Review Article

Humus balancing in Central Europe—concepts, state of the art, and further challenges

Christopher Brock[1]*, Uwe Franko[2], Hans-Rudolf Oberholzer[3], Katrin Kuka[2], Günter Leithold[1], Hartmut Kolbe[4], and **Jürgen Reinhold[5]**

[1] Justus-Liebig-Universität Gießen, Professorship of Organic Farming, Karl-Glöckner-Straße 21c, 35394 Gießen, Germany
[2] Helmholtz-Centre for Environmental Research UFZ, Department Soil Physics, Theodor-Lieser-Straße 4, 06120 Halle (Saale), Germany
[3] Forschungsanstalt Agroscope Reckenholz-Tänikon ART, Reckenholzstraße 191, 8046 Zürich, Switzerland
[4] Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, Referat 71 (Pflanzenbau, Nachwachsende Rohstoffe), Waldheimer Straße 219, 01683 Nossen, Germany
[5] Förderverband Humus e.V., Nächst Neundorfer Landstraße 6a, 15806 Zossen, Germany

Abstract

Humus-balancing methods are simple tools for the assessment of interactions between agricultural land use and soil organic matter (SOM). Aside from this commonality, approaches for humus balancing differ considerably with regard to their specific aim, scope, and methodical approach. The term "humus balance" covers both simple models to quantify SOM change in arable soils, or soil organic C (SOC) change in particular, and models that refer to the optimization of soil productivity in arable soils by calculating organic-fertilizer demand, without quantifying SOM or SOC change. This situation naturally has caused much discussion and misunderstandings. Against this background, the aim of this review is to systematically explore the different methodical approaches to humus balancing in order to contribute to a more sophisticated discussion of this model family, its opportunities, and limitations. As humus balancing has long history as well as special actual relevance in Germany, and, lately Switzerland, we focus on these countries and discuss the different approaches that are presently available and applied there. We argue that humus balances can be roughly categorized into "ecological" and "agronomical" approaches based on their specific concepts and methodology. Ecological humus balances comprise a strong link to quantitative SOM change, while humus balances of the agronomical family refer to the maintenance of soil productivity without a quantitative link to SOM change. Lately, some models have been presented that link the two concepts. However, we identify that humus-balancing methods often are insufficiently validated, partly because the validation of agronomical humus balances is not easily possible without a very comprehensive field-experimental basis. Further, the comparability of different approaches even within the two concept families is low at present, indicating the need for a comparative model evaluation for a proper assessment of the methods.

Key words: humus balance / soil organic matter / soil productivity / methodology

Accepted October 1, 2012

1 Introduction

Humus-balancing methods are tools for the assessment of interactions between agricultural land use and soil organic matter (SOM). They are mainly used as management support tools in farming practice, but are, furthermore, even recognized in legislation on agricultural subsidies in Germany, and in Germany's law on soil protection (BBodSchG). It is important to mention that the term "humus balance" does not refer to a distinct methodical approach, but rather to a family of models and methods with different scopes and implementations. Furthermore, despite humus and SOM are often considered to be very similar ecological items the "humus balance" does not necessarily aim at the quantification of SOM changes. For example, the standard humus-balance method in Germany as presented by *VDLUFA* (2004) calculates organic-matter (OM) demand in crop rotations to maintain "site-specific" SOM levels that sustain a high yield level of agricultural crops coinciding with high N-use efficiency. The objective of this approach thus is organic amendment, and not the anticipation of SOM-level changes. On the other hand, the CCB model of *Franko* et al. (2011) is a humus-balance method that is explicitly designed to quantify soil organic C (SOC) change as an indicator of SOM levels in arable fields. Both approaches belong to the humus-balance model family, but their methodical implementations and, consequently, their scopes, differ considerably. This situation has caused much discussion, as expectations towards a humus-

* Correspondence: Dr. Ch. Brock;
e-mail: christopher.j.brock@agrar.uni-giessen.de

balance method may not be in accordance with the true specific scope of the tool.

Against this background, our aim is to review the methodology of humus balances and scopes of existing approaches. To do so, we first give an introduction to the development of humus balances and to the emergence of the different methodical approaches that are still reflected in the methods being in use today. In the second chapter, we give an overview of humus-balance methods presently in use or at least being recently published and available for application. It shall be noted that we focused on methods that are currently applied or in discussion for the practical application in Austria, Germany, and Switzerland. In a global perspective, more methods are available (*e.g.,* ICBM by *Andrén* and *Kätterer,* 1997; or SIMEOS-AMG based on *Saffih-Hdadi* and *Mary,* 2008), but they are outside the focus of this paper.

Finally, we try with an outlook on humus balancing, with special consideration of validation and rating of humus balances, as these points are the major challenges of all models and humus balances in particular.

2 Methodology of humus-balance methods

2.1 Development of humus-balance methods – a methodical introduction

A very early approach to humus balancing was the concept of "natural soil potency" (in German: "Natürliche Bodenkraft") presented by Albrecht Daniel Thaer in the early 19th century (*Thaer,* 1811; *Feller* et al., 2003). Thaer divided arable soil use (cropping systems of single crops, fallow) according to the improvement or depletion of the "soil potency". This basic approach already reflects the principle of humus balancing that is still in use today:

$$\textit{humus balance} = \textit{humus supply} - \textit{humus demand}. \qquad (1)$$

Parameterization of this algorithm is, however, differing between models and follows at least two methodical basic concepts, as will be shown below.

In the 20th century, several humus-balance approaches have been developed in different countries, but while these remained scientific insights in W Europe, they gained big importance in E Europe and the former USSR. Here, a significant methodical differentiation becomes obvious: models developed in W European countries (*e.g., Henin* and *Dupuis,* 1945; *Janssen,* 1984; *cf.* overview in *Shibu* et al., 2006) referred to OM turnover in soils as a function of ecological site properties and input amount and quality. Humus balances thus gave information on the development of SOM levels in soils, or at least on OM turnover and remainder in soils. As this methodical approach is based on modeling soil-ecological processes that regulate OM turnover, we refer to the concept as the "ecological" approach to humus balancing. In this approach, the "humus demand" term in Eq. 1 is understood as "humus loss".

In the former USSR and E Europe, humus balances referred to soil productivity and calculated OM demand in crop rotations to achieve optimal productivity of soils indicated by high yield levels (*e.g., Rauhe* and *Schönmeier,* 1966; *Lykov,* 1977; *Asmus* and *Herrmann,* 1977). These methods do not consider the actual state of soil-ecological processes and OM turnover, but agronomic parameters as crop rotation, fertilization, and, sometimes, yield levels and/or N uptake by plants. We therefore will call approaches that belong to this concept for "agronomical" humus-balance methods in this paper. Agronomical humus balancing determines the term "humus demand" in Eq. 1 as OM demand in crop rotations to sustain a high level of productivity.

The general methodical difference between the two approaches is that the agronomical approach aims at productivity with regard to crop yields, while the ecological approach aims at the state and development of SOM levels. As a consequence of the different methodical concepts, the specific scope of the instruments is differing as well: Humus-balance methods of the ecological group allow for the quantitative assessment of management impact on SOM levels and thus may be used with any assessment that requires such absolute quantitative information, as life-cycle assessments or greenhouse-gas (GHG) inventories. Humus balances of the agronomical group on the other hand do not allow for an anticipation of absolute SOM-level changes, but for the assessment of management systems with respect to the achievement of optimal agronomic SOM functions for the long-term production of high crop yields.

The following section will give a short methodological introduction to the different humus-balance approaches.

2.1.1 The ecological approach

The ecological approaches usually do not deal with "humus" because this is not a well-defined item that can exactly be observed, but with SOC as the main component of SOM. From an ecological point of view, the SOM storage in soil is clearly in the center of attention. Nearly all soil functions strongly depend on SOC (*Reeves,* 1997). Therefore the absolute change of C storage in soil is the methodological goal. Moreover, with the increasing alertness for the interaction of SOM and atmosphere any changes of SOM storage have shown to be important items for the calculation of GHG budgets and C sequestration.

A very generalized description of this approach is

$$SOC_{\text{end}} = f\,(\textit{management, site conditions}\ [\textit{soil properties}\ \text{and}\ \textit{climate}]);\ SOC_{\text{initial}}. \qquad (2)$$

Parameters of this approach usually are results from model calibrations on long-term experiments or use results of more complex models. The construction of ecological approaches is more built on a deterministic analysis of processes related to SOM turnover but usually with a high degree of simplification. This still provides the opportunity to identify the parameters not only from empirical calibrations. Generally, these methods are based on the calculations of the SOM decomposition under the specific local conditions and the SOM reproduction from all sources like crops, by products, and organic amendments.

2.1.2 The agronomical approach

Humus balances of the agronomical approach aim at the preservation of optimal soil functions in arable soils and calculate the required amount of organic amendments to meet this goal. It is specific for most of this approaches that single crops are rated according to their specific net value of "OM demand" or "OM supply" in order to assess the demand for organic amendment in crop rotations for the maintenance or achievement of optimal SOM functions. Even though the maintenance of sufficient SOM levels is the prerequisite for a preservation of optimal SOM functions, the quantification of SOM-level changes has not been within the scope of these methods. Agronomical humus balances may for methodical reasons not be interpreted with regard to the quantification of a positive or negative impact on SOM levels, but with regard to an organic-fertilizer demand in the crop rotation to achieve a balanced so-called "humus reproduction" and optimal influence on SOM functions.

The generalized formulation of this approach is

$$\textit{demand of OM} = f\,(\textit{crop rotation, yield level, N input, site conditions}), \tag{3a}$$

$$\textit{supply of OM} = f\,(\textit{crop rotation, organic amendments}), \tag{3b}$$

and combining both items in order to calculate the resulting balance.

Parameters of the agronomical approach are based on empirical observations in long-term field experiments, quality assessments of organic amendments, and models relating N uptake of crops to SOM turnover. Humus-balance approaches based on that concept have been presented by *Rauhe* and *Schönmeier* (1966), *Lykov* (1977), *Asmus* and *Herrmann* (1977), *Leithold* (1984, 1991), *Hülsbergen* (2003), and *Brock* et al. (2012).

It is typical for the agronomic approach to categorize single crops according to their generalized net impact on SOM into the classes "humus-demanding crops" (all nonlegumes except for green-manure crops), and "humus-building crops" (all legumes, fodder grass, and green-manure crops), respectively.

2.2 Present approaches

Table 1 summarizes information on seven methodical approaches to humus balancing that are presently available and considered for application in practice and/or research in Austria, Germany, and Switzerland. These are: the method of *VDLUFA* (2004) as the standard method for humus balancing in Germany, the Static Humus Unit Method after *Leithold* et al. (1997) that has been the first method that was adapted for application in organic farming, the Dynamic Humus Unit Method implemented by *Hülsbergen* (2003) comprising a consideration of yield levels and soil conditions in the balance calculation, the Humus Balance Model HU-MOD (*Brock* et al., 2008, 2012) giving a more process-based approach to identify the humus-balance parameters from N cycling, the SALCA humus-balance method (*Oberholzer* et al., 2006) based on an approach of *Neyroud* et al. (1997) that integrates a simplified model of SOC turnover, the Site-adjusted Organic Matter–Balance Method STAND (*Kolbe,* 2010) recognizing site impact and management activities in order to get a link between humus balances and SOM change, and the CCB model (*Franko* et al., 2011), a practice-applicable simplified model on SOC turnover and SOC change in arable soils.

The methods differ in their aims, model concepts, complexity, scopes, and validation procedures. The VDLUFA method, the two Humus Unit Methods, and the SALCA method belong to the agronomical approach as described above, HU-MOD and STAND link agronomic humus balancing and SOM-change assessment, and CCB is a true model on SOC turnover and allows for the absolute quantification of SOC changes. Regarding complexity, the VDLUFA method as well as the Static Humus Unit Method and STAND are using sets of static crop-related coefficients. These sets are differentiated into subsets according to site (STAND) or farming system (Static Humus Unit Method). SALCA calculates humus-balance coefficients more dynamically, but is still based on a very simple parameterization procedure. The Dynamic Humus Unit Method and HU-MOD are approaches that model humus-balance coefficients dynamically based on a complex parameterization, and CCB is a dynamic model on site-dependent OM turnover. However, even the more complex humus-balancing methods have comparably low data requirements and can, as computer applications, be used as management-support tools by farmers as well.

In the following section, the seven methods will be described in detail.

2.2.1 VDLUFA method

The aim of the VDLUFA method for humus balancing is to quantify OM demand in crop rotations with regard to the maintenance of soil productivity in terms of crop yield, to the maintenance of "adequate" SOM levels with regard to site and management, and to the assessment of N-loss risk with excessive OM supply (*VDLUFA,* 2004).

From a methodological point of view, the VDLUFA method is a joint implementation of the ROS method (*Asmus* and *Herrmann,* 1977) and the "parameters for extended Humus reproduction" of *Kundler* et al. (1981). The parameters of the two approaches have been implemented as a range between "lower" (*Asmus* and *Herrmann,* 1977) and "upper" (*Kundler* et al., 1981) values for the "humus demand" of nonlegume crops. According to the method description, the "lower value" shall be applied for soils that are in good condition whereas the "upper value" shall be used for soils that require some extra supply of OM. "Humus demand" of crops is related to "humus supply" by legumes, all green-manure crops, and fer-

Table 1: Comparison of humus-balance methods. Method references: VDLUFA (*VDLUFA,* 2004; *Kolbe,* 2005), STAND (*Kolbe,* 2010), Humus Unit (*Leithold* et al., 1997), Dynamic Humus Unit (*Hülsbergen,* 2003), HU-MOD (*Brock* et al., 2012), SALCA (*Oberholzer* et al., 2006), CCB (*Franko* et al., 2011). LTFE = long-term field experiment; SOM = soil organic matter; SOC = soil organic carbon, STN = soil total nitrogen.

		Method / Model						
		VDLUFA	Humus Unit	Dynamic Humus Unit	HU-MOD	SALCA	STAND	CCB
Aim	*agronomical approach: sustaining soil productivity*	assessment of soil fertility maintenance in crop rotations, demand calculation of organic amendment			assessment of management change impact on SOM levels	demand calculation of organic amendment to sustain an optimal SOM level	assessment of management related impact on SOM levels	–
	ecological approach: predicting SOM change	–	–	–		–		calculation of SOM changes in arable soils
Methodology		crop and fertilizer-related parameters on OM demand based on a) SOC change under crop rotations at high yield level in LTFE (lower values) b) a N balance of cropping systems and empirically determined parameters for humus build-up by crops and organic inputs (upper values)	crop- and fertilizer-related parameters on OM demand based on a N balance of cropping systems and empirically determined parameters for humus build-up by crops and organic inputs	deterministic model on OM demand in crop rotations based on a N balance of cropping systems and empirically determined parameters for humus build-up by crops and organic inputs	deterministic model on cropping system impact on SOM levels based on nitrogen and carbon pools and fluxes in the soil–plant system	calculation of carbon mineralization dependent on soil properties and crop rotation as well as carbon input by plants and organic fertilizers	empirically determined parameters for cropping system impact on SOM levels	deterministic model (4 pools) on organic-matter turnover in arable soils
Driving variables (input data)	*management data on:* crops, type and amount of organic amendments and ...	–	farming system (organic or conventional)	crop yield	crop yield and mineral N-fertilizer	shares of row crops and perennial legumes/grass in rotations	crop yield	crop yield and irrigation amount and residue management
	site	not considered	not considered	4 site-quality classes according to agronomical soil quality		clay content, pH, SOC start level	6 site classes according to soil and climate	minimum data set: clay content soil type, annual rainfall and temperature, initial SOC value
Output		OM demand to sustain soil productivity			relative impact of different scenarios on SOM levels	OM demand to sustain SOM levels	SOM-level change	SOC dynamics, SOC balance, N balance, Biologic Active Time
Accomplished validation		comparison of humus balances with LTFE treatments that are considered as "optimal" regarding SOC maintenance, yield levels, and N efficiency	correlation between humus-balance results and states of different SOM quantity (SOC and STN state and change) and quality (hot water–extractable soil C and N, enzyme activities, microbial biomass) indicators in LTFE		correlations between SOM-level variation and humus-balance variation in LTFE	comparison of humus balances and SOM-level change in LTFE	statistic analysis of differences between observed and predicted SOC change in LTFE	statistic analysis of differences between observed and predicted SOC values in LTFE

tilizers. All applied parameters have tabulated values that are independent on yield and site condition.

The rating scheme of the VDLUFA humus balance applies threshold values to assess insufficient, balanced, or excessive humus reproduction. Insufficient humus reproduction is interpreted as a threat to soil quality whereas excessive humus reproduction is considered as an ecological threat. As with most methods within the agronomical group, empirical evaluations of the method and the rating scheme have been conducted, but validation in modeling terms still has to be considered insufficient. Evaluations of the VDLUFA method based on the comparison of method results with agricultural indicators have been presented by *Körschens* et al. (2005), *Kolbe* (2010, 2005), *Beuke* (2006), *Brock* et al. (2008), and *Brock* (2009). The different evaluations referred to cannot in general be compared to each other, as they use different approaches and data sets to assess the method performance. For example, *Körschens* et al. (2005) as well as *Beuke* (2006) refer to the optimal OM supply in crop rotations with regard to crop-yield levels in long-term field experiments, but without considering SOM-level changes. In contrast, *Kolbe* (2010), and, in another validation step, *Beuke* (2006) relate calculated balances to SOM-level change in long-term field experiments, without consideration of yield levels. And *Brock* et al. (2008) examine correlations between calculated balances and different SOM quantity and quality indicators (see section 2.2.2 for details on this evaluation). Results of these evaluations showed that the performance quality of upper and lower values was dependent on several base conditions, as site and farming system (organic *vs.* conventional). However, the only validation directly referring to the original method aims (maintenance of "adequate" SOM levels, high yield levels, high N efficiency) has been presented by *Kolbe* (2005). Based on the assessment of 330 treatments in altogether 39 long-term field experiments, the author showed that the "lower values" were better able to predict organic-manure demand in crop rotations for the maintenance of SOM levels on sandy and silty soils under climate conditions in E Germany ([sub]continental climate, low precipitation), while the "upper values" were better suitable on loam and clay soils, and in general with higher precipitation (Atlantic climate). Further, the "upper values" calculated a higher demand of organic manure for optimal yield levels than the "lower values", but at the same time mineral N fertilization on average was lower in the reference "optimal treatments" that were identified applying the "upper values". Nitrogen balances were positive with both value classes, but showed slightly lower amounts with the "upper values". However, the author underlines that considerable demand for methodical improvement existed with both parameter sets.

2.2.2 Static Humus Unit Method for organic agriculture

In order to provide a humus balance for organic agriculture, *Leithold* et al. (1997) presented a modification of the *Kundler* et al. (1981) humus balance that considers a higher demand for OM-borne N with organic farming. The modification was conducted based on calculations applying the Horizontal Nitrogen Balance (*Leithold,* 1991), which showed that the missing N supply by mineral fertilizers in organic farming called for a considerably higher demand for N from SOM mineralization even with lower crop-yield levels (*Leithold,* 1996). Therefore, specific parameters were presented for nonlegume main crops only. Legumes usually are not fertilized in conventional farming as well, and therefore no adaptation need was considered. The Static Humus Unit Method was included in a comparative evaluation of humus-balance methods by *Brock* et al. (2008). In this evaluation, results of this method showed significant positive correlations with the state of humus quantity (SOC and STN state and change) and quality indicators (hot water–extractable soil C and N, microbial biomass, enzyme activities) in treatment comparison within different LTFE in 35% of experiment × indicator combinations ($n = 94$), and significantly failed in 10% of combinations (*Brock* et al., 2008, Tab. 6.33, p. 153).

2.2.3 Dynamic Humus Unit method

The Dynamic Humus Unit Method of *Hülsbergen* (2003) is an implementation of the Horizontal Nitrogen Balance (*Leithold,* 1991) to a fully applicable humus-balance tool. Basically, the algorithm estimates OM contributing to humus built-up on the basis of C input with plant biomass and organic amendments, and calculates humus mineralization on the basis of N in plant biomass considering different N sources and sinks in the system. However, the model uses a bipartite approach: Humus-demand of nonlegume main crops is calculated based on the algorithm of *Leithold* (1991), while humus-supply values for legume and green-manure crops are empirically derived from observations in field experiments. The Dynamic Humus Unit Method basically follows the agronomical assessment concept (see above) and aims at the maintenance of soil productivity. According to *Küstermann* et al. (2008), it may be used for SOC-change quantification as well. However, the quantification of SOC change was not an intended aim of the method according to *Hülsbergen* (2003) because the model approach implies considerable uncertainties with this feature. Still, the model has been evaluated for plausibility in farming practice based on balance calculations for several hundred farms (*Hülsbergen* et al., 2005). The comparative humus-balance evaluation by *Brock* et al. (2008) referred to above showed a significant positive correlation between balances and humus indicators in 28% of experiment × indicator combinations ($n = 92$), while the model significantly failed in 9% of combinations (*Brock* et al., 2008, Tab. 6.33, p. 153).

The model has been integrated into the complex sustainability assessment tool REPRO (*Hülsbergen,* 2003). Today, this tool is applied with a sustainability certificate of the German Agricultural Association (DLG).

2.2.4 HU-MOD

The humus-balance model HU-MOD (*Brock* et al., 2008, 2012) is a further development of the Dynamic Humus Unit Method of *Hülsbergen* (2003) and thus is based on the Horizontal Nitrogen Balance concept of *Leithold* (1991). Basically, the algorithm calculates the net humus reproduction estimating the supply of OM contributing to humus build-up on the basis of C input with plant biomass and organic amendments and calculates humus mineralization from the N cycle. The humus reproduction is estimated considering OM input with aboveground plant residues, roots, and exudates. Humus mineralization is calculated by separating the contribution of each active N pool, including the humus pool, to plant N supply. All parameters except for crop type, main product yield level, and type and amount of fertilizer, use tabulated values, if actual data is not available. The model has been validated for its ability to predict management-change impact on SOM levels by trend in two long-term field experiments. Differences between humus balances were positively correlated with differences in SOM-level development in each field experiment (r^2 = 0.94...0.99 in experiment 1, and r^2 = 0.29...0.56 in experiment 2), but regression coefficients varied considerably between the experiments (b = 0.62...1.53 in experiment 1, and b = 0.18...0.28 in experiment 2). Thus, the model was able to qualitatively assess management impact on SOM levels on an ordinal scale (negative—no—positive impact). Further, the model was included in a method comparison of *Holenstein* (2010) that applied a similar evaluation method as described above and supported the good performance of the tool (r = 0.59...0.86). In the latter evaluation, correlation quality of the humus-balance model was on the same level as for a complex SOM-turnover model (Roth-C) that was applied in comparison. An evaluation of an early stage of model development is comprised in the survey of *Brock* et al. (2008) referred to above (see sections 2.2.2 and 2.2.3). As parameterization has been improved considerably afterwards, the validations in *Brock* et al. (2012) and *Holenstein* (2010) have to be considered more appropriate with regard to the actual model-development stage.

2.2.5 SALCA

The original humus-balance method of *Neyroud* et al. (1997) was extended with respect to humus-reproduction data for additional crops and organic fertilizers (*Oberholzer* et al., 2006). This method calculates soil OM losses and gains separately. SOM loss is calculated based on (1) an estimated typical SOM content of the soil and (2) the mineralization coefficient. Both the typical SOM-content estimate and the mineralization coefficient are dependent on the soil clay content. The mineralization coefficient further is modified based on soil pH and mechanical-impact intensity on the soil in the crop rotation. The latter is determined indirectly depending on the percentage of root crops and of temporary ley in the crop rotation as an indication of intense tillage enhancing SOM mineralization or low tillage intensity reducing SOM decomposition. Inputs of OM are compulsory crop residues like stubbles and roots, optional residues such as cereals and rape straw and organic fertilizers. The quantity of humus reproduction is calculated as fixed amount per crop, without taking into account the actual yield, whereas the effect of organic amendments depends on the applied quantity and the type as well. SALCA was validated by comparing balance results with real changes in C stocks in treatments of three long-term field trials in Switzerland comprising various treatments with mineral and organic fertilizers (*Holenstein,* 2010). The method was able to distinguish systematic management effects on SOC but failed to match measured stock changes quantitatively.

2.2.6 CCB

The Candy Carbon Balance (CCB) model (*Franko* et al., 2011) is a simple derivation of the CANDY model (*Franko* et al., 1995; *Franko* and *Oelschlägel,* 1995; *Franko,* 1997) and the CIPS model (*Kuka* et al., 2007). The CANDY parameters are used for the quality description of OM pools including the yield-depending calculation of the amount of crop residues. CCB calculates the turnover of C and N in the topsoil depending on climate conditions, soil properties, and management activities (cultivation, management, organic fertilizer, and irrigation). The model aims at the estimation of C sequestration as basic information for the assessment of further soil functions. Considered processes of humus dynamics are mineralization, humification, and input of fresh OM (crop residues, by products, and organic amendments). The absolute impact of management activities on the SOM dynamics is indicated depending on initial condition and site-specific parameters that are expressed in terms of Biologic Active Time (BAT). Minimum requirement of data input are

– for soil: clay content and soil type (according to the German “Reichsbodenschätzung” [soil classification], *cf. Capelle* et al., 2006);

– for climate conditions: long-term averages of air temperature and precipitation;

– for management: yearly information about crop, yield, usage of by-products, kind and application rate of organic amendments, irrigation rate.

More soil parameters may be specified by model users or will be calculated from pedotransfer functions. Soil-physical parameters like pore volume, field capacity, and wilting point are used to estimate the amount of OM that is long-term-stabilized according to the concept of the CIPS model (*Kuka* et al., 2007) The validation of the CCB model was based on data sets from long-term field experiments (391 treatments from 40 experiments) and a comparison of simulation results with observed values (4794 measurements of SOC). The root mean square error (RMSE) of the model amounts to 1.19 g SOC (kg soil)$^{-1}$. Further work is required for the model validation in terms of soil total nitrogen and microbial biomass time series.

The CCB model is applied on plot or subplot level. Results can easily be aggregated to higher levels using standard database operations. The maximum temporal resolution is 1 year.

2.2.7 STAND

The method introduced by *Kolbe* (2010) is an improved, site-adjusted, semiquantitative procedure of SOC balance and quantification of optimal organic-matter amendment based on the VDLUFA method to be used for terrestrial soils in order to easy accomplish calculations in agricultural practice and consulting. As descendant of the VDLUFA method it aims at sustaining soil productivity. But the improvement is directed on the sustaining of a site and management-typical SOM storage as well. STAND is based on empirical humification parameters depending on type and amount of added OM and on site-specific parameters for the impact of the grown crops. The result of this method is the management-related change of SOM storage starting from an initial value. The balance result is assigned to one of five classes representing the sustainability of the crop rotation together with the organic amendments. The parameters of the method are based on the parameters (lower values) of the VDLUFA method that have been varied and calibrated for different site conditions using results from 39 long-term experiments in Central Europe. The error in predicting SOM change with STAND was 2.1–2.3 g SOC (kg soil)$^{-1}$ (*Kolbe* 2010). STAND can be applied on farm-field level, and its results are related to a time horizon when the SOM is approaching a steady state (about 25 years).

3 Discussion

With regard to the application of humus balancing for management support in farming practice, both the agronomical and the ecological approach feature their special opportunities and limitations. Models of the ecological group produce quantitative results, but they require information on soil properties and climate conditions. Agronomical humus balances have a strongly reduced sensitivity to site-specific data, but cannot predict quantitative SOM changes.

As spatially representative data on field scale are very difficult to collect, models with higher sensitivity on these kinds of data may have the potential for better forecasts but will produce a considerable error if applied with roughly estimated inputs.

The overview given in the chapter above shows that depending on the actual problem and the available data any user may choose an equivalent method. There are agronomical approaches of different complexity to relate management decisions to general aspects of soil productivity calculating required organic amendments, while other methods give a forecast of changes in SOC amount using the ecological approaches. Some methods include even a combination of both aspects.

While their easy applicability as a management support and/or assessment tool is a great advantage of the simple humus-balance methods (VDLUFA, Static Humus Unit, STAND, SALCA), one big shortcoming is that a procedure for parameter generation (*i.e.,* parameterization of new parameters) is not defined. The methods are not scientific models, but operational implementations of empirical and logical scientific findings. As such, they are not based on a consequent approach for parameterization, and the procedure of parameter generation is not described sufficiently to be reproducible in detail. Therefore, any adaptation or further development of these methods, *e.g.,* the calculation of balance parameters for new crops, requires the knowledge on the specific methodical background. More complex methods, like CCB, the Dynamic Humus Unit Method, and HU-MOD, require a larger set of input data but these approaches bear the advantage that parameterization is specified in detail. This situation offers the opportunity to reproducibly calculate or adapt parameters.

Another important and often controversially discussed issue is the validity of humus balances. This is especially relevant with the models of the agronomic approach that produce the required amount of organic amendments as a result. In this case, validation criteria are not easily definable because nearly all LTFE have only treatments with very large differences of organic-matter input giving no opportunity for a direct experimental identification of the optimum. In the description of the VDLUFA method it is stated that balanced humus reproduction shall provide “adequate” SOM levels and low nitrogen-loss potential at high yield levels. As already discussed in section 2.2.1 with the description of the VDLUFA method, a validation that considers all criteria from the method description has been presented by *Kolbe* (2005), and even though the author states that the method in principal was suitable as a practice-applicable management support tool, he concluded on a considerable demand for adaptation, especially with regard to the consideration of site impact. Further, the VDLUFA method features a rating scheme based on classes on an ordinal scale that include specifications of the implications of strongly negative (insufficient) and strongly positive (excessive) balances. Up to now, no validation of this rating scheme and the denoted threshold values and implications is available and the most other methods provide no rating scheme at all.

Concerning the Humus unit Methods (Static and Dynamic), results of quantitative method evaluations and plausibility assessment with regard to balance variation of large samples in practice application have been presented (*Leithold* et al., 2007; *Hülsbergen* et al., 2005; *Mönicke* et al., 2004), but systematic validation is urgently required.

For all methods that refer to absolute or relative SOM-change assessment (CCB, STAND, HU-MOD) individual validations have been conducted and are reported with the model descriptions, respectively.

4 Conclusions

It is necessary to be aware of the specific scope of the different humus-balancing methods. Models that we categorize into the “agronomical approach” aim at the assessment of organic-matter demand in crop rotations to maintain soil productivity, while those models grouped into the “ecological approach” target the quantification of SOM-level changes. The choice of a method must therefore first of all depend on the objective of the application.

Further, the final decision about the selection of a humus-balancing method must be based on available validation results concerning the specific subject (site conditions, crop rotation, and scope), as well as on the availability and quality of the required input data. For any qualified decision it would be very helpful if the method validation could be based on some standardized methods according to the specific aim. It is necessary to define statistical measures that allow a ranking of the methods according to their performance under different conditions. It is clear that a real performance comparison of methods having the same scope has to be based on the same database. Looking over the methods referred to in this paper it is obvious that this is currently not the case. The extent of the validation data sets is very different between methods and there is nothing like a reference data set available.

Acknowledgments

The authors acknowledge the contribution of all participants of the second workshop on humus balance methodology and validation of the task group on validation of humus balances in the VDLUFA work-group on humus balances for their contribution to the discussion and final elaboration of this paper. Further, we would like to thank the referees of this paper for their highly valuable comments.

References

Andrén, O., Kätterer, T. (1997): ICBM: The introductory carbon balance model for exploration of soil carbon balances. *Ecol. Appl.* 7, 1226–1236.

Asmus, F., Herrmann, V. (1977): Reproduktion der Organischen Substanz des Bodens. Akademie der Landwirtschaftswissenschaften der DDR, Berlin.

Beuke, K. (2006): Überprüfung der Humusbilanzierung anhand von Dauerversuchen in verschiedenen Klimaregionen Europas. Diploma Thesis, Universität Trier, Trier.

Brock, C. (2009): Humusdynamik und Humusreproduktion in Ackerbausystemen und deren Bewertung mit Humusindikatoren und Humusbilanzen. Gießener Schriften zum Ökologischen Landbau 2, Dr. Köster, Berlin.

Brock, C., Hoyer, U., Leithold, G., Hülsbergen, K.-J. (2008): Entwicklung einer praxisanwendbaren Method der Humusbilanzierung im ökologischen Landbau. Gießener Schriften zum Ökologischen Landbau 1, Dr. Köster, Berlin.

Brock, C., Hoyer, U., Leithold, G., Hülsbergen, K.-J. (2012): The humus balance model (HU-MOD): A simple tool for the assessment of management change impact on soil organic matter levels. *Nutr. Cycl. Agroecosys.* 92, 239–254.

Capelle, A., Ulonska, H.-J., Rötscher, T. (2006): Administrative und wissenschaftliche Nachnutzung von Primärdaten der Bodenschätzung. *Wasserwirtschaft* 96, 64–68.

Feller, C., Thuriés, L., Manlay, R., Robin, P., Frossard, E. (2003): "The principles of rational agriculture" by Albrecht Daniel Thaer (1752–1828). An approach to the sustainability of cropping systems at the beginning of the 19th century. *J. Plant Nutr. Soil Sci.* 166, 687–698.

Franko, U. (1997): Modellierung des Umsatzes der organischen Bodensubstanz. *Arch. Acker- Pfl. Bodenk.* 41, 527–547.

Franko, U., Oelschlägel, B. (1995): Einfluß von Klima und Textur auf die biologische Aktivität beim Umsatz der organischen Bodensubstanz. *Arch. Acker- Pfl. Bodenk.* 39, 155–163.

Franko, U., Oelschlägel, B., Schenk, S. (1995): Simulation of temperature-, water- and nitrogen dynamics using the Model CANDY. *Ecol. Model.* 81, 213–222.

Franko, U., Kolbe, H., Thiel, E., Ließ, E. (2011): Multi-site validation of a soil organic matter model for arable fields based on generally available input data. *Geoderma* 166, 119–134.

Henin, S., Dupuis, M. (1945): Essai de bilan de la matière organique du sol. *Ann. Agron.* 15, 17–29.

Hülsbergen, K.-J. (2003): Entwicklung und Anwendung eines Bilanzierungsmodells zur Bewertung der Nachhaltigkeit landwirtschaftlicher Systeme. Shaker, Aachen.

Hülsbergen, K.-J., Küstermann, B., Schmid, H. (2005): Humusmanagement im ökologischen Betrieb. Schriftenreihe der Bayerischen Landesanstalt für Landwirtschaft 6/2005, pp. 55–69.

Holenstein, H. (2010): Humusbilanzen in Schweizer landwirtschaftlichen Dauerfeldversuchen – Validierung von Humusbilanzmodellen. Master Thesis, Department of Geography, University of Zurich UZH, Zurich, Switzerland.

Janssen, B. (1984): A simple method for calculating decomposition and accumulation of 'young' soil organic matter. *Plant Soil* 76, 297–304.

Kolbe, H. (2005): Prüfung der VDLUFA-Bilanzierungsmethode für Humus durch langjährige Dauerversuche. *Arch. Agron. Soil Sci.* 51, 221–239.

Kolbe, H. (2010): Site-adjusted organic matter-balance method for use in arable farming systems. *J. Plant Nutr. Soil Sci.* 173, 678–691.

Körschens, M., Rogasik, J., Schulz, E. (2005): Bilanzierung und Richtwerte organischer Bodensubstanz. *Landbauforschung Völkenrode* 55, 1–10.

Küstermann, B., Kainz, M., Hülsbergen, K.-J. (2008): Modeling carbon cycles and estimation of greenhouse gas emissions from organic and conventional farming systems. *Renew. Agr. Food. Syst.* 23, 38–52.

Kuka, K., Franko, U., Rühlmann, J. (2007): Modelling the impact of pore space distribution on carbon turnover. *Ecol. Model.* 208, 295–306.

Kundler, P., Eich, D., Liste, W., Rauhe, K. (1981): Mehr tun als nur ersetzen. *Neue Deutsche Bauernzeitschrift* 36, 8–9.

Leithold, G. (1984): Untersuchung der Beziehungen zwischen ackerbaulichen Maßnahmen, Ertrag und Humusreproduktion sowie Erarbeitung einer Methode zur Berechnung des Bedarfes des Bodens an organischer Primärsubstanz. Habilitation treatise, Martin-Luther-University Halle-Wittenberg, Halle (Saale), Germany.

Leithold, G. (1991): Zur Herleitung der Gleichung der "horizontalen" Stickstoffbilanz. *Wiss. Zeitschrift d. Universität Halle*, 91 M 6, 139–145.

Leithold, G. (1996): The Special Qualities of Humus and Nitrogen Budget in Organic Farming, in Proceedings of the 11th International Scientific Conference IFOAM in Copenhagen, Denmark, August 11–15, 1996, pp. 52–55.

Leithold, G., Hülsbergen, K.-J., Michel, D., Schönmeier, H. (1997): Humusbilanzierung – Methoden und Anwendung als Agrar-Umweltindikator, in Deutsche Bundesstiftung Umwelt (ed.): Umweltverträgliche Pflanzenproduktion. Initiativen zum Umweltschutz 5. Zeller Verlag, Osnabrück, Germany, p. 43–54.

Leithold, G., Brock, C., Hoyer, U., Hülsbergen, K.-J. (2007): Anpassung der Humusbilanzierung an die Bedingungen des ökologischen Landbaus. KTBL-Schrift 458, KTBL, Darmstadt, pp. 24–50.

Lykov, A. (1977): A method for the calculation of the soil humus balance in intensive arable crop production (in russian). *Isvestija TSCHA* 6, 14–20.

Mönicke, R., Beer, V., Kurzer, H. J. (2004): Ergebnisse der Humusbilanzrechnung im Freistaat Sachsen – dargestellt an 1000 repräsentativ verteilten Dauertestflächen. *Infodienst der Sächsischen Landesanstalt für Landwirtschaft* 11/2004, 62–71.

Neyroud, J.-A., Supcik, P., Magnollay, F. (1997): La part du sol dans la production intégrée. 1. Gestion de la matiére organique et bilan humique. *Revue Suisse Agriculture* 29, 45–51.

Oberholzer, H.-R., Weisskopf, P., Gaillard, G., Weiss, F., Freiermuth Knuchel, R. (2006): Methode zur Beurteilung der Wirkungen landwirtschaftlicher Bewirtschaftung auf die Bodenqualität in Ökobilanzen. Agroscope, Zürich, Switzerland.

Rauhe, K., Schönmeier, H. (1966): Über die Bedeutung des Humusersatzes beim Übergang zu industriemäßigen Produktionsmethoden. *Wiss. Zeitschrift d. Karl-Marx-Univ. Leipzig* 15, 1–5.

Reeves, D. (1997): The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil Till. Res.* 43, 131–167.

Saffih-Hdadi, K., Mary, B. (2008): Modeling consequences of straw residues export on soil organic carbon. *Soil Biol. Biochem.* 40, 594–607.

Shibu, M., Leffelaar, P., van Keulen, H., Aggarwal, P. (2006): Quantitative description of soil organic matter dynamics—A review of approaches with reference to rice-based cropping systems. *Geoderma* 137, 1–18.

Thaer, A. (1811): Grundsätze der rationellen Landwirtschaft. Berlin, Germany.

VDLUFA (2004): Humusbilanzierung. Methode zur Beurteilung und Bemessung der Humusversorgung von Ackerland. Eigenverlag VDLUFA, Speyer, Germany.

