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Simplified model of management on SOC flows and stocks and crop yield

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Executive summary

This deliverable report summarises the work on developing a simplified model of management on SOC flows and stocks and crop yield. The model is described in more detail in two manuscripts for scientific journals of which one has been submitted and the other is in preparation:

Taghizadeh-Toosi, A., Christensen, B.T., Hutchings, N.J., Vejlin, J., Kätterer, T., Glendining, M., Olesen, J.E. (2014). C-TOOL: A simple model for simulating whole-profile carbon storage in temperate agricultural soils. *Ecological Modelling (submitted).*

Olesen, J.E., Smith, P., Porter, J.R., Yeluripati, J., Ghaley, B.B., Schelde, K., Baby, S., Ferrise, R., Kuikman, P., Lesschen, J. (in prep). A simplified model for assessing soil carbon management effects on soil carbon stocks and crop yield.

The simple model was developed to simulate the crop yield - soil carbon stock/flow relationship under diverse climatic conditions and soil and crop management practices (type of crops and catch crops, tillage, and fertilization practices). Modelling and data analysis activities of WP1 (mainly Tasks 1.1 and 1.2), as well as prior expert knowledge and judgement, contributed to the formulation of the simple carbon model to assess crop yield-soil carbon response functions.

Briefly, the simple carbon model consists of two linked models: 1) A soil carbon prediction model and 2) a yield trend prediction model. The simple soil carbon model that distinguishes soil C in topsoil and subsoil as affected by soil carbon inputs and management was developed and tested against the LTE database described above. The model has been described by Taghizadeh-Toosi (submitted). The model describing effects of soil carbon management on crop yield takes its departure in the response of crop yield to N fertiliser rates and adjusts parameters describing this curve depending on soil C flows and stocks, considering how these affect crop N supply as well as crop water supply and health aspects. This model has been formulated with a preliminary calibration (to be expanded) and it currently under elaboration for a journal manuscript.

1. Introduction

Soil and crop management has significant effects on soil carbon (C) flows and stocks and hence on soil functions and the ecosystem services that soils supply; hence management can be effectively used as a tool to control and direct the services. Soil functions vital to crop productivity and other agroecosystem services rely on a range of physically, chemically and biologically defined soil properties. In intensive production systems soil properties are modified directly through management (e.g. drainage, irrigation, tillage, fertilization, crop rotations, plant protection) and indirectly by effects derived from implementing the management measures (e.g. soil compaction and soil erosion). The interaction between soil properties and management affects the functioning of the soil and thereby provides a feed-forward effect on crop growth and other ecosystem services (Schjønning et al., 2004).

The quantity and quality (the stock) of organic matter (SOM) in agricultural soils represents a key property that exerts a decisive modifying effect on other soil properties and thereby also on soil functions. The transformation (the flow) of SOM has a direct and immediate impact on soil func-tions. The importance of SOM storage and turnover to individual soil properties and functions has been subject to detailed research for decades and many specific mechanisms have been elucidated. Much less is known on the integrated effect of SOM on crop growth and yields because SOM derived effects are confounded with those of soil management (Schjønning et al., 2009). In the SmartSoil project it is assumed that these effects can be described through the flows and stocks of carbon and their effects on soil and crop health and crop water and nutrient supply (Figure 1).

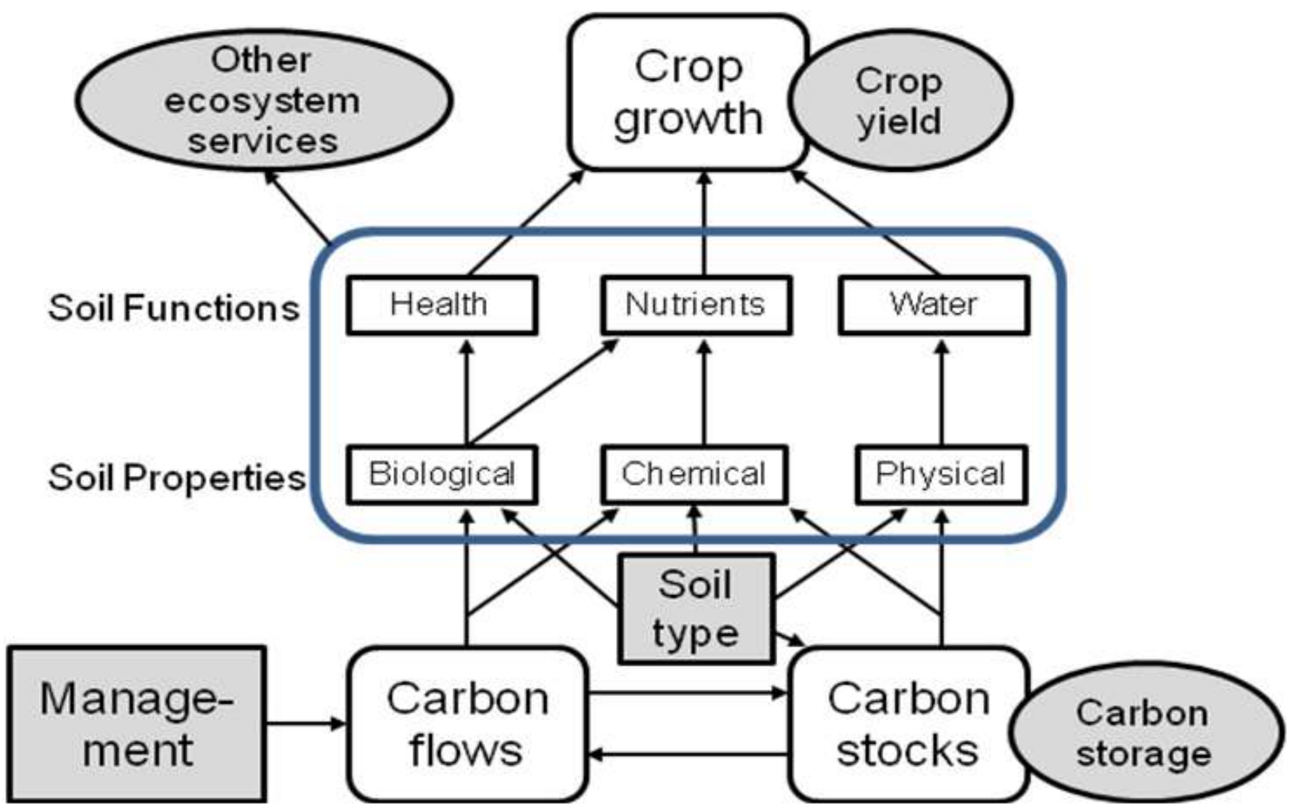

Figure 1. Inter-linkages between soil management, carbon flows and stocks, and crop yield.

It is assumed that SOM flows and SOM stocks play separate and different roles in relation to soil properties, soil functions and crop productivity, and that soil management can be designed to optimize either flow-derived or stock-derived functions (Figure 1). The different management options refer to different time scales (Christensen and Johnston, 1997). Management targeting SOM flows will be effective over relatively short time scales (weeks to months) while management options targeting SOM stocks will be effective only over longer time-scales (years to decades).

SOM flows and stocks affect soil biological, chemical and structural properties and functions differently. Soil structure affects soil porosity, gas and water exchange and soil tilth, and is mainly affected by SOM stocks. Biological properties affect soil and plant health and nutrient dynamics and are largely determined by SOM flows that fuel the activity of soil organisms. Soil chemical properties are affected by both SOM flows and stocks. The mineralogical and textural composition of soils is considered to influence soil structure and the retention of SOM in soil and involves the SOM saturation concept (Hassink, 1997; Dexter et al., 2008). The potential for protection of SOM may be related to the soil mineral fraction < 20 μm (Schjønning et al., 2012).

Healthy soil may be defined as soil containing optimal physical, chemical and biological conditions for plant growth. Concerning biological conditions, changes in the flow of SOM have a direct effect on the diversity and function of the soil microbial community, which play a key role in crop produc-tivity by the decisive influence on plant nutrient uptake, growth and health Moreover, the spatial organization of the soil matrix determines the availability of resources and the exchange of gas and water. These are complex interactions that cannot be fully described for use in decision support through use of complex simulation models. SmartSoil has therefore instead developed a simplified model that aims at predicting effects of soil and crop management on 1) Soil carbon stocks, and 2) crop productivity. This simplified model has relied on knowledge gained from using existing simulation models and analyses of long-term datasets on crop and soil management as well as results from more dedicated experiments that allow effect of short- and long-term soil management on soil carbon and crop productivity to be distinguished. It also applies a conceptual approach where the effects of crop yield are translated into a nitrogen fertiliser response curve. The model thus aims to predict the effects of crop management on developments in soil carbon and resulting effects on crop yield potential and response to nitrogen fertilisation.

2. Soil carbon model

Reliable projections of changes in SOC at farm- and regional-scales are required to predict the impact of agricultural activity on the global C cycle, to estimate the responses of climate changes and to allow farmers and policy makers to develop and implement management options that may reduce CO_2 emissions from agricultural soils and protect the soil resource. Dynamic process-oriented simulation models are generally considered to be efficient tools for projecting the effects of management on SOC and several models are able to simulate C turnover in agricultural soils. Some are dedicated C models (e.g. RothC, ICBM, and Yasso07 (Andrén and Kätterer, 1997; Coleman and Jenkinson, 1996; Tuomi et al., 2009)), while other models include nitrogen (N) and water, or have a scope that extends to the ecosystem level (e.g. DNDC, CENTURY and Daisy (Hansen et al., 1991; Li, 1996; Parton et al., 1987)). Most contemporary models are heavily parameterised, require extensive input data, and attempt to simulate both short-term and long-term dynamics of C in the soil. Further, many simulation models are difficult to calibrate because different parameterisations provide similar fits to observed data. To simulate changes in SOC at farm- and regional-scales, models should require as few parameters as possible while still including the core mechanisms that regulate C turnover at the relevant timescale.

2.1 C-TOOL model

The C-TOOL model was developed to enable simulations of the medium- to long-term changes in SOC in temperate mineral soils under agricultural management, using fewer parameters and input data than the dynamic process-oriented models currently available. The model structure was inspired by the models presented by Petersen et al. (2002) and Saffih-Hdadia and Mary (2008), and shares many principles with other SOC turnover models, including CENTURY (Parton et al., 1987), CN-SIM (Petersen et al., 2005), Daisy (Hansen et al., 1991), ICBM (Andrén and Kätterer, 1997) and RothC (Coleman and Jenkinson, 1996). C-TOOL considers the inputs and turnover of C associated with three SOC pools in the topsoil (0-25 cm) and three corresponding pools in the subsoil (25-100 cm), the transport of SOC from topsoil to subsoil, and emissions of CO_2.

Figure 2 shows the compartment structure of C-TOOL. The focus on medium- to long-term trends in SOC storage facilitates a relatively simple model structure. Thus different categories of organic inputs can be merged and the microbial biomass can be ignored as a separate C pool (Kätterer and Andrén, 1999). In contrast to the model framework presented by Petersen et al. (2002), the present C-TOOL model discriminates between SOC in topsoil (0-25 cm) and subsoil (25-100 cm), and includes vertical transport of C from topsoil to the subsoil. More complex simulation models seek to incorporate biological, chemical and physical processes known to occur in the soil and draw on state-of-the-art knowledge on soil organic matter composition and stabilisation. However, SOC pools in such simulation models do not yet correspond to specific and measurable fractions of soil organic matter even though some progress in this direction has been achieved (Christensen, 1996; Skjemstad et al., 2004; Sohi et al., 2001; Zimmermann et al., 2007).

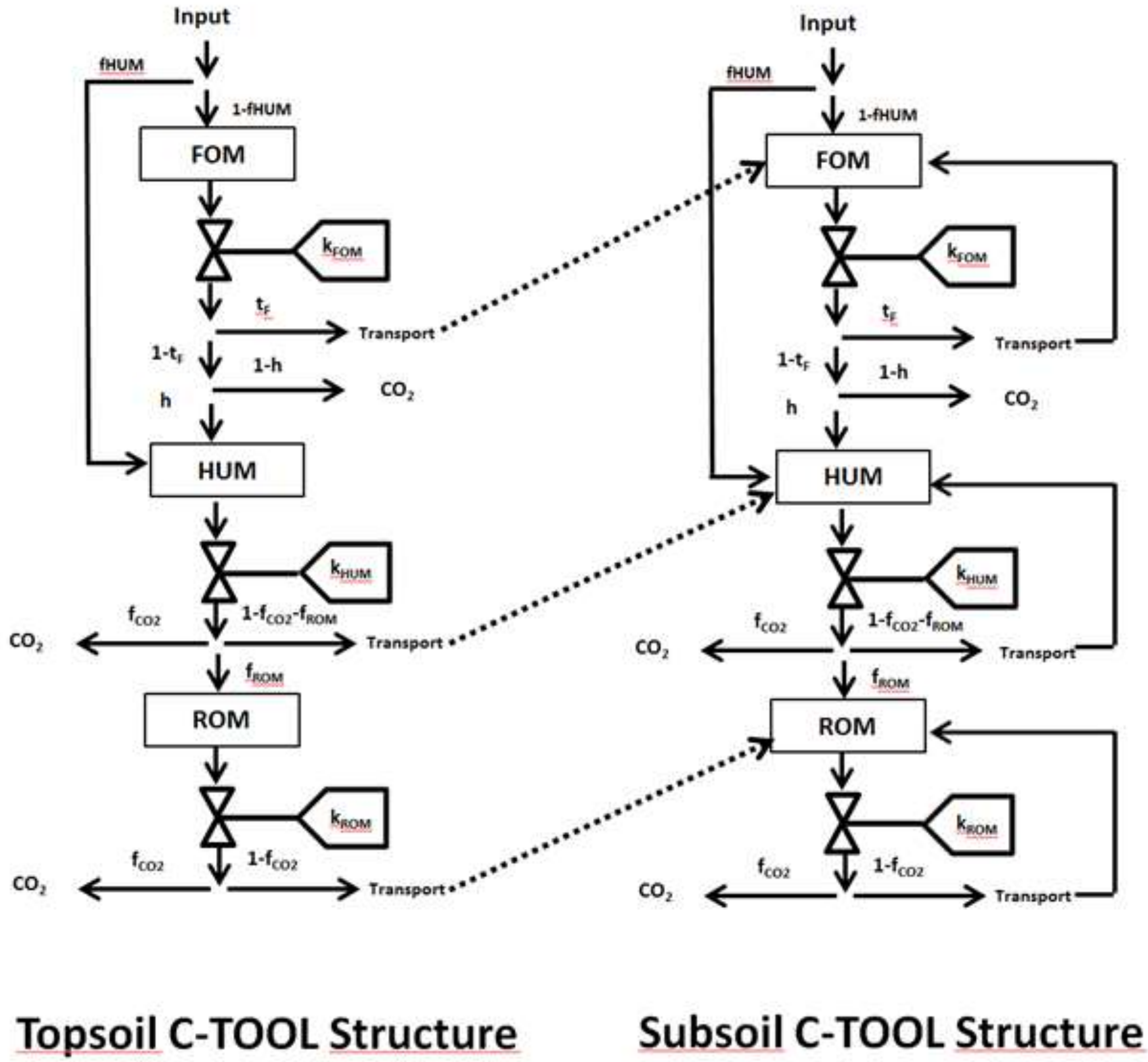

Figure 2. C-TOOL model structure for top and subsoil; FOM: Fresh Organic Matter, HUM: Humified Organic Matter, ROM: Resistant Organic Matter, fHUM: fraction of input going to HUM, kFOM: decomposition rate of FOM, kHUM: decomposition rate of HUM, fROM: fraction of FOM going to ROM, kROM: deccomposition rate of ROM, tF: The fraction of downward transport, h: Humification coefficient, fCO_2: fraction of released CO_2.

The C-TOOL structure is built around three conceptual pools: C in fresh organic matter (FOM), C in humified organic matter (HUM), and C in resistant organic matter (ROM). Carbon enters the soil via addition of FOM in aboveground plant residues, roots and rhizodeposition, and a fraction of the organic matter in animal manure. These inputs to FOM are all ascribed the same decomposition rate.

The HUM pool includes C in organic matter that has been subject to microbial transformation and has become physically and/or chemically stabilised in the soil. Since animal manure has been exposed to microbial transformation in the digestive tract and during subsequent storage, a fraction of the manure

C is allocated directly to HUM. This is regulated by fHUM (> 0 for manure and 0 for plant residues). The C in the HUM pool is ascribed a decadal scale half-life.

The ROM pool contains C in organic matter that has been rendered biologically resistant by physico-chemical mechanisms. In C-TOOL, the ROM pool is assumed to have a very slow turnover. Most SOC turnover models include a compartment that is either considered biologically inert or has a very slow turnover time (Falloon and Smith, 2000), and ROM turnover is considered of little importance in simulations over one or two centuries (Andrén and Kätterer, 1997). Radiocarbon dating suggests that the smallest possible size of the ROM pool corresponds to ca. 10% of the SOC in topsoil (assuming that ROM is of almost infinite age) while the upper limit for ROM is ca. 50% of the SOC (Petersen et al., 2005). Using inverse modelling and data from six long-term bare fallow experiments, Barré et al. (2010) found the stable C pool to account for ca. 25 % of the initial SOC content (Barré et al., 2010) .

Various factors affect the decomposition process, including the nature of the added organic matter and environmental factors such as soil temperature, water availability, pH and texture (Stockmann et al., 2013). In C-TOOL, the driving variables are soil texture (clay content), soil temperature, soil C/N ratio, and the type, quantity and application date of organic matter inputs. C-TOOL does not consider soil water as a limiting factor when simulating C turnover over decades to centuries but assumes that temperature is the overarching climatic driver for C turnover in the European temperate area from which data for parameterisation was retrieved. The model is therefore not applicable to soils exposed to prolonged dry seasons or water-logged soils.

The turnover rate in the model is modified by a temperature response function (F_T), which is set to at 10°C in the following manner (Kirschbaum, 1995):

$$F_T(T) = 7.24 \exp\left[-3.432 + 0.168T\left(1 - \frac{0.5T}{36.9}\right)\right] \quad (1)$$

The C-TOOL model uses a one-way, convection type transport model for simulating vertical transport of C in the soil (Jenkinson and Coleman, 2008). This model represents a simplification of the transport patterns reported in previous studies (Bruun et al., 2007; Dörr and Münnich, 1989). In C-TOOL, the transport of C occurs from all topsoil pools (0-25 cm depth) to the corresponding subsoil pool (25-100 cm) and is fixed fractions of the SOC turnover in the donating pools (Figure 1). For the subsoil pools, the vertical transport of SOC is also calculated but the amount of SOC is brought back to the donating SOC pool.

Tillage is often assumed to enhance the turnover of SOC (Chatskikh et al., 2009), but a recent meta-analysis suggests that tillage does not affect total SOC stock but merely its distribution in the topsoil layers (Luo et al., 2010). Adopting the paradigm of simplicity, C-TOOL does not consider the effects of soil tillage intensity. However, in the yield model in section 3 requires specific information on the carbon concentration in the top 5 cm layer, whereas C-TOOL only considers the top 25 cm. Here we assume that is C concentration in the top 5 cm layer is identical to the entire topsoil for soil that is regularly ploughed, and otherwise depends on the duration since adoption of no-tillage or reduced tillage (Y_P being the number of years since ploughing) and the depth of the non-inversion tillage (D in cm). The carbon concentration in the top 5 cm layer (C_5) is assumed to be a factor (f_{N5}) times the concentration in the top 25 cm layer (C_{25}), which increases linearly from 1 to a maximum value of f_X over a period of (Y_{NT}) years for no-tillage systems:

$$f_{N5} = f_X\ [1+min\ (Y_P/Y_{NT},\ 1)\ \{1\text{-}max((D\text{-}5)/20,0)\}] \quad (2)$$

For the calculations in here we set f_X to 2 and Y_{NT} to 20.

The introduction of no-tillage or reduced tillage will also affect the distribution between topsoil and subsoil carbon which is not included in the C-TOOL model (Luo et al., 2010). Therefore the soil carbon concentration in the topsoil (C_{25}) to be used for the calculations in both eqn (1) and in the yield model in section 3. The soil carbon in the top soil is assumed to be a fraction f_{N25} of the carbon concentration calculated by C-TOOL, and f_{N25} is set to be 10% of f_{N5}.

2.2 Estimating carbon inputs

The annual input of organic C to a soil arises from many sources, including aboveground crop parts shed during the growth period, stubbles left after harvesting, and root-derived C deposited during and after the growth phase. The C input from aboveground crop residues can be determined by inverse modelling, crop modelling (Bruun et al., 2003) or by allometric relationships between yields and C input to the soil (Kätterer et al., 2011). The simplest approach is to use allometric relationships and this is used for the C-TOOL simulations. Even when straw is harvested, a substantial fraction of the plant biomass is returned directly to the soil. In conventional farming, 50% of the C in total non-grain production may be returned, partly because these fractions are scattered as small particles or left in stubble and thus not harvestable by combine (Jørgensen et al., 2007).

The belowground C inputs include dead roots and rhizodeposition. Gerwitz and Page (1974) assumed that root-derived C was the only input to soil below the plough layer (25 cm here) and that this input could be described by an exponentially decreasing depth distribution (Gerwitz and Page, 1974). According to Kätterer et al. (2011), 71% of the roots are allocated to the upper 20 cm, 80% to 30 cm and 85% to 40 cm (Kätterer et al., 2011).The fraction of the root-derived C allocated to the topsoil (0-25 cm) depended on crop type and it was 70% for autumn sown crops (Kätterer et al., 1993), 80% for spring sown crops (Hansson and Andrén, 1999), and 90% for grassland (Kätterer and Andrén, 1999). Values for carbon allocation to roots are crop specific and were derived from various studies (Table 1). The C concentration in plant dry matter assumed to be 45% in all crop parts. Using the parameters in Table 1, Table 2 shows the allometric calculations of total C deposition.

Table 1. Values of carbon allocation to harvest (main and secondary products) and roots.

Crop	Harvest index of main crop relative to aboveground biomass (α)	Biomass of secondary crop product as proportion of yield of main crop product (δ)	Root and exudate C as proportion of total C assimilation (β)
Winter wheat	0.45	0.55	0.25
Spring barley	0.45	0.55	0.17
Winter barley	0.39	0.55	0.17
Rye	0.38	0.80	0.25
Oat	0.40	0.60	0.17
Cereals for whole-crop silage	0.75	0.00	0.17
Other cereals, mainly triticale	0.38	0.80	0.25

Oilseed rape	0.37	0.90	0.25
Grass and grass clover	0.70	0.00	0.45
Potatoes	0.70	0.00	0.11
Sugar beets	0.70	0.00	0.12
Fodder beets	0.70	0.34	0.12
Swedish turnip	0.70	0.00	0.12

Table 2. Calculations of total C (Mg ha^{-1}) deposited in top and sub soil.

Parameters

α = Harvest index of main crop product relative to aboveground biomass
β = Root biomass and exudate C (below-ground C) as proportion of total net C assimilation
δ = Biomass of secondary crop product (e.g. straw) as proportion of yield of main crop product
ζ = Proportion of secondary crop product that is harvested
ε = Concentration of C in biomass DM (kg Mg^{-1})
ξ = Proportion of root and exudate C deposited in top soil (0-25cm)

Input

Y_{main} = DM yield of main crop product (Mg DM ha^{-1})

C partitioning

C_{main} = C yield of main crop product = εY_{main}
C_{tot} = total C assimilation = $1/((1 - \beta)\ \alpha)\ C_{main}$
The above-ground carbon in crop residues (C_{resid}) is calculated as:
If there is only one crop product or if the secondary product is not harvested:

$$C_{resid} = (1/\alpha - 1)\ C_{main}$$

If the secondary product is harvested:

$$C_{resid} = (1/\alpha - 1 - \delta\ \zeta)\ C_{main}$$

The below-ground carbon in root residues and exudates (C_{resid}) are calculated as:

$$C_{below} = \beta\ C_{tot} = \beta\ /((1 - \beta)\ \alpha)\ C_{main}$$

The C in residues, roots and exudates deposited in topsoil ($C_{rootTop}$) is calculated as

$$C_{rootTop} = C_{resid} + \xi\ C_{below}$$

The C in residues, roots and exudates deposited in subsoil ($C_{rootSub}$) is calculated as

$$C_{rootSub} = (1 - \xi)\ C_{below}$$

α, β and δ are defined in Table 2, $\varepsilon = 0.45$, $\xi = 0.7$ (winter crops), 0.8 (spring crops) or 0.9 (grassland).

The composition of the different types of animal manure was available for some years at each site, and these data were used to estimate C inputs for the manured treatments. The fraction of the animal manure (f_{HUM}) that is transferred directly to the HUM pool (Figure 1) was estimated using data from Stemmer et al. (2000), who examined soils to which a batch of 14C labelled straw and 14C labelled animal manure had been applied 30 years earlier (Stemmer et al., 2000). The soils were under crop rotations or kept bare fallowed. The ratio of 14C to organic C content averaged over the treatments was 1:1.358 after 30 years. Considering the clay content dependent value of *h*, the f_{HUM} for animal manure was calculated as f_{HUM}=1.358-1-h, providing f_{HUM} values for animal manure in the range 0.14-0.16 depending on soil clay content. The f_{HUM} for plant materials was set to 0.

2.3 Model parameterisation

Guenet et al. (2013) found that FOM decomposition rates may range from 0.2 to 10 yr^{-1}. In our study, the decomposition rate of the FOM pool (k_{FOM}, 1.44 yr^{-1}) was taken from Petersen et al. (2005). The initial fraction of SOC allocated to the topsoil ROM pool was 0.405 and the decomposition rate of ROM pool (k_{ROM}) was set to 4.63 10^{-4} yr^{-1} so that the simulated ^{14}C age of Askov soils equals that of the "pre-bomb" measurements. The fraction of topsoil HUM partitioned to the ROM pool (f_{ROM}) was set to 0.012, a value that under steady state conditions maintains the fraction of SOC in the ROM pool at 0.405 (Petersen et al., 2005).

The fraction of topsoil FOM transported to the subsoil is expressed by the parameter tF. In a study with ^{14}C labelled ryegrass, Jenkinson and Rayner (1977) found that 0.40-0.75 % of the labelled C was leached over a period of two years (Jenkinson and Rayner, 1977). Using ^{14}C labelled barley straw, Sørensen (1987) observed that 9-10 % of the labelled C that was retained in the soil after 8 years was residing in the subsoil, i.e. below 20 cm (Sørensen, 1987). On the basis of this span, a tentative value of t_F = 0.03 is utilised in C-TOOL. For the HUM and ROM pools, a fixed proportion (f_{CO2}) of the decomposed C is emitted as CO_2. The value for f_{CO2} was set to 0.628.

The two remaining C-TOOL parameters; i.e. the decomposition rate of HUM (k_{HUM}) and the total initial soil C content in the long-term treatments were estimated by simultaneous optimisation, utilising a Marquard-Levenberg algorithm (Marquard, 1963). The optimisation was performed with a weighted squared error sum as the target function, using measured topsoil SOC data and the corresponding simulated data. The initial distribution of SOC between HUM and ROM pool influences C-TOOL simulations (Bruun and Jensen, 2002), but this distribution cannot be related to measurable entities. The procedure used when optimising the initial SOC content and kHUM was to begin the simulations with an initialisation period of 30 years i.e. prior to the period for which measurements were available. For each treatment, the total SOC at the start of the initialisation period was optimised on the measured value at the start of the experiment, with the condition that the partitioning of SOC between pools was: FOM, 0; HUM, 0.595; and ROM, 0.405. The model parameters were estimated using data from long-term experiments as Rothamsted in UK, Ultuna in Sweden and Askov in Denmark.

3. Yield model

The yield model predicts the crop yield response to fertilisation. It is assumed that the crop yield Y (Mg ha^{-1}) can be described through the following threshold function:

$$Y = \mathrm{Min}(Y_n + \mathrm{NUE} * N\ ,\ Y_x) \qquad (3)$$

where Y_x is the maximum yield (Mg ha^{-1}) at infinite N fertilisation, Y_n is the minimum crop yield (Mg ha^{-1}) at no N input, N is N input in fertiliser or manure in fertiliser N equivalents (kg N ha^{-1}), and NUE (Mg DM kg^{-1} N) is the N use efficiency. The principle of the response function is illustrated in Figure 3.

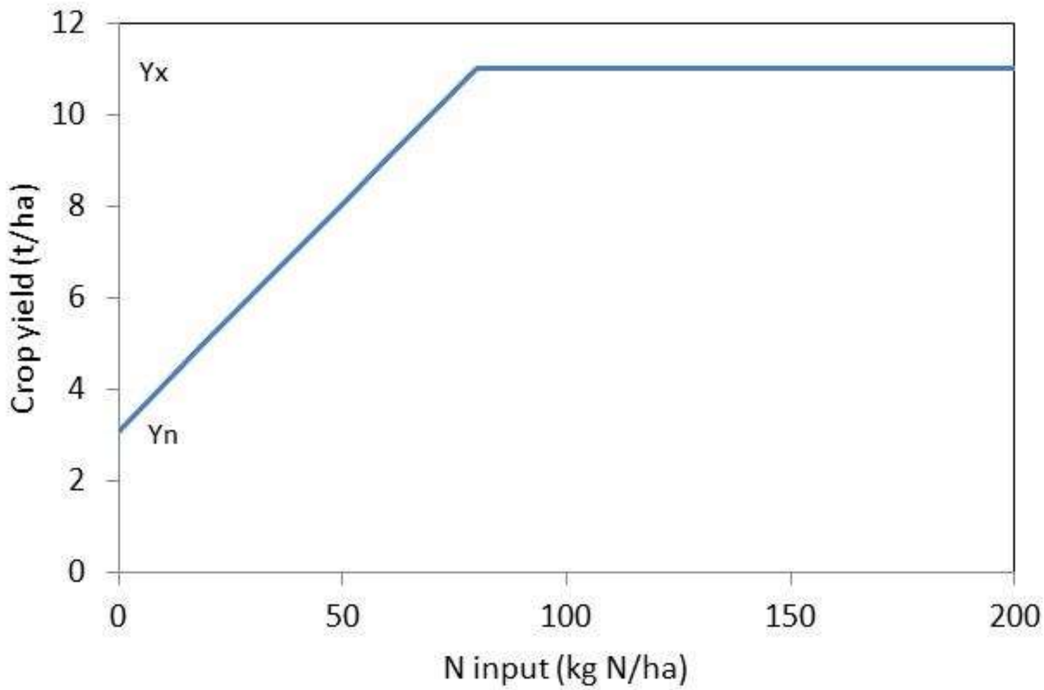

Figure 3. Response of crop yield to N input.

The N use efficiency (NUE) can be estimated from it sub-components:

$$NUE * N = (NRE * N_{fert} + NRR * N_{org}) / (NPCT*10) \quad (4)$$

where NRE (kg N kg^{-1} N) is the N recovery efficiency of applied mineral fertiliser (N_{fert}, kg N ha^{-1}), NRR is the N replacement rate, which is the relative N uptake of N in fertiliser or manure (N_{org}) compared to the standard N fertiliser, and NPCT is the content of N in dry matter yield (%). NRE typically has a value of 0.4-0.6 for cereals, and NRR may vary from 0.1 in compost to 0.8 in pig slurry.

The maximum yield Y_x is assumed to depend on soil carbon content and on the potential (maximum achievable) yield (Y_p, t ha^{-1}) at the particular site for the particular crop. This potential yield can be defined depending on NCUs, mostly related to climate and this may be defined from model simulations. The maximum yield is then a function of Y_p:

$$Y_x = f_h(C_{10})\ f_e(C_5)\ f_w(C_{25})\ Y_p \quad (5)$$

where

$f_h(C_5)$ is the crop health effect of soil carbon in the top 5 cm soil layer. The effect will likely depend on crop type, but an assumption could be that it linearly reduces crop yield by 5% below a soil carbon content of 3%.

$f_e(C_5)$ is the crop establishment effect of soil carbon in the top 5 cm soil layer. The effect will likely depend on crop type, but an assumption could be that it reduces crop yield when the Dexter index exceeds 10 (linear reduction in crop yield by 5% for Dexter index between 10 and 20). The Dexter index is defined as the clay to organic carbon content (Dexter et al., 2008).

$f_w(C_{25})$ is the soil water supply effect of soil carbon in the top 25 cm soil layer. This effect depends on soil water retention as well as soil water infiltration (water harvesting), which is assumed to increase with increasing soil carbon content. It is also assumed to depend on the climate, which may be taken as the ratio of potential evapotranspiration to precipitation (E_p/P) during the growing season. When E_p/P is larger than a given threshold (e.g. 1.5) this function is reduced linearly by 10% for soil carbon content below 3%. The effect may further be scaled by E_p/P so that higher values of this gives larger yield reductions at low soil carbon.

The minimum yield (Y_n) is assumed to depend on soil N supply, which is assumed to depend partly on soil carbon, but in reality more on soil N. The basic crop N supply (N_u) (taken and N uptake in yield) without N fertilisation is assumed to be calculated as

$$N_u = a_1 \, F_T(T) \, N_s + a_2 \; N_r + a_3 \, N_c \qquad (6)$$

where
a_1, a_2 and a_3 are model parameters
N_s is the soil total N content
N_r is the average annual input of N in crop residues, manure etc. over the past 5 years
N_c is the input of N in fresh crop residues (cover crops, grass etc.) immediately prior to the crop
T is annual mean temperature (^{o}C).

These parameters were estimated using data from a long-term experiment in Denmark (Olesen et al., 2000) using a regression approach that related harvested grain N to soil N and N inputs (Petersen et al., 2013). For winter wheat these parameters were estimated at a_1= 0.0049, a_2 = 0.45 and a_2 = 0.39.

4. Discussion

The simplified model here combines a model of long-term soil carbon dynamics in the topsoil and subsoil with a model of yield response to N supply from soil, manure and fertiliser. This approach was chosen because one of the major effects of changes in soil carbon is a concomitant change in soil nitrogen that affects soil supply of N to the crops (Kirkby et al., 2011). The model also attempts to incorporate the effects of other soil functions as illustrated in Figure 1. As such this model provides one of the first attempts at linking soil carbon with soil functions and how it affects crop yield.

The model for soil carbon dynamics was rigorously calibrated against data from long-term experiments (Taghizadeh-Toosi et al., 2014). It provides a simple and robust approach to estimate effects of crop management on soil carbon, including interactions with soil texture.

In contrast to the soil carbon model, many of the parameter estimates indicated above for the yield model are based on expert judgments. However, some these estimates will be further substantiated by comparison with results of analyses of long-term experiments and modelling studies conducted in WP1. For the N response applied in the model, general concepts are used for which there is a considerable source of data available to populate the model.

In the current form the model mostly considers the effects of soil carbon stocks on soil functions, whereas the effects of soil carbon flows is presently insufficiently represented. There is in particular a need to further consider the effect of addition of organic matter with high C:N ratio on short term yield effects, since such organic matter is known to immobilise nitrogen and thus lower yields. Thus this model represents a first attempt that need both further refinement, calibration and validation.

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