MATHMOD 2022 Discussion Contribution Volume, 10th Vienna Conference on Mathematical Modelling, Vienna, Austria, July 27-29, 2022

Modelling Crop Rotations and Nutrient-Balances in Organic Farming Systems

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1. INTRODUCTION

ROTOR is an agronomic planning tool used by farmers and consultants to generate and evaluate crop rotations, which are crucial to organic farming systems in terms of their projected yields, humus-, nitrogen- (N), phosphorus- (P), and potassium- (K) balances, considering weed infestation risks and phytosanitary restrictions. ROTOR has been developed since 1997 at the Leibniz-Centre for Agricultural Landscape Research (ZALF). A rule-based static approach is used to determine crop sequences and to assess their yields (Bachinger and Zander 2007).

The fact that ROTOR 3.1 runs within the commercial software Microsoft (MS) Access and that the software's structure and database have grown over the years, becoming less maintainable, made a software re-engineering indispensable. The newly developed version 4.0 of ROTOR is an open-source standalone software written in Python with a PostgreSQL database. The graphical user interface (GUI) was created with Qt and PyQt. Although the core principles of the underlying models have remained, the calculations of nutrient-balances were refined, whereas the generation of crop rotations was comprehensively revised. The modular structure of the new software allows for easy scalability and better maintainability.

2. THE SOFTWARE RE-ENGINEERING OF ROTOR 4.0

2.1 ROTOR 4.0's functionalities

The site-specific parameters such as the soil rating index (SRI) and precipitation necessary for the generation and assessment of crop rotations are gathered from user input. Standard values for manure types and soil specifications are retrieved from the database but can all be modified by the user. The new database in ROTOR also contains user-related project data and all data used in the nutrient and humus calculations. The user input, as well as all results, are stored in a project file. Projects can be imported and exported as a JavaScript Object Notation (JSON) file with the extension '.rotor'.

In ROTOR 4.0, three use-cases for the generation and assessment of crop rotations are implemented. All three options rely on the 'key-and-lock principle' (chapter 2.2) and evaluate the crop rotations executing all nutrient and humus calculations, as well as the weed infestation risk assessment. The new software inhibits user inputs where not needed or not possible for the selected method of crop rotation generation or assessment.

i. The 'free generation' allows an unordered input of crops and available organic manure types. ROTOR then generates and - if necessary - extends and completes optimized crop rotations putting the crops in sensible orders. The result includes recommendations for manure use and amounts.
ii. The option 'assessment' allows any ordered selection of crops and cover crops, as well as manure types and amounts. This method is meant to evaluate existing crop rotations. Its criteria are the nutrient- and humus-balances, but also the rules of succession. The input crop rotation is checked for discrepancies from ROTOR's key-and-lock principle and phytosanitary restrictions.
iii. The 'guided generation' provides a context sensitive user input for the generation of new crop rotations. In the selection for each crop in a rotation, all impossible options are greyed out or not displayed according to the expert knowledge implemented in ROTOR, as these options are not only dependent on the currently selected crop, but also on the previous and following selections.

2.2 The models in ROTOR

Modelling in ROTOR consists of two parts: The model for the generation of crop rotations and the calculations of nutrient- and humus-balances. The latter remains unchanged in its principle in ROTOR 4.0 but is adapted to the changes in the model for the generation crop rotations.

Several rules apply in the generation of sensible crop rotations in organic farming:

i. The first crop should be legume-grass (Bachinger and Zander 2007).
ii. Leaf crops should not follow leaf crops.
iii. No wheat after cereals.
iv. Grain legumes should not follow grain legumes or legume grass (Stein-Bachinger and Reckling 2013).

v. Alternation between leaf crops and cereals.
vi. Alternation between winter and summer crops (Kolbe 2008).
vii. Summer crops after cover crops.
viii. Deep rooting crops to loosen the soil after shallow rooting crops (Stein-Bachinger and Reckling 2013)

Crop rotations should be composed of 30-50% legumes, 30-60% cereals, 5-25% leaf crops and 20-60% cover crops per area according to the farming type (dairy, stockless or stock farming) (Stein-Bachinger 2013). Phytosanitary restrictions limit the frequency and share of crops or crop types in a crop rotation according to their infestation risks in order to prevent pest and fungal infestations and plant diseases and therefore the use of pesticides (Stein-Bachinger and Reckling 2013). Since in organic farming no mineral fertilizers are applied, the nitrogen-balance must be regulated in part by using legumes, as they fix atmospheric nitrogen in the soil. They can be cultivated as main crops or as catch crops that are either undersown or sown after the main crop’s harvest. This distinction is crucial to the model as it is based on the concept of ‘crop production activities’ (CPA), describing the variable time span starting after and ending with the harvests of the main crops and their cultivation methods (Bachinger and Zander 2007). The CPAs in the database have to be created manually for each crop according to expert knowledge.

A crop sequence is generated applying the key-and-lock principle by matching the properties of the preceding crop with the requirements of the current crop concerning crop type, N-delivery of the preceding CPA with the N-need of the current CPA and a matching catch crop (Bachinger and Zander 2007). Thus, a CPA with an undersown catch crop needs to be followed by a CPA with a catch crop. To make the rather complex calculations concerning the N levels required and output by each CPA applicable in the generation of crop rotations in a software, the N-delivery of each CPA to the following is classified as either high or low according to expert knowledge (Bachinger and Zander 2007).

The above-mentioned rules i. – v. are implemented by an entry for possible preceding crop types (cereal, leaf crop, grain legume and legume grass) in the CPA database table. The alternation of summer and winter crops (vi.) is ensured by the according SQL-queries in the crop rotation generation. Rule vii., cover crops should always be followed by summer crops, is implemented by restricting the availability of the option for cover crops in the GUI to summer crops. The last rule mentioned (viii.) is partially neglected in the software, as there is no clear definition of deep and shallow rooting plants. Root structure not only depends on the crop, but also on several surrounding factors such as the soil type and its density. With the previously mentioned preceding crop type defined in each CPA, this principle is only applied by a rule of thumb, since legumes are generally classified as deep rooting, whereas cereals tend to have shallower roots (Kutschera et al. 2018).

The new model reduces the possible number of CPAs per crop to 16, as only the four crop types, two levels of N delivery of the previous crop and a Boolean value for undersowing that can, but does not necessarily affect the N-delivery to the next crop. This reduction was achieved not only by removing all degrees of freedom introduced by parameters of the CPA that do not affect the N-delivery of a CPA such as manuring, but also by shifting the timespan describing a CPA. Although in agronomy, a cultivation period starts after the harvest of the main crop, the revised model applies a timespan starting with the sowing of a main crop, making it obsolete to include the type of catch crop (none, undersown, or sown after the main crop’s harvest), reducing the maximum number of manually created CPAs by a factor of three.

After the generation of a crop rotation, the yields are calculated. These amounts can be modified by the user. Based on the yields, the humus balance is calculated according to Ebertseder et al. (2014). The P and K balances are assumed to be the difference of by manuring added and by the harvest removed P and K. The N-balance is obtained by a complex chain of calculations, not only determining the N removed by harvest and added by manuring, but also the amount of atmospheric N fixed by legumes, the amount of mineralised N that is available to the plants, the N lost through leaching, and volatilisation. The weed infestation risks are assessed by assigning values to relevant elements of the cultivation methods such as tillage (Bachinger and Zander 2007).

3. CONCLUSIONS

The new version 4.0 of ROTOR is a software for the generation and evaluation of crop rotations in organic farming systems. The new modular software build facilitates the introduction of new CPAs and functionalities. Currently, an economic assessment of crop rotations is implemented and the software’s accessibility will be improved by the development of a web frontend.

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