). According to measurements, despite similar C inputs, the final SOC contents differed significantly among the NPK+StrawN and NPK+FYM treatments because of differences in organic matter stability in FYM and straw. Such a qualitative difference cannot be specified as part of an EPIC model input. Consequently, the SOC development patterns obtained from the model were similar for both treatments, with individual predicted values just between the measured ones. It appears that C mineralization processes in EPIC assume a “medium” decomposability of organic matter, i.e. somewhere between one of straw and FYM. Regardless of that, it has to be noted that the absolute degree of change of SOC contents that occurred during the 44 years of the experiment has been quite low.

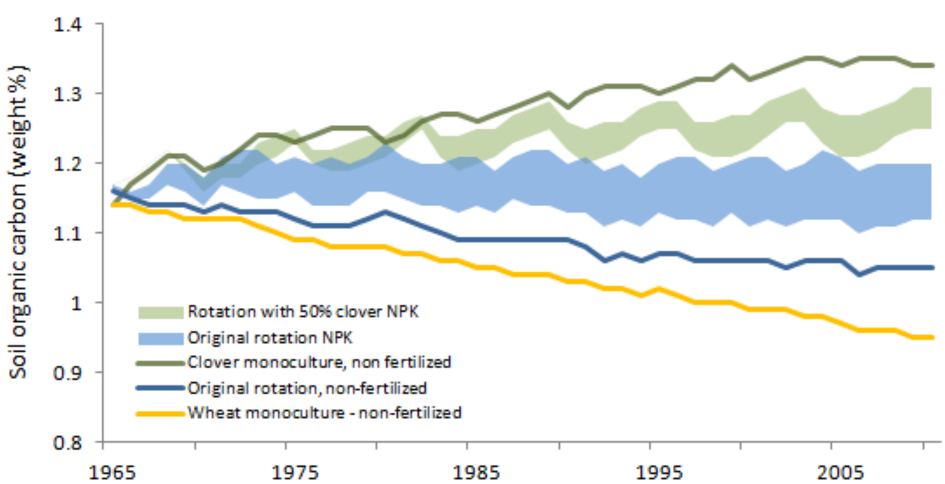
Figure 3. Measured and predicted SOC contents in the Nil+Nil treatment and the treatments with combined mineral and organic fertilization. The bars represent SOC ranges across plot replicates.



Model predictions

A validated model can be used for making valid predictions, or just for approximate estimates. Any well-validated model may not be valid for a set of different experimental conditions outside its domain. For example, a model validated for different mineral fertilizer application rates would give more reliable prediction for other fertilization scenarios than for a simulation of torrential rain. As can be deduced from the validation process, our predictions regarding different mineral-only fertilization regimes are probably be more accurate than those involving an organic external input. In the latter case, estimates are still possible, however their uncertainty is going to be high and any conclusions pertaining to the future have to be cautious.

Figure 4. Predicted SOC contents under varying cropping sequences. Solid strips depict ranges that depend on soil cultivation intensities - lower border represents conventional tillage and upper border soil tillage minimization.



We used validated EPIC model for predicting the potential SOC increase in the result of changed crop rotation and soil cultivation intensity (Fig. 4). A series of simulations was performed for the time period 1965-2009 with fixed site and weather conditions and varying crop composition and tillage parameters (ploughing depth and soil mixing intensity by cultivation operations). Clover appeared to have a positive influence on SOC content, whereas wheat — negative. When grown in monoculture, fertilized clover was associated with highest predicted SOC values within all simulations. We also simulated 6-year crop rotation with 50% proportion of clover (3 years of clover - wheat - potato - oats underseeded with clover). Final SOC contents were close to those resulting from original crop rotation with NPK+FYM fertilization. The simulations also showed that SOC increase can be expected after reducing tillage depth and an overall cultivation intensity. The predicted SOC contents were negatively related to the number of soil cultivation operations. This is an additional positive effect of clover insertion to crop sequence, because no soil cultivation is appliedfor clover.

Conclusions

Results from the field experiment combined with the EPIC modelling predictions indicate that current trends in agriculture make it difficult to increase SOC in arable soils of the Trutnov district. Among the assessed management options, (1) providing external input of stabilized organic matter (FYM) or (2) increasing a proportion of fodder crops (clover) in crop rotations occurred to be most effective measures towards this goal. Both of the measures prerequisite ongoing animal husbandry on farms, an expectation hardly possible due to overall recession of this sector. Stabilization of SOC contents can be achieved under minimized soil cultivation in combination with higher mineral fertilizer application rates.

References

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