CCB Manual

Version 20.19.1.14

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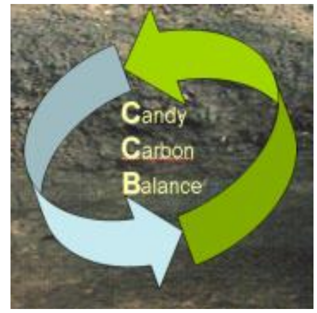
1 Introduction

1.1 Development of CCB (purpose)

CCB (CANDY carbon balance) started as a simplified version of the carbon dynamic model in CANDY (find the CANDY manual under www.ufz.de/candy). It describes the turnover of soil organic carbon and nitrogen in annual time steps for average site conditions depending on crop yields, input rates of fresh organic matter and the initial organic carbon content of the soil. The biologic active time is estimated from site conditions (soil physical parameters of the top soil, tillage system, average rainfall and air temperature). Outputs of CCB include dynamics of total organic carbon, SOM reproduction and Nitrogen mineralization.



The model has been validated using a dataset from 40 long-term experiments situated in Central Europe including 391 treatments with a total number of 4794 C_{org} observations. Statistical measures to prove model validity were mean error (ME = -0.001) and root mean square error (RMSE = 0.119). In addition a number of tests were performed to make sure that the model has no systematic error for different types of site conditions and management activities (Franko et al., 2011). Further extensions of the model where based on single datasets from long term field experiments: the consideration on conservation tillage (Franko & Spiegel, 20xx), the interaction of stabilised OM with soil structure (Franko & Merbach, 2018), and the dynamics of the physically stabilized SOM including the potential limitation of this pool (Franko & Schulz, 2019). Furthermore, the model was used successfully to predict changes of SOC storage and N mineralisation on regional level (Witting et al., 2019). Therefore, the CCB model is considered applicable for advisory service for arable fields on a wide range of site conditions.

1.2 Overview of CCB

The CCB model can be used in different workflows depending on the modelling demands, data availability and scale of interest. The standard workflow is considering the simulation on field scale including the availability of C_{org} measurements for the parameterization of the initial SOC concentration and the validation of the simulation.

Key procedures of the standard workflow are:

- Simulation of SOC concentration, mineralization, and reproduction of SOM on annually time step
- Simulation of soil nitrogen dynamics (esp. N-mineralization from fresh organic matter and soil organic matter) on annually time step
- Within the model setup it is possible to consider the following criteria:
    - crop rotations, crop yield, handling of by-products,
    - application of organic manure and mineral fertilizer
    - soil properties of the topsoil (e.g. soil texture)
    - climate data (air temperature, rainfall)
    - conventional tillage (ploughing) and reduced tillage (conservation tillage)
    - irrigation

Furthermore the CCB model system can be used in several “expert” modes which adapt CCB to special modelling demands that mainly result from special situations of data availability. These special application cases are described in section 2.6 and cover the topics:

- Indicator based simulation: Assessment of the humus supply level without the need of measurement data for C_{org}.
- Simulation of a pre-treatment: If an experiment starts with considerable changes of the management it may be reasonable to include the history of this place in the simulations.
- Simulation in ‘regional-mode’: Developed for meso to large scale studies. Inter alia crop share statistics can be used as data input instead of crop rotations.

The following chapters contain an user guide for the program interface and then provide a more detailed description of the algorithms implemented in CCB together with an explanation of the model parameters (‘3 Theoretical Documentation’). The description of the program interface is based on the standard workflow. Information concerning the expert mode is only mentioned where necessary and is described in an extra section at the end of the Theoretical Documentation. Finally, section ‘4 Input-/Output Parameters & Database’ describes the CCB Database and its manipulation.

2 Interface of CCB

2.1 Install Interface / Initialization

To start the CCB model following files are necessary:

- CCB executable file (e.g. CCB_2019.exe)
- borlndmm.dll (library necessary to run CCB)
- CCB compatible database (e.g. CCB_demo_db.mdb)

The best way for a first start is to copy all files in one directory. Then start the CCB_2019.exe file. The program will ask for a connection to a CCB compatible database (when starting CC the very first time):

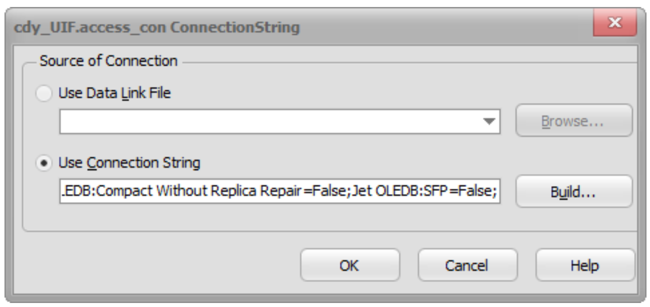


Figure 1: Start the creation of a CCB database connection

Click on [Build] to tell the model how it can connect to the database file.

First step is the specification of a DB-Provider. The selection of "*Microsoft Jet 4.0 OLE DB Provider*" is recommended, but "*Microsoft Office 12.0 Access Database Engine OLE DB Provider*" works as well.

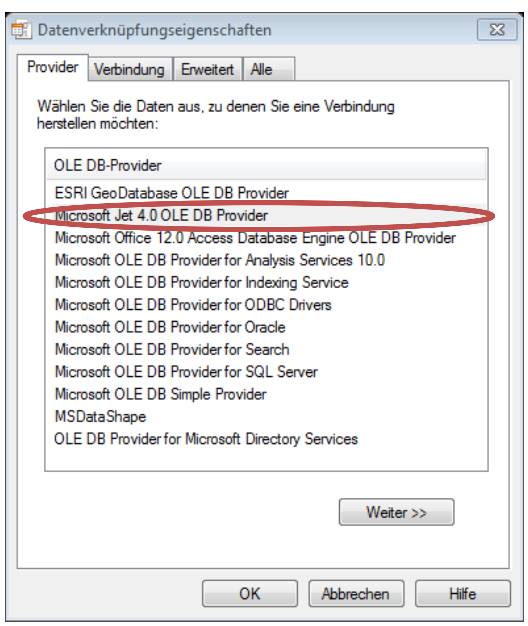


Figure 2: Selection of database provider

Select the provider and click [Weiter]. Then you have to specify the filename (and path) of the CCB – Access-Database that you have got together with CCB_2019.exe. It is strongly recommended to make a copy of the template and give it a name that reminds you to the content (like ccb_my_experiment.mdb)

In the next step you have to select this file. This is easy with the Jet 4 Provider. Just click on […] and open the file.

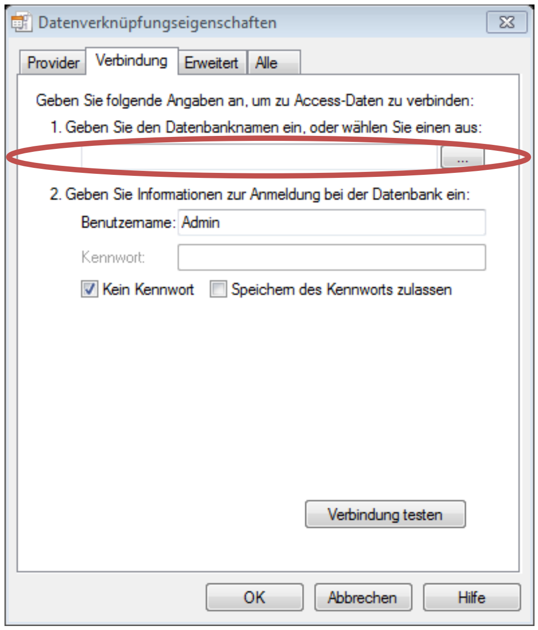


Figure 3: Selection of the CCB database

After finishing this step click on [Ok] (you may check the connection with [Verbindung testen] but if you don’t mix up the file names it should work anyway.

Now you see:

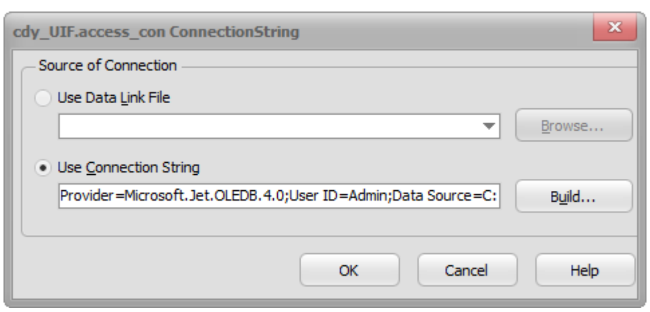


Figure 4: Finish the creation of a CCB database connection

Click [Ok] and you should have a proper running CCB program showing its data connection in a listbox.

CCB will store the information about this data connection in the registry of the computer system and on the next start it will try to connect to the same database. If this fails you will be asked to select the desired file (see Figure 5).

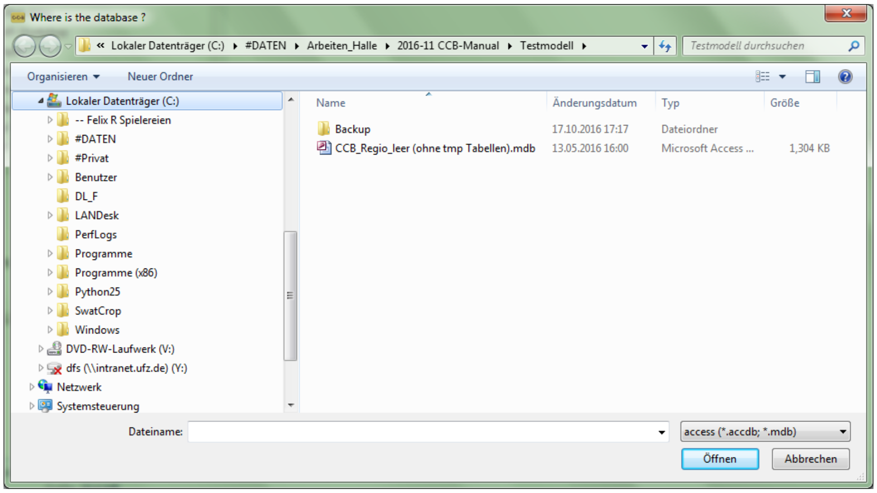


Figure 5: Selection of CCB database when connection fails.

2.2 Main Interface

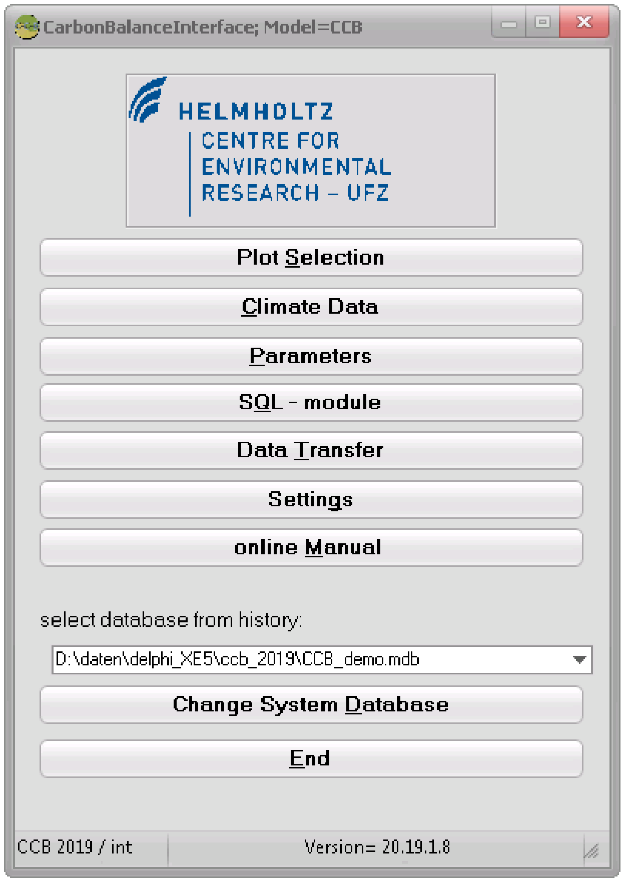


Figure 6: CCB main interface

This main form provides following menu items:

Plot Selection:	Go to data input, model start and result presentation
Climate Data:	Edit climate data (weather and N-deposition)
Parameters:	View and edit model parameters
SQL – module:	Tool to run short sql scripts
Data Transfer:	Move selected data sets into another database
Settings:	Check and change the configuration
online Manual	Opens the Manual (internet connection required)
Select database from history	Switch between databases that have been use before
Change System Database:	Select an existing database
End	Close the program

2.3 Data input

2.3.1 Generation of experiments & plots

First step is the selection of the database containing model parameters and user specific data. The last used database is shown in the selection list above the button *„Change System Database“.* If this field is empty or if the database shall be changed – click on the button and select the appropriate file from the standard windows dialog. Open this pop down menu for a quick switch between different databases.

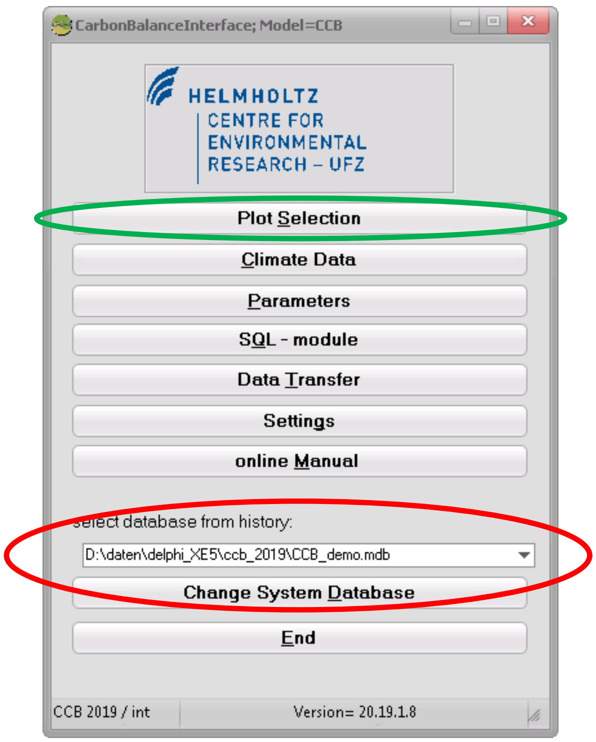


Figure 7: Database selection (red circle) and editing user data (green circle)

The data in CCB are usually organised as treatments *(plots*) of an *experiment*. Each experiment may contain numerous plots and one database can contain several experiments. Of course an experiment has not to be a real one – it may contain as well records of different farm fields or similar units. Click on “Plot Selection to start editing your data.

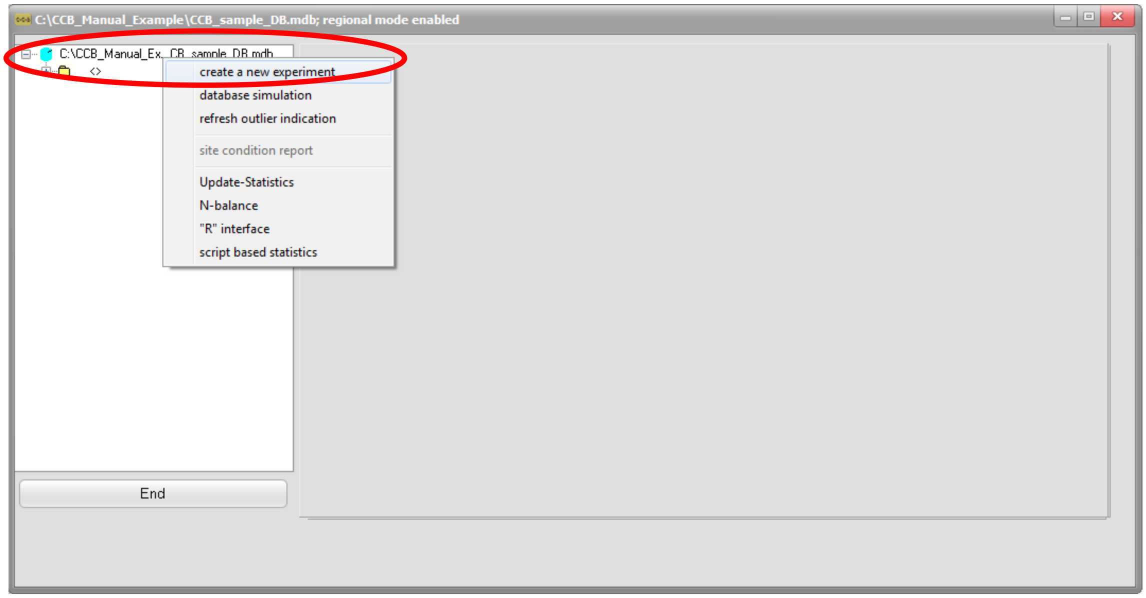


Figure 8: Create a new experiment folder

A right click on the path of your current database is opening a context menu where you should select *„create a new experiment“*, give it a name and continue.

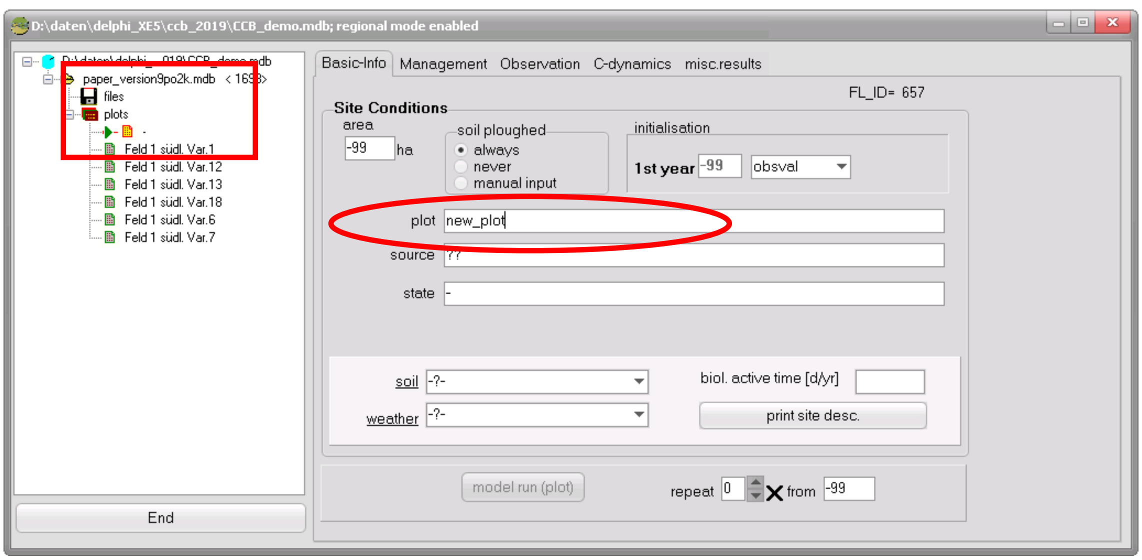


Figure 9: Editing a plot name

The new experiment is shown as folder containing already one plot. Click on the sheet-like pictogram to edit the data for this first plot. More plots can be added from the context menu (right click) of the plots symbol. The model results depend on the items soil, weather, the selection of the initialisation mode, and the selection of the tillage option (soil ploughed) – all other fields in this tab are only for the description. The plot name will be shown in the tree view at the left side of this form.

2.3.2 Soil data

You have to select the soil data for your corresponding plot in the ‘Basic-Info’-tab of the ‘Plot Selection’. The drop-down menu will show you all soils stored in the CCB database. To add additional soils you can either directly use the database (see section ‘4 Input-/Output Parameters & Database’) or use the CCB internal tools.

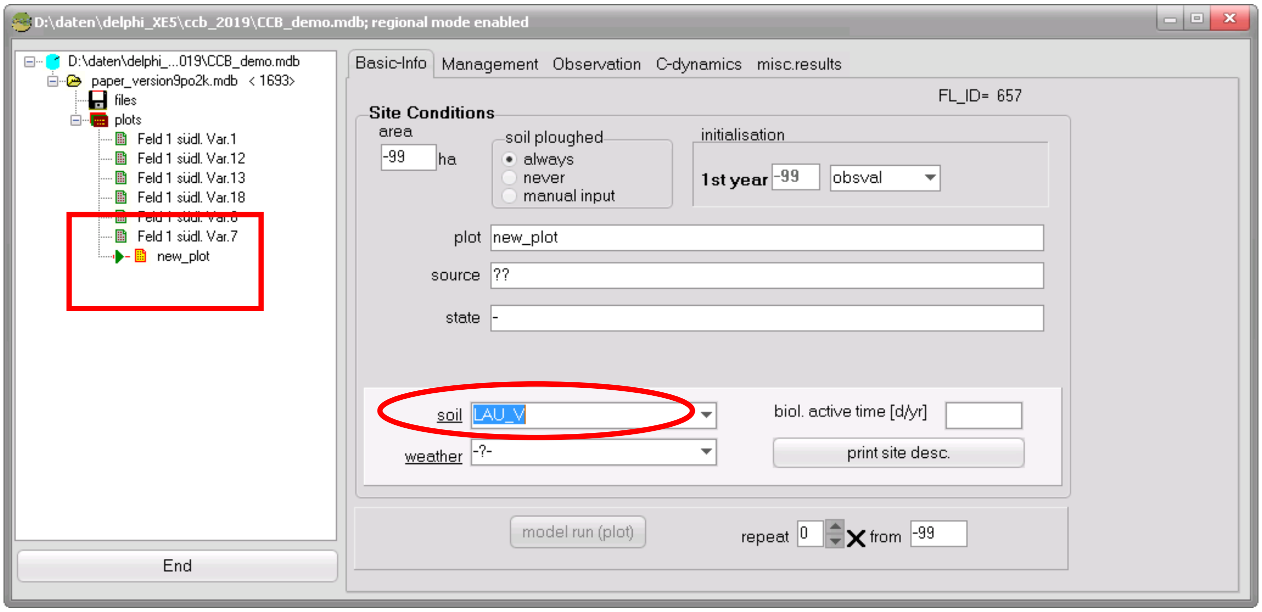


Figure 10: Selection of soil data

For using the CCB internal tools you can either double-click on ‘soil’ or go to the main menu, click ‘Parameters’ and select the ‘Soil Profiles’ tab. CCB needs some information about the uppermost soil layer 0-3 dm. All underlined items are necessary inputs all other parameters will be used by the model if specified from the user – otherwise the model is calculating estimates during the simulation run.

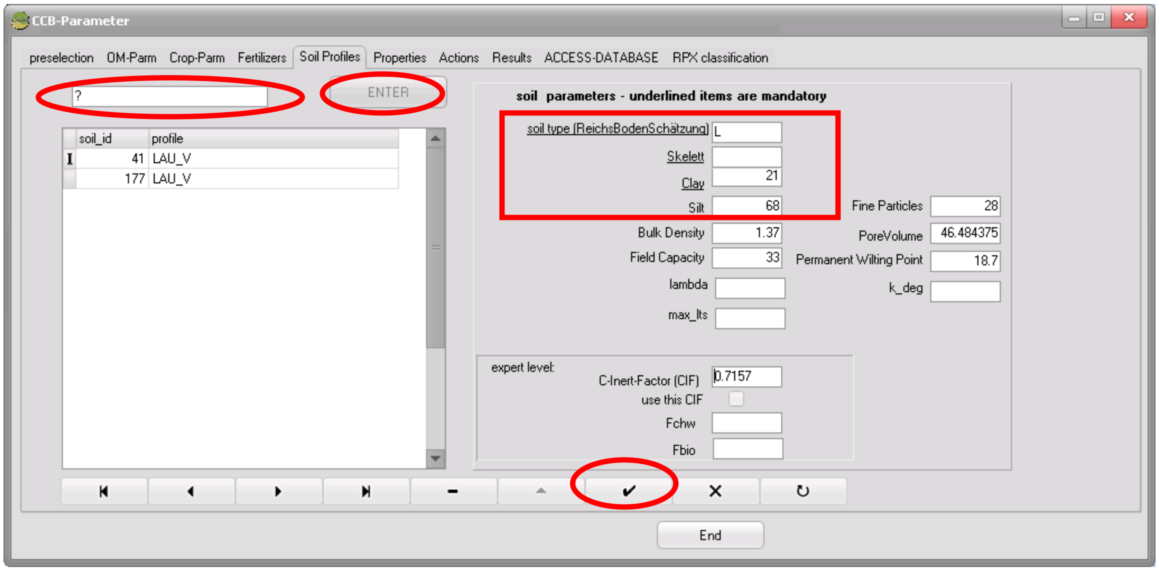


Figure 11: Creating new soil datasets; don't mind the empty fields for lambda, k_deg, and max_lts – this will only be used for special model tasks that will be explained later

Enter the new soil name instead of the "?" and click on *„ENTER"*. At finish the data should be saved clicking on the  button.

2.3.3 Climate data

Same as with soil data you have to select the climate data for your corresponding plot in the 'Basic-Info'-tab of the 'Plot Selection'. The drop-down menu will show you all climate stations stored in the CCB database. To add additional climate data you can either double-click on 'weather' or go to the main menu, click 'Climate data'.

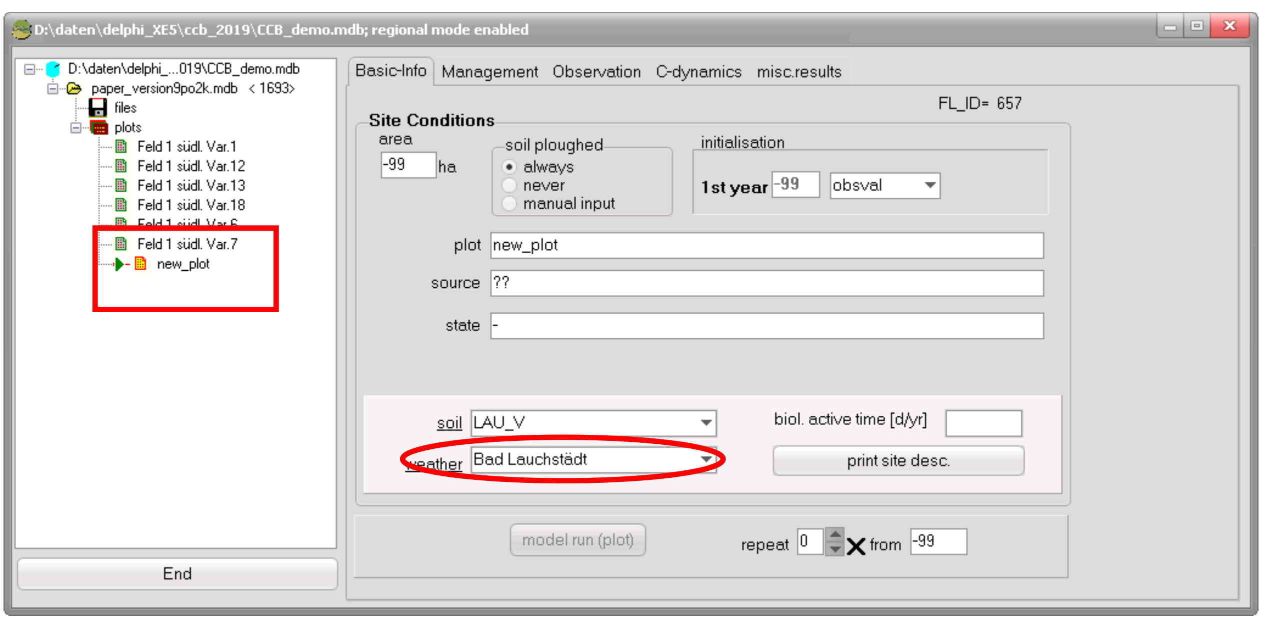


Figure 12: Selection of climate data

The climate data is stored separately and can be assigned to any plot. CCB is able to use climate data (annual rainfall and average air temperature) for each year or only one record as long-term average. The last case is indicated using the year 0. Start editing with a new name for this site and click on "*create new station*".

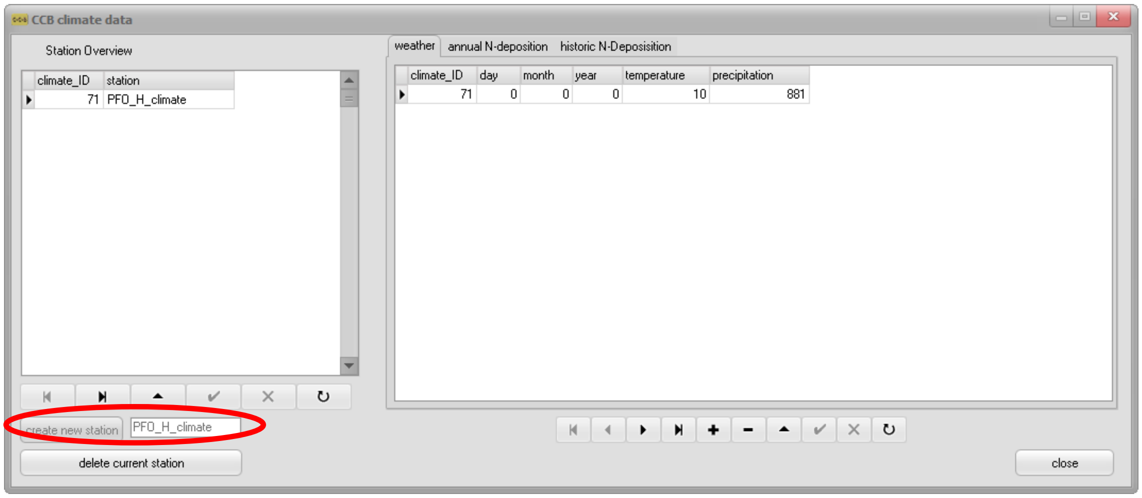


Figure 13: Editing climate records

With the 3 tabs 'weather', 'annual N-deposition' and 'historic N-Deposition' following climate information can be edited:

climate_ID	Unique value	[-]
station	Name	[-]
temperature	Annual average	[°C]
precipitation	Annual sum of precipitation	[mm]
N_dep_y	Annual N-deposition	[kg ha^{-1} a^{-1}]
basic year	First year to start calculated N-deposition	[-]
N-dep(basic)	Initial value of N-deposition	[kg ha^{-1} a^{-1}]
final year	Last year to finish calculated N-deposition	[-]
N-dep(modern)	Final value of N-Depositions	[kg ha^{-1} a^{-1}]

The input of N-deposition has only an impact on the calculation of N-balances and is not used during simulation of SOM turnover.

2.3.4 Management data

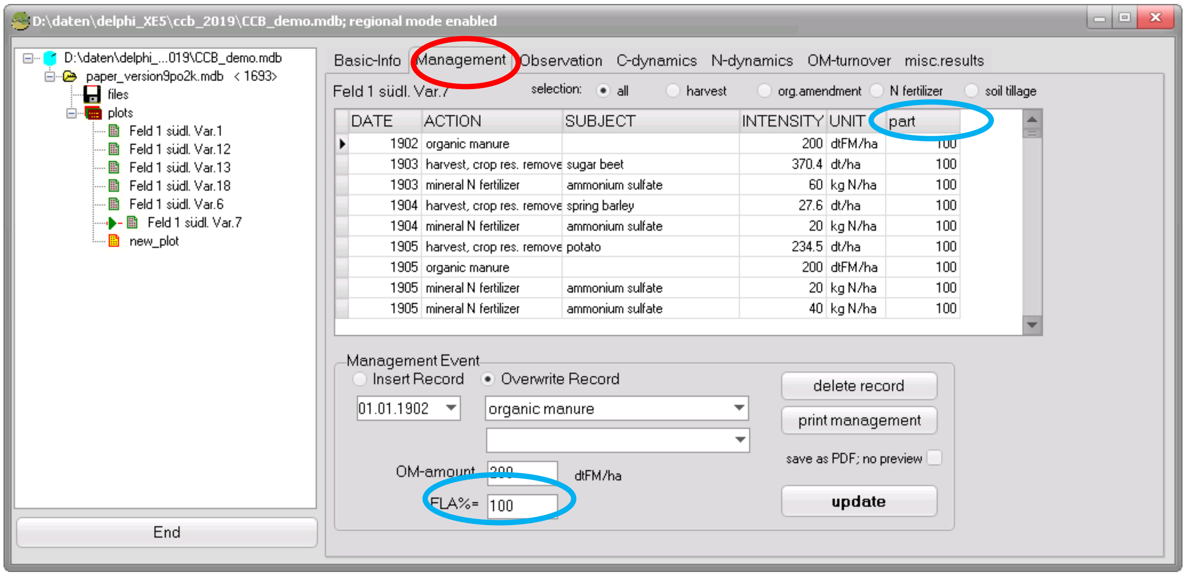


Figure 14: Editing management data at the appropriate tab (red circle) with information elements for the area-weight of each activity that are required for the 'regional mode' (blue circles)

The Management-sheet is a compilation of management events for the selected plot. In the lower part of the form you can edit every single „Management Event“:

Insert Record: The record is added to the database

Overwrite Record: The current record is changed

Date: Only the year is significant – if known day and month can be given to have a better documentation

Event description: - Please select first the appropriate event from the upper dropdown menu („*harvest, crop res. removed*“, „*organic manure*“, „*mineral N fertilizer*“, “*irrigation*“, „*harvest, crop res. ploughed*“ and “*reduced tillage*”)

- after that please select the related object (crop, fertilizer …)
- and finally edit the intensity (yield or amount).
- When using the 'regional-mode' also the regional share of the affected area of an management event has to be defined using the item “FLA%” (for further details see section ’2.6 Special application cases’).

delete record: Only the current record is deleted

print management: Output of management data on printer or as PDF-file

It is important to select the proper harvest mode: “crop res. removed" means that all by-products are removed together with the main product while “crop res. ploughed” means that e.g. straw is left on the field. This doesn’t interfere with an eventual specification of conservation tillage in that year.

You can copy the management data from one plot to another plot using drag'n drop. First activate the 'source' plot and open the management tab. Point with the mouse on the source plot, hold shift and start dragging the plot symbol to drop it onto the 'destination' plot. During this operation the mouse pointer will change to give you some assistance.

2.3.5 Observations

CCB works with data about C_{org} (mandatory) and some other optional indicators like N_t (see following table). All can be selected using the drop-down menu. C_{org} and N_t dynamics require to specify an initial value checking the box. This will set the year number to 0. If there is a soil sample from the same year that should be used for model assessment it will have the year number 1.

N_t	total soil nitrogen	[M%]
mic.biom. C	C in microbial biomass	[µg/g]
organic Carbon (C_{org})	total organic carbon	[M%]

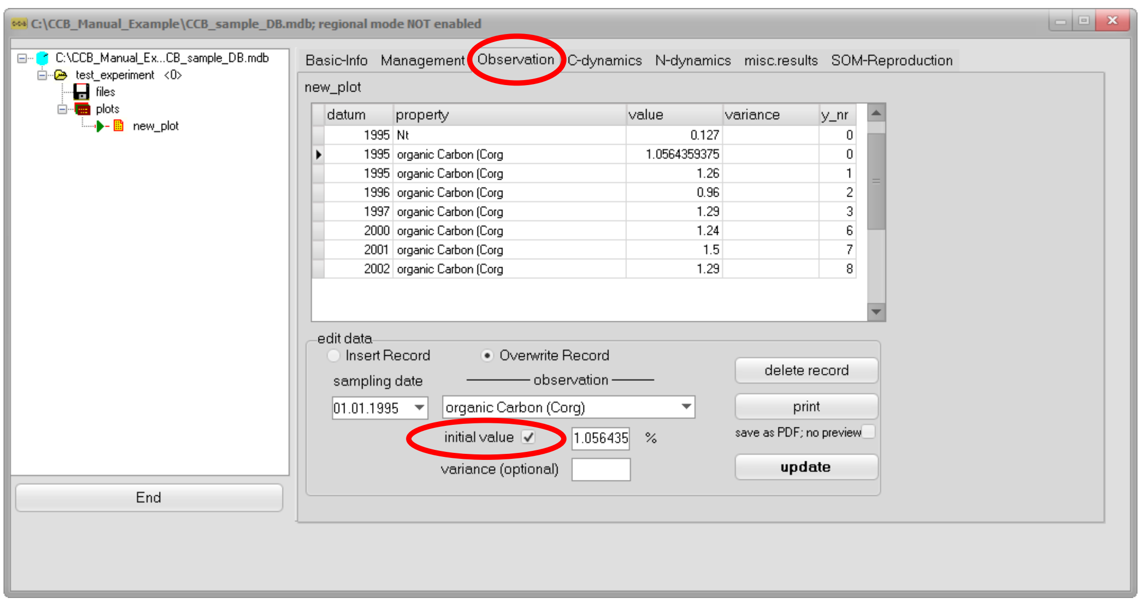


Figure 15: Editing observation data

Also in this sheet you find the Options *„Insert Record" and „Overwrite Record"* as well as following items:

sampling date:	Only the year is required day and month are ignored by the model.
observation:	Select the category
initial value:	Only one is allowed for N_t and C_{org}
variance:	Insert variance (optional)
print:	Print or send the data to a PDF-file

2.4 Editing parameters

2.4.1 Overview

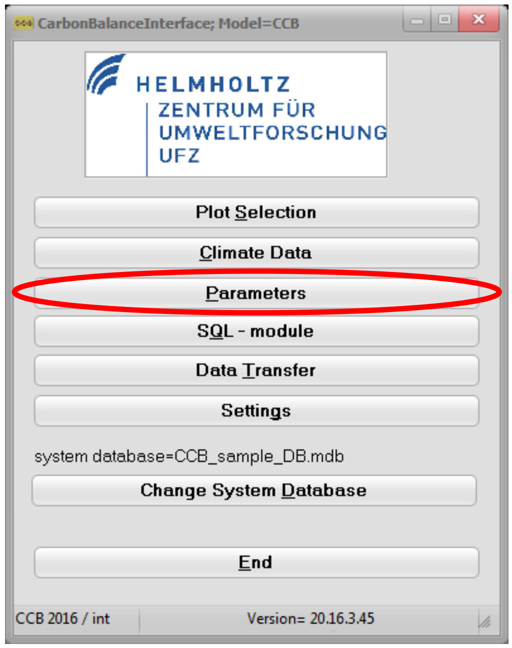


Figure 16: Start editing parameters

Go to the main menu and select „Parameters“ to start the editing of model parameters. You find a collection of sheets for different parameter types. There are two kinds of sheets: sheets containing adaptable parameters and sheets showing model parameters which are not changeable, thus just for your information. The sheet “ACCESS-DATABASE” is providing you access to the complete datasets of the model database.

Preselection	select parameters which shall be shown in the dropdown menus of the management parameterization
OM-Parm	parameterization of organic matter: residues & org. substrates (database-table cdyopspa)
Crop-Parm	parameterization of crops (database-table cdypflan)
Fertilizers	parameterization of mineral fertilizers (database-table cdymindg)
Soil Profiles	parameterization of soil profiles (top soil, 0-30cm) (database-table soilproperties)
Properties (measurement keys)	list of selectable observations to be used for model assessment (helpful to directly read the database table “measurements”)
Actions	list of selectable management actions with their item_ix (helpful to directly read the database table “cultivation”)
Results	overview over aggregated model results (error analysis and N balance)
ACCESS-DATABASE	access to the complete model database
RPX classification	class limits of the carbon reproduction index

2.4.2 Preselection

Within the sheet “preselection” you have the possibility to select (-1) and unselect (0) management options. You can either double-click on an item to change the selection status or manually type in the desired option (-1 or 0). Management options that are unselected will not be shown in the dropdown menus of the management parameterization of your plots (plot selection). This is especially handy if you have a large collection of management options.

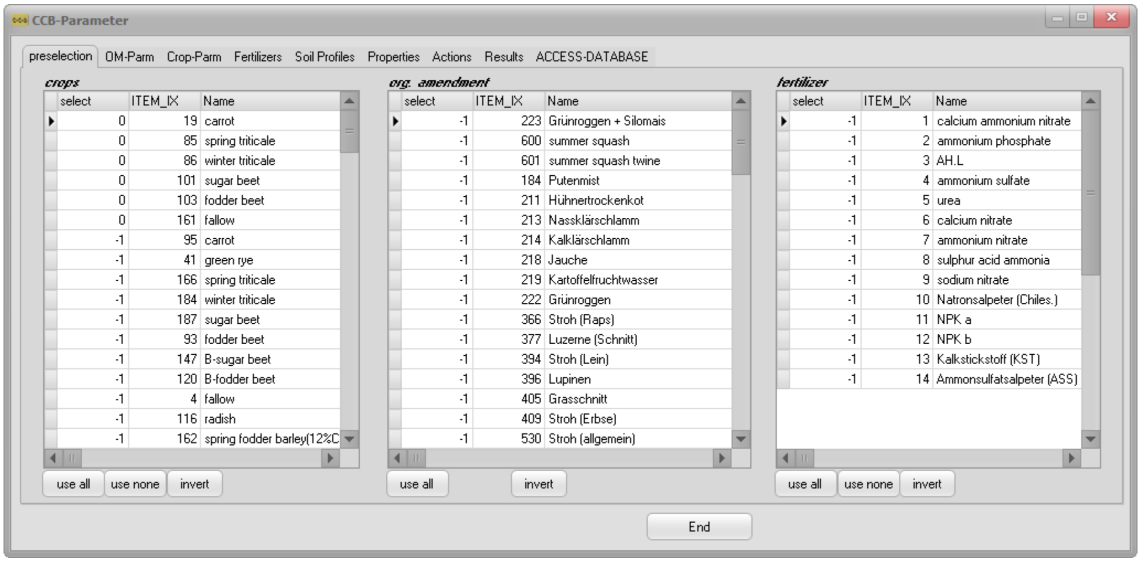


Figure 17: Preselection of management options

2.4.3 Organic matter, crops, fertilizers & soil profiles

Within the following sheets model parameters are easily adaptable by typing the new values into the corresponding fields. The idea is that in the database table **cdypflan** all the cultivatable plants are defined regarding what types and which amounts of fresh organic matter they produce and in **cdyopspa** all possible organic matter types (including organic amendments) are defined regarding their decomposition. For a description of the individual model parameters please see the sections ‘3 Theoretical Documentation’ and ‘4 Input-/Output Parameters & Database’.

2.4.4 Results

The 'Results' sheet gives an overview on aggregated model results (error statistics and N-balance).

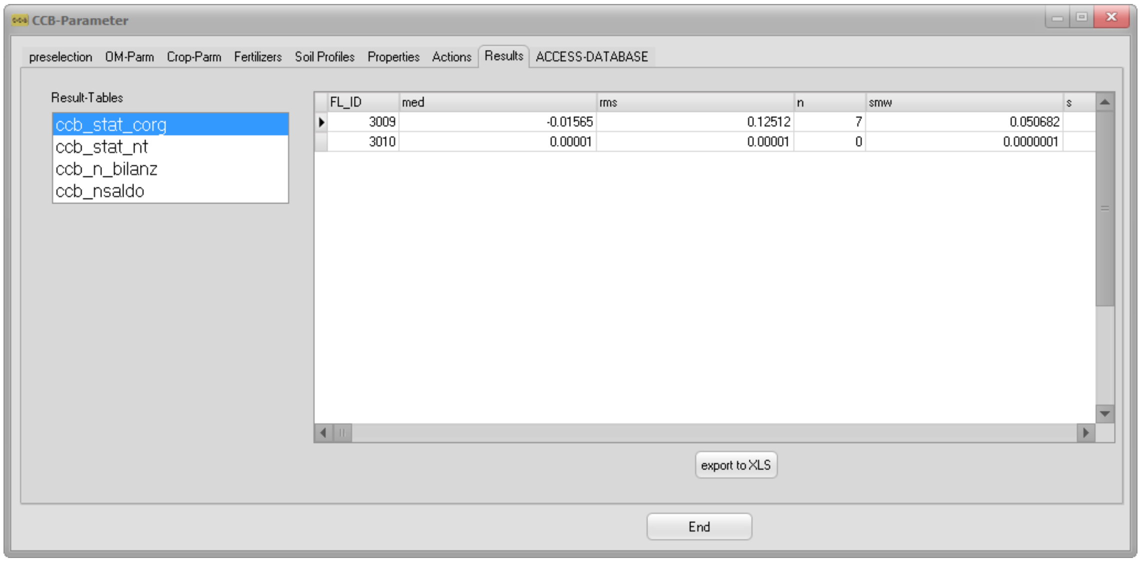


Figure 18: Results sheet

Error statistics

The error statistics for C_{org} and N_t simulations can be (re)calculated for all datasets using the context menu of the database in the tree-view of the form „plot selection" (right click on the database name):

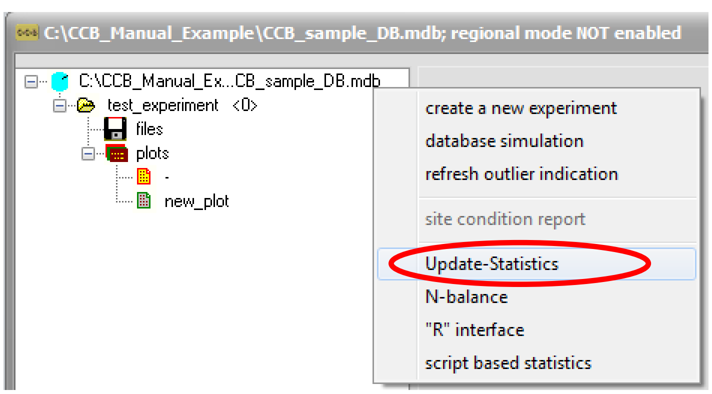


Figure 19: (Re)calculate error statistics

The results are stored in the tables **ccb_stat_corg** and **ccb_stat_nt**. In many cases an export to Excel may be helpful for further using these results.

fl_id	unique plot identifier
med	mean error (error = residue= difference between model and measurement)
rms	root mean square error

n	record count
smw	standard error of the residues ($\sqrt{\sigma^2/n}$)
s	standard deviation of the (hypothetical) normal distribution of residues (square root of variance)
rele	med (mean error) related to observation mean of the plot
r_krit	least significant r value (as reference)
r_sim	correlation between observation and simulation results
r_dif	correlation between med (mean error) and time
ef	model efficiency
rmsprz	relative root mean square error
medprz	relative mean error (residues related to each single observation)

The following only for Corg for a detailed assessment a decomposition of the mean standard deviation of the residues following H.G.Gauch, J.T.G.Hwang G.W.Fick (2003): Modelevaluation by comparison of model-based predictions and measured values. Agron. J. 95:1442–1446

sb	squared bias
nu	non unity slope
lc	lack of correlation

<u>*N-balance*</u>

The context menu of the database in the tree-view of the form „plot selection" provides the opportunity to (re)calculate the nitrogen balance for two different viewpoints. During the calculation several tables are filled with data.

Table **ccb_n_bilanz** (annual balance elements):

fl_id	plot identifier
year	balance time step
idx	unique indicator: str(FL_ID) + "_" + str(year) (plot_year)
	<u>sources</u>
n_m_om	N mineralisation/imobilisation from turnover of organic compounds (SOM &FOM)
n_org_inp	total N input with organic amendments (manure, compost etc.)
n_kop_inp	N input with by-products left on field
N_saat	seed bound N input (table N_SAAT_IMP)
n_dng	N-input with mineral fertilizer
n_bindung	symbiontic N fixation of legume crops (table LEG_PARM)
n_deposition	atmospheric N.deposition (from climate data)
asym_nbind	asymb. N-fixation (depends on application rate of min. N.fert.)
	<u>sinks</u>
n_ewr	N uptake of the crop residues (stubble+root)
n_entz	total N-Uptake by crop (main + by-product)

Table '*ccb_nsaldo*' (average data over the whole time interval):

fl_id	plot identifier
n_mindg_inp	N-input with mineral fertilizer
n_orgdg_inp	total N input with organic amendments
n_mos_inp	Nflux from turnover of organic ccompounds (SOM&FOM)
n_leg_inp	symbiontic N fixation of legume crops
n_asym_inp	asymb. N-fixation
n_depos_inp	atmospheric N.deposition
n_saat_inp	seed bound N input
n_gratis	n_bindung + asym_nbind + n_deposition + n_saat
n_ewr_upt	N uptake of the crop residues (stubble+root)
n_HUKP_upt	total N-Uptake by crop (main + by-product)
n_saldo_soil	(N_gratis) - (n_entz+n_ewr)
n_saldo_plot	(n_org_inp + n_dng + N_gratis) - (n_entz)

The final balance tables that are shown in the interface are: **nmin_saldo** and **nt_saldo**:

Table **nmin_saldo**: balance of the fluxes related to the N_{min} pool neglecting the N losses (average data over the whole time interval):

fl_id	plot identifier
n_pflanze_out	total N-Uptake by crop (main + by-product)
n_mindg_inp	N-input with mineral fertilizer
n_mos_ inp	Nflux from turnover of organic ccompounds (SOM&FOM)
n_leg_inp	symbiontic N fixation of legume crops
n_asym_inp	asymb. N-fixation
n_depos_inp	atmospheric N.deposition
n_saat_inp	seed bound N input
saldo_nmin_soil	(N_mineralised + N_gratis) - (N_entz + N_ewr)
anz	aggregated years

Table **nt_saldo**: balance related to the total nitrogen stock in the topsoil of a field, neglecting the N losses (average data over the whole time interval):

fl_id	plot identifier
n_abfuhr	N offtake from field: n_entz - n_kop_inp
n_mindg_inp	N-input with mineral fertilizer
n_orgdg_inp	total N input with organic amendments
n_leg_inp	symbiontic N fixation of legume crops
n_asym_inp	asymb. N-fixation
n_depos_inp	atmospheric N.deposition
n_saat_inp	seed bound N input
n_saldo_plot	(n_org_inp + n_dng + N_gratis) - (n_entz)

2.4.5 Access-database

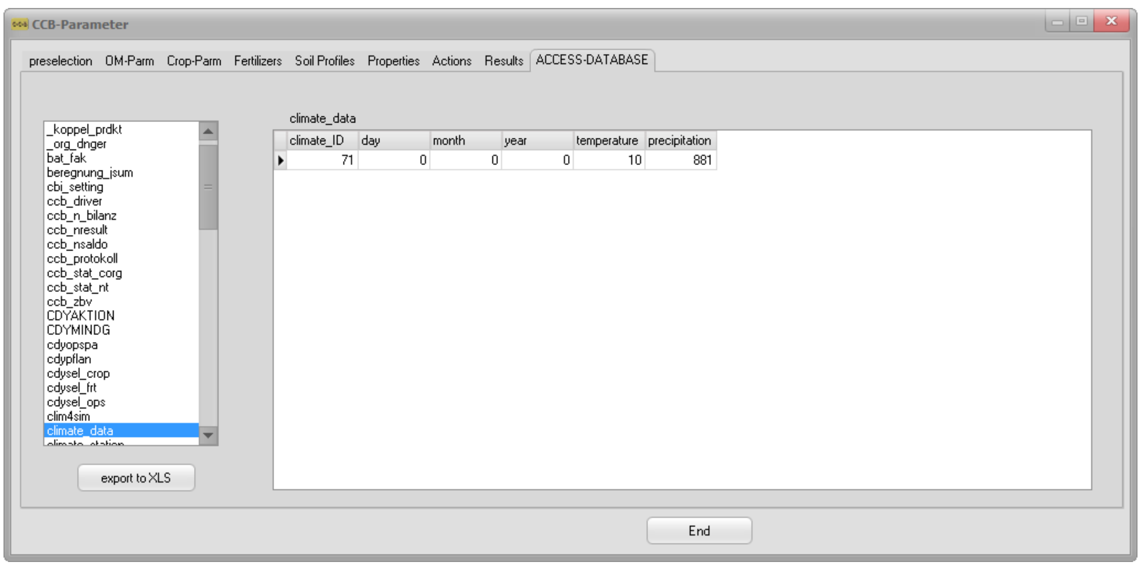


Figure 20: Access to the complete model database

The sheet ‘ACCESS-DATABASE’ gives you access to the complete model database. First double-click on a dataset then right-click on a record and use tab to navigate through the data. To change values: move to the item (background is yellow), press ENTER (background is blue, complete item is selected), click on the item (background is white) and start editing single symbols.

2.5 Simulation & result presentation

2.5.1 Start simulation runs

Choose the *„Basic-Info"* tab and click *„model run (plot)"* to simulate one selected plot.

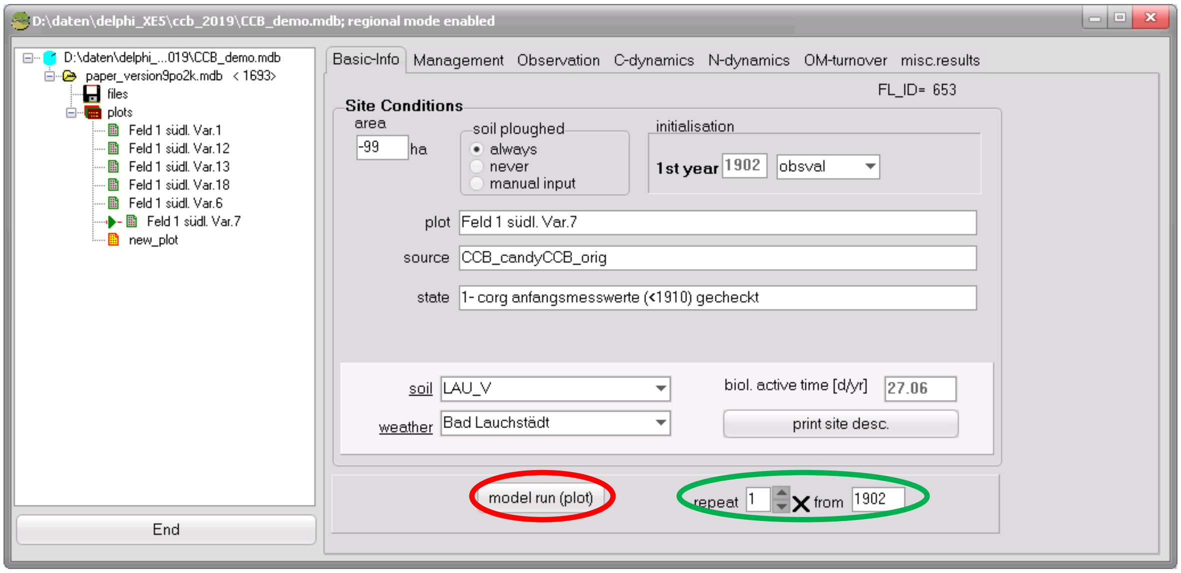


Figure 21: Start simulation of the selected plot (red circle) with possible repetitions (green circle)

It is possible to simulate a certain management in a circular mode without entering the same data for each year. This repetition mode requires the number of additional cycles and the year where the repeated cycle should be started (Figure 21, green circle). This works only if climate data are available for the extended time interval. The parameters for this special simulation (count and initial year) are saved with the actual model run in a piggyback number where the right four items are the year and the leading numbers represent the repetition count. Therefor the sample in the picture is stored as 11902 in the database.

Furthermore it is possible to simulate one complete experiment (all plots: *„experiment simulation"*) or the complete content of the database (*„database simulation"*) via right clicks on the respective hierarchy.

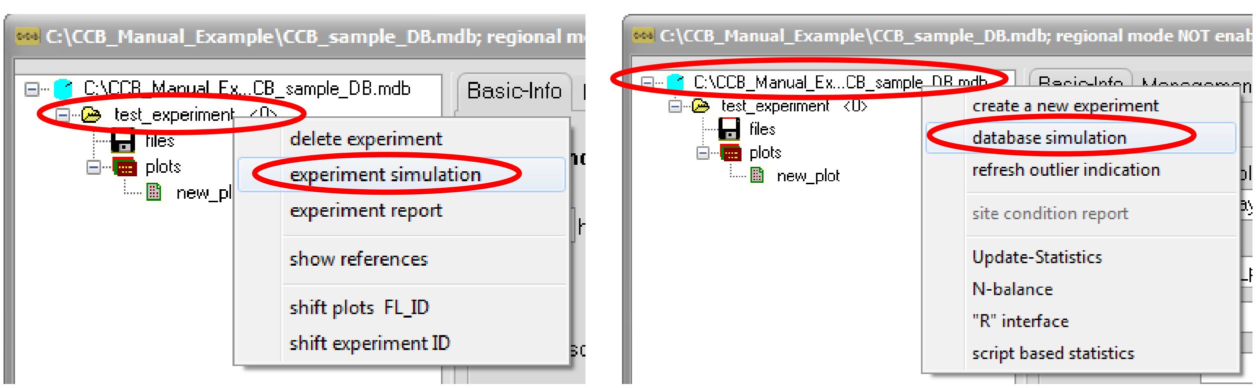


Figure 22: Select simulation of one complete experiment (left) or the complete database (right)

If appropriate, it is possible to repeat the management scenario several times starting at a given year. This may reduce the effort for data input especially for general problems for instance if a cropping system can only be described with yield data that are constant over time.

When a database simulation or experiment simulation was selected an additional screen will allow you (un)select plots, which will be simulated:

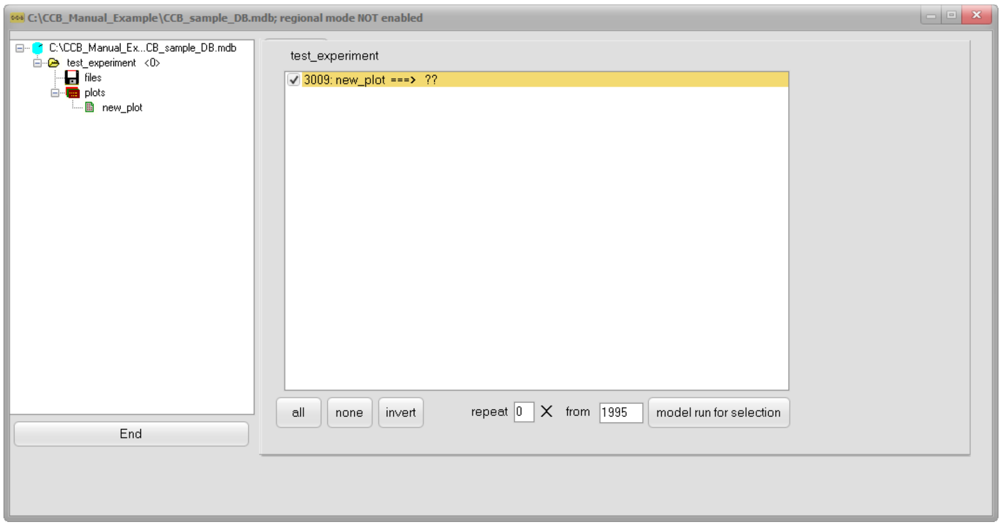


Figure 23: Stat simulation run of one complete experiment or the complete database

The run button brings up the simulator form that shows all selected plots for this simulation run. Please click the „*calculate*“ button to proceed (only necessary when simulating an complete experiment or database).

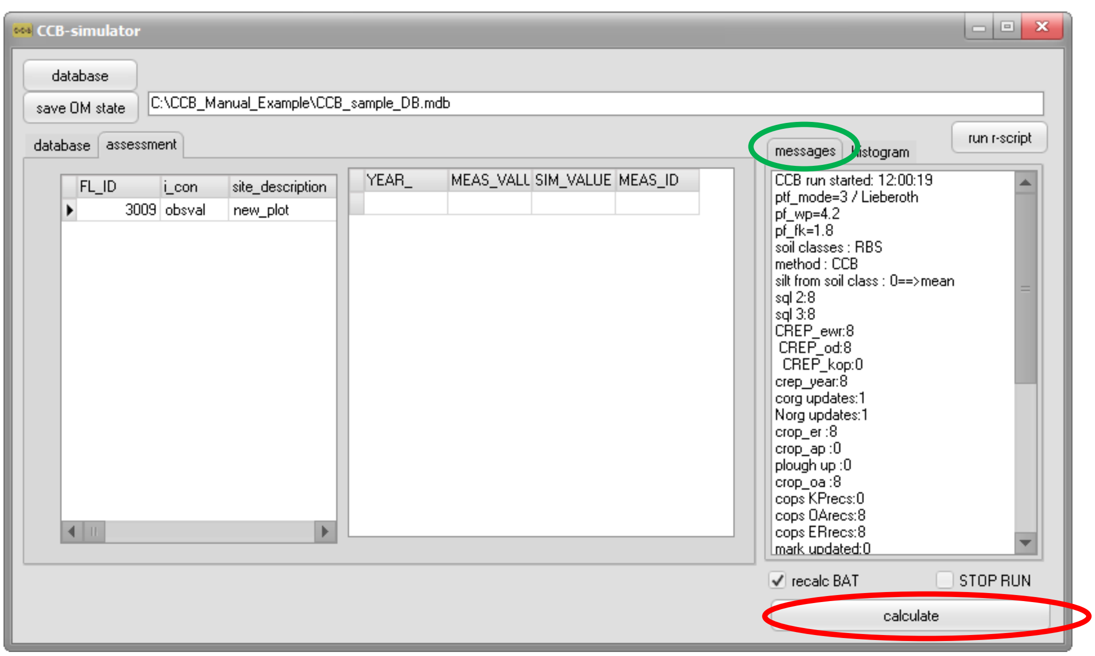


Figure 24: Summary screen of a simulation run

During the run you can see messages from the model that may help to identify possible errors in the input data (green circle, Figure 24).

2.5.2 Checking results

After finishing the simulation we go back to the user interface and may view the results in the appropriate sheets as a simple graph together with some statistics. These can also be reported (printer or PDF file) or exported (XLS file).

The sheets ‘C-dynamics’, ‘OM-turnover’, ‘N-Dynamics’ and ‘micr.BM’ are presenting the results of the simulation run with respect to C_{org}, N_{org} and C in microbial biomass respectively (only if observation values are available). Measured values are considered for the statistics and the plot as well. Outliers will be shown as red triangles if the option for outlier identification has been activated from the context menu of the database.

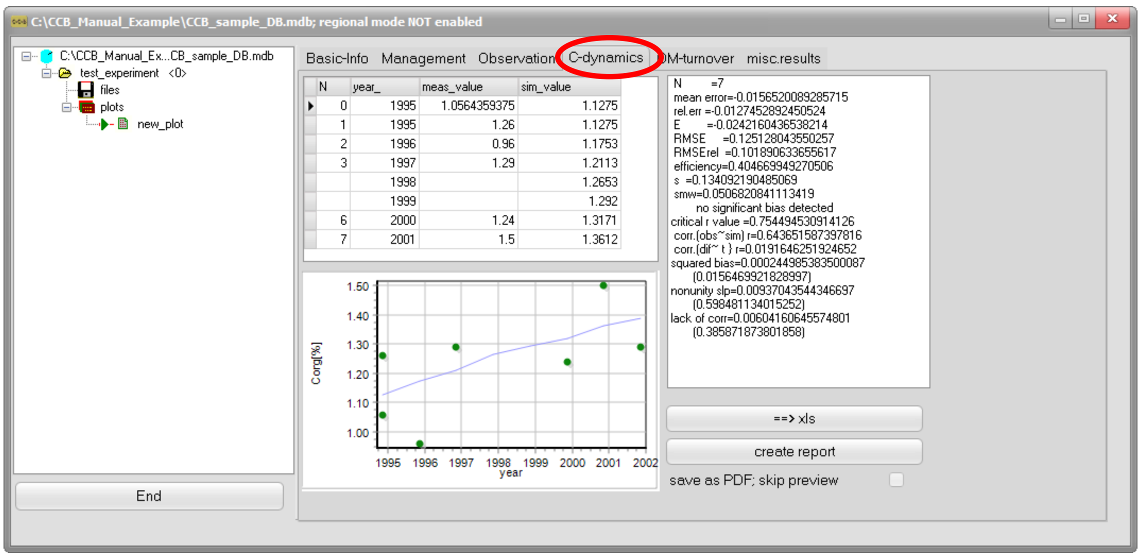


Figure 25: Presentation of results (C-dynamics)

While the sheet ‘C-dynamics’ is presenting the temporal development of C_{org}, the sheet ‘OM-turnover’ is given an overview about carbon fluxes:

Column name	Plot selection	Description	Unit
SOM gain	SOM reproduction	C_{org} input from FOM to SOM	kg C / ha / a
SOM loss	SOM decomposition	C_{org} loss from SOM to CO_2	kg C / ha / a
saldo	SOM saldo	SOM balance = C_{rep} - C_mineralisation	kg C / ha / a
CO2 prod.	total C emission	total carbon loss from SOM and FOM to CO_2	kg C / ha / a
soil C storage	total C in soil	total C in soil from all SOM pools	t / ha
BAT	BAT	biologic active time	d / yr
REP_IX	REP_IX	SOM reproduction index = C_{rep} / BAT	-

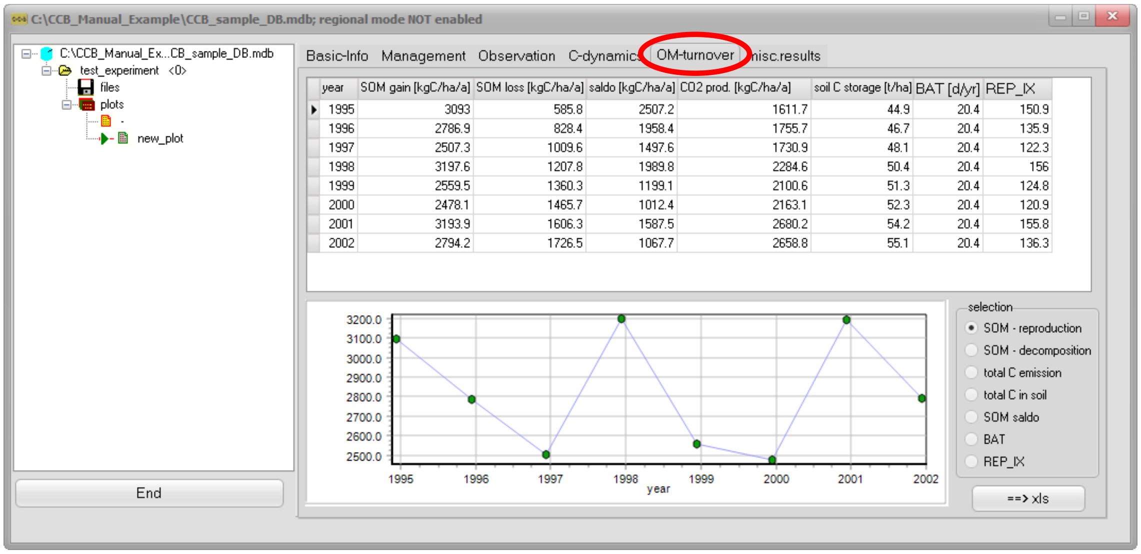


Figure 26: Presentation of results (OM-turnover)

Within the sheet ‘misc. results’ a collection of different outputs is presented. For more information on the individual outputs please also see the sections 3 (Theoretical Documentation) and 4 (Input-/Output Parameters & Database):

Column name	Dropdown-menu	Description	Unit
n_m_om	N-mineralisation	N mineralisation from organic matter plus the fast available nitrogen from organic amendments like slurry etc.	[kg/ha/a]
n_ops	N in FOM	total N in fresh organic matter	[kg/ha]
C_ops	C in FOM	total C in fresh organic matter	[kg/ha]
c_som		total C in soil organic matter	[kg/ha]
n_som		total N in soil organic matter	[kg/ha]
c_lts	phys.stab. SOC	physicaly protected C in soil organic matter	[kg/ha]
cnr	CNR	cabon-nitrogen ratio	-
crep	C_rep flux	C reproduction flux from FOM into SOM	[kg/ha/a]
bat	BAT	biological active time	[day]
bd	BD	bulk density	[g/cm³]
pwp	PWP	permanent wilting point	[VOL %]

2.6 Special application cases

2.6.1 Indicator based simulation

A common problem of applications on meso to large scale is the un-availability of reliable information about the initial C_{org} concentration. One option is here to estimate the level of previous SOM management based on the indicator RepIX that includes the soil carbon reproduction (C_{rep}) as well as the site conditions (BAT) for an assessment of the management. RepIX=C_{rep}/BAT is an indicator for the steady state C_{org} level related to the specified data about management, soil and climate that may be useful to run the model without C_{org} observations. To activate this option it has to be selected in the tab Basic-Info (Figure 27; red circle). The value for RepIX can be inserted in the following window (Figure 28; red circle). The classification scheme shows the ratio between actual RepIX and a recommended reference value that is calculated from soil texture. This preliminary scheme may have to be adapted to individual tasks. The value is shown beside the drop down menu as text on a button (Figure 27; green circle) and may be changed clicking on this button.

This option should only be used for special cases. Soil physical parameters are estimated by the model. Therefore, it is recommended to use this option only with soil data that have only soil texture data.

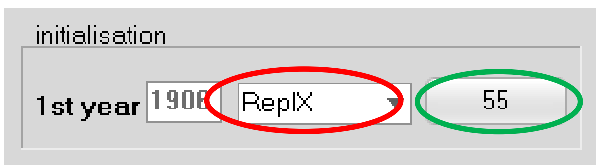


Figure 27: selection of RepIX to initialize the model

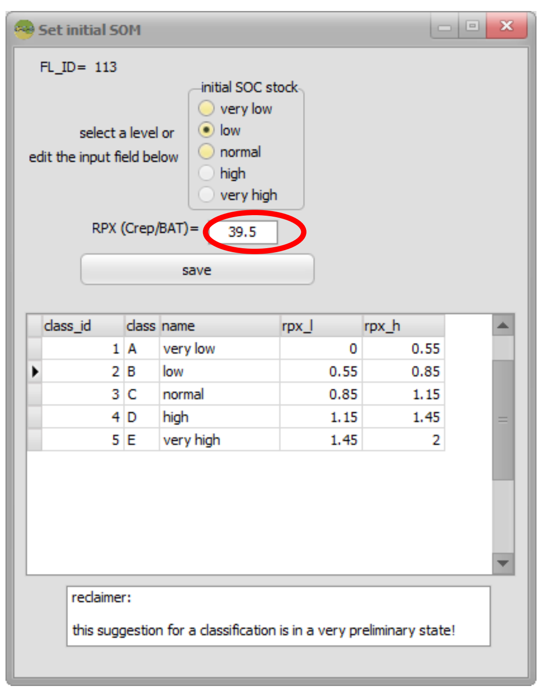


Figure 28: form to edit RepIX values including a rough classification on preliminary level

2.6.2 Simulation of a pre-treatment

If an experiments starts with considerable changes of the management it may be reasonable to include the history of this place in the simulations. In this case it is possible to simulate the history (i.e. as pre-treatment) in a separate plot of the experiment and enable the scenario option within the “*settings*”.

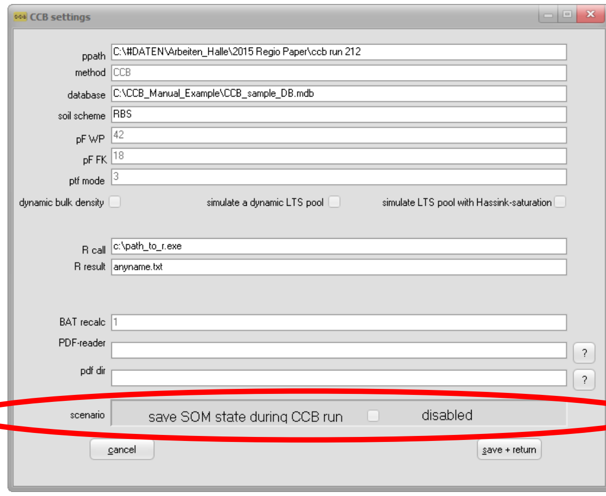


Figure 29: Possibility to enable the scenario option for simulation of a pre-treatment

The soil condition after this pre-treatment is stored in the tables ***som_state*** and **fom_state**. This data can be used as initial condition for other plots under the condition that the last year of the pre-treatment simulation is just prior the intended start of the new simulation. The plot with the pre-treatment can be selected as initial condition instead of “obsval” or “ReplX”:

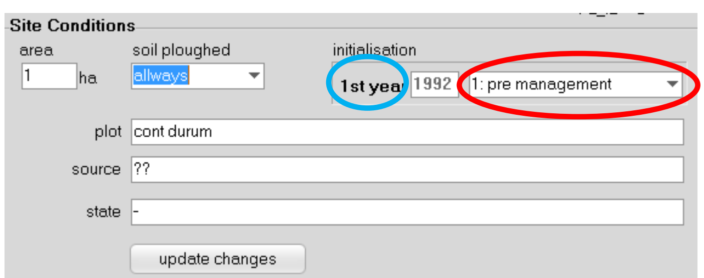


Figure 30: Set a pre-treatment as initial condition

CCB looks through the records of previous simulation with state recording to find matches where the year of the state record is just before the specified 1st year. In order to edit the input field for the initial year you have to double-click the label 1st year (blue circle). After this, it is possible to select matching records with the SOM state from pre-management.

A pre-management can also be helpful if no initial value for C_{org} is available. Some pre-management like a standard crop rotation may be applied for a long time interval. This pre-management itself requires an initial value but the longer the pre-management is simulated the lower is the impact of this initial C_{org} on the results of the actual scenario.

2.6.3 Regional-Mode

The ‘regional-mode’ was developed for meso to large scale studies, where crop rotations are not available. Within the Regio-CCB modification, crop share statistics can be used as data input instead of crop rotations. Furthermore also the share of conservation tillage and conventional tillage can be considered. Input of crop shares and tillage shares can be parameterized on an annually basis.
To activate the ‘regional-mode’ right-click on your database within the ‘Plot Selection’ and then click on ‘regio mode’. When the ‘regional-mode’ is activated the additional item (“FLA%”) will be available in the management parameterization (see also section ‘2.3.4 Management data’). The “FLA%” item is defining the regional share of the affected area of a management event, e.g. the regional share of a cultivated crop.

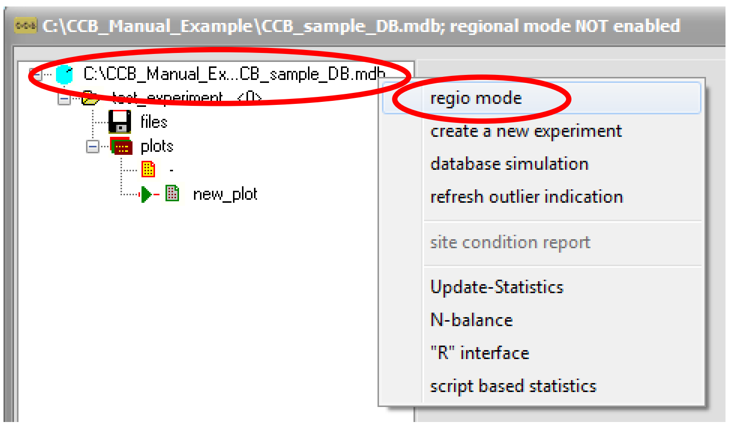


Figure 31: Activation of the ‘regional mode’

The ‘regional’-mode can only be activated for a complete database**. It is recommended to back-up your database before doing so**. Furthermore please consider to check your management parameterization of already existing plots. The ‘regional-mode’ has a different theoretical concept in the parameterization of the agricultural management.

2.6.4 Using the batch mode

CCB can be started from the command prompt as well. In this case the program call has to be complemented by a selection of following options / parameters (not case sensitive):

GO	automatic start of simulation run
RC= <repletion count>	number of cycles
TC=< initial year>	cycle loops back to this year
PPQ=<preprocessing sql script>	useful to select several plots to be simulated
POQ=<postprocessing sql script>	useful for automated result processing
ID=<unique plot identifier>	recommended if a single plot is simulated

DB=<mdb file >	name of the database incl. complete path
NW or !	exit from application after finishing the simulation run

Further options may be available for special applications - please contact the developer.

If the model is used in batch mode it is simulating all plots that are marked with status=1 in the table **site_state** (see section ‘4 Input-/Output Parameters & Database’). This behaviour can be used to start the model for a number of plots. In this case it is recommended to provide an appropriate SQL script over the PPQ parameter.
Following an example for starting CCB in batch mode:

```
ccb.exe DB= CCB_sample_DB.mdb PPQ1=use_none.sql PPQ2=use_all.sql go !
```

with ‘use_none.sql’:

```
UPDATE field_description INNER JOIN site_state ON field_description.FL_ID = site_state.FL_ID SET site_state.status = 0
```

and ‘use_all.sql’:

```
UPDATE site_state SET site_state.status = 1 WHERE (((site_state.FL_ID)>0));
```

2.7 Known problems

There may be some adaptations required to make CBB running properly. If you edit the data with the CBB interface it is strongly recommended to use a decimal point as decimal symbol because all data changes are made via SQL which is using the comma as list separator! It is no longer required to set the short date format to german style (dd.mm.yyyy). Still, these settings can be customized or checked at the MS-Windows Control Panel under “Region and language” (German: Systemsteuerung “Region und Sprache”) and [Additional Settings/Weitere Einstellungen]:

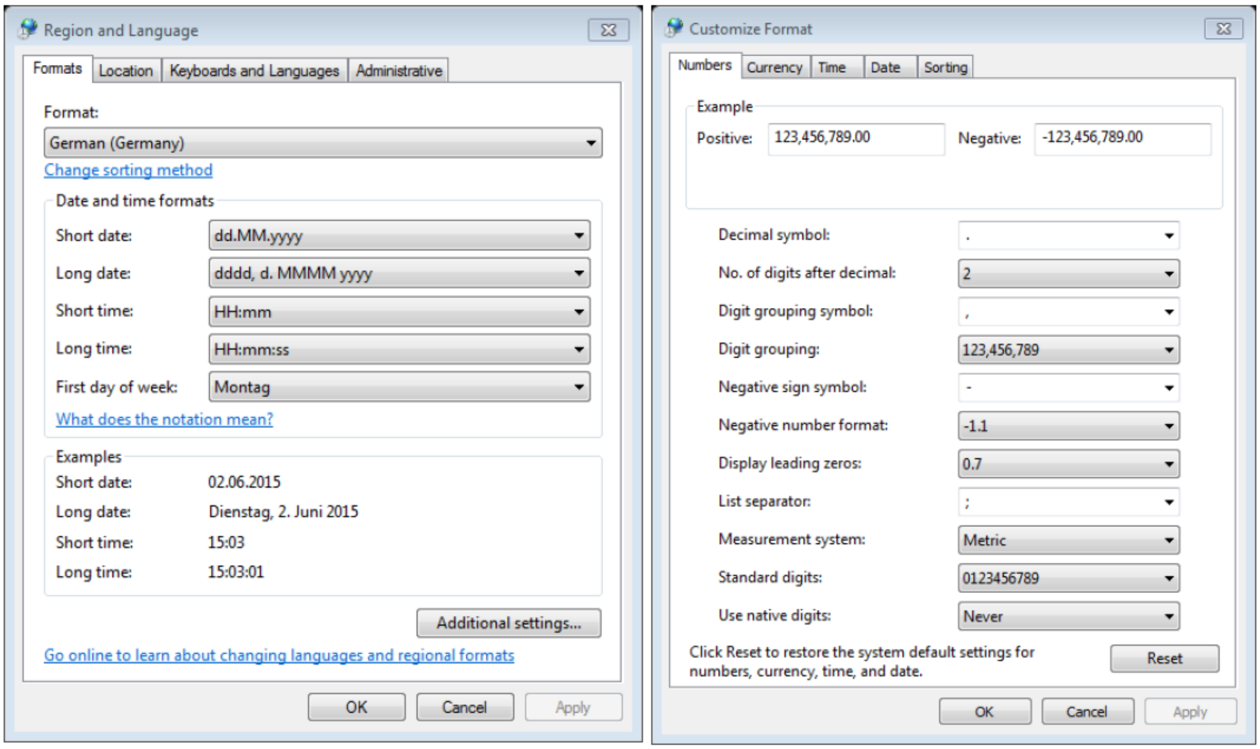


Figure 32: MS-Windows Control Panel “Region and Language” (left) to control the [short date/Datum (kurz)] entry and the [additional settings/Weitere Einstellungen] (right) to customize the [Decimal/Dezimaltrennzeichen] and [Digit grouping symbol/Symbol für Zifferngruppierung]

If required, users may change the settings in the registry database of the windows system. Therefore you need to start the program regedit.exe that is localized in the windows folder. The information is stored under

- HKEY_CURRENT_USER/Software/ccb

If changes are necessary users should proceed very carefully to avoid problems with the CCB model.

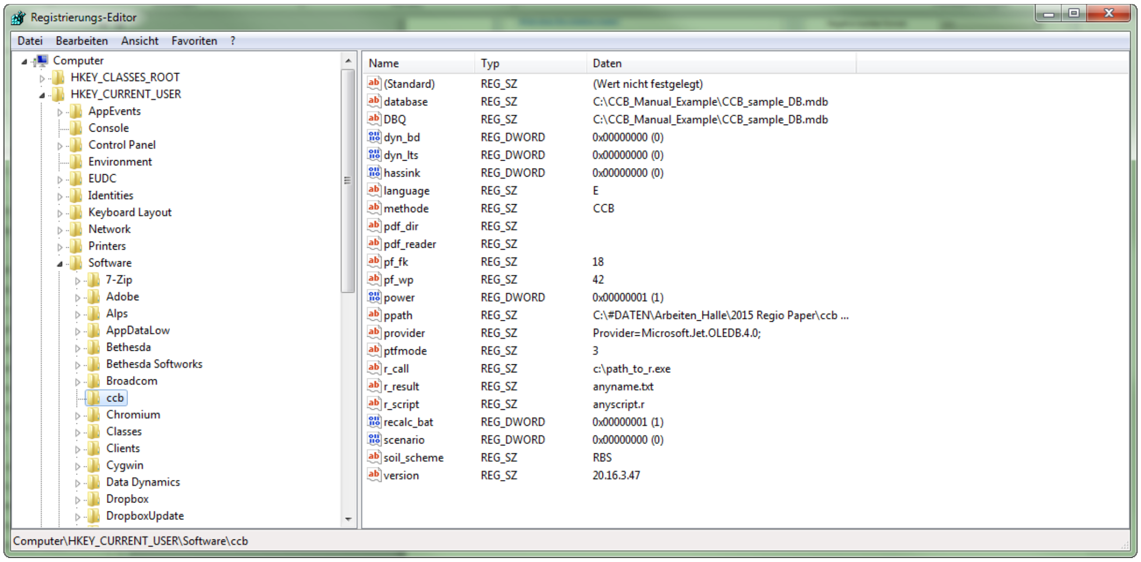


Figure 33: Registry Editor with the keys for the CCB model

3 Theoretical Documentation

3.1 Model structure

The general construction of the CCB model is shown in Figure 34. The used pools are the same as in the CANDY model (Franko, 1989; Franko et al., 1995). SOM is divided into an active pool (A-SOM), where the mineralization takes place, a stabilized pool (S-SOM) representing the passive but decomposable part of the SOM and a long term stabilized pool (LTS-SOM) that is here taken as inert. Beside SOM there are a number of FOM pools that are characterized by the origin of organic matter (OM).

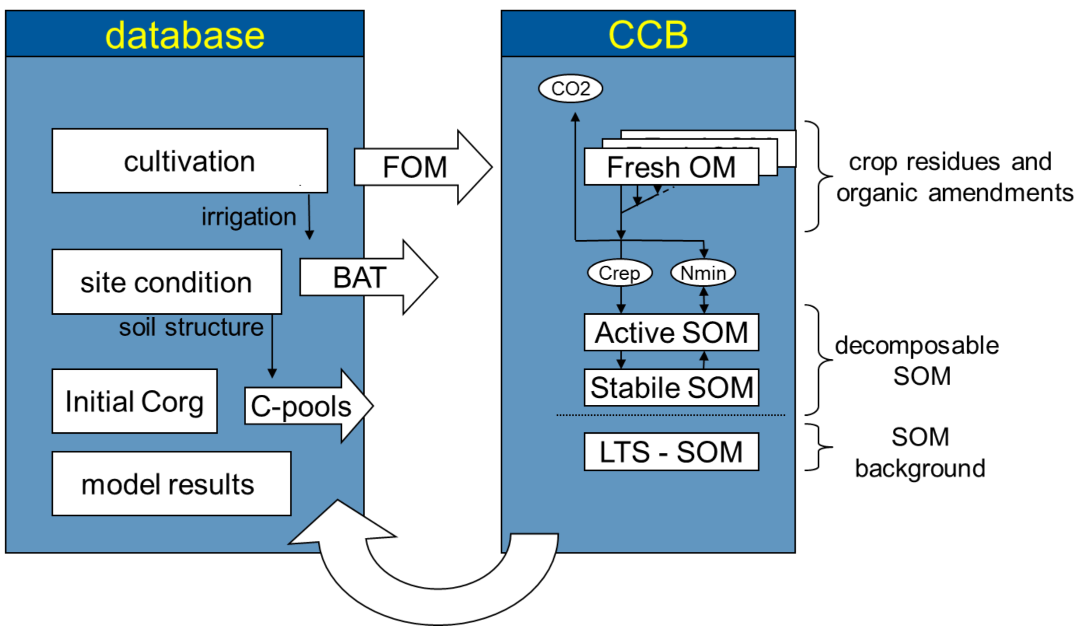


Figure 34: CCB general approach

The modelling of turnover kinetics is based on first order kinetics. The used time variable *t* is the Biological Active time (BAT) according to the concept used in CANDY (Franko et al., 1995, Franko and Oelschlägel, 1995). BAT is calculated as annual value according to the air temperature, the amount of rainfall plus irrigation water and the soil texture (content of fine particles < 6.3 micrometer, including clay and fine silt). In order to provide information about nitrogen mineralization the model must be able to describe the interaction between SOM turnover and nitrogen fluxes connected with the turnover of the FOM pools and the mineralisation of the active SOM.

The state variables for the pool sizes in the model have the dimension of mass unit per area unit – usually kg ha^{-1} which is equal to 10^{-1} g m^{-2}. The observation data for carbon and nitrogen storage in soil are often available as concentration (ppm or M %) in the fine soil material (< 2 mm grain size). Therefore the model results are presented as concentration using the bulk density, gravel content and the depth of the top soil layer to transform the units. Generally a top soil layer of 0.3 m is assumed. The conversion between mass (*M*) and concentration (*CONC*) of any pool is accomplished according to the following equation (Eq. 1):

$$M = CONC \cdot \rho_B \cdot h \cdot \left(1 - \frac{GC}{100}\right) \cdot 10^4 \quad \text{Eq. 1}$$

M:	pool mass in g m^{-2}
CONC:	matter concentration in %
ρ_B:	bulk density in g cm^{-3}
GC:	gravel content in %
h:	depth in m

Table 1: CCB input variables that pertain to conversions between mass and concentration

Variable	Definition	Unit	Name in database	Database table
ρ_B	soil bulk density	g/cm³	*bd*	**soilproperties**
GC	gravel content	%	*skelett*	**soilproperties**

SOM dynamics are usually explored by C_{org} observations but because its close relation to soil nitrogen the C/N ratio is often used to additionallycharacterize the SOM. Therefore the model description includes relations to nitrogen fluxes and pool sizes.

3.2 Supply of fresh organic matter

The supply of fresh organic matter to the soil results from:

a) organic amendments (oa),
b) by-products that are left on the field after harvest such as straw and leafs (bp),
c) crop residues such as roots and stubble (res).

The amount of fresh organic matter input from organic amendments (FOM_{oa}) is given in the scenario data and the carbon input C_{oa} can be calculated from the substrate specific parameters for dry matter content (DM_{oa}) and carbon content in dry matter (CC_{oa}).

$$C_{oa} = FOM_{oa} \cdot DM_{oa} \cdot CC_{oa} \quad \text{Eq. 2}$$

The FOM input from the other both pathways has to be calculated as follows. The amount of by-products (FOM_{bp}) is calculated from the yield (in dt/ha) and a crop specific harvest index (HI):

$$FOM_{bp} = yield \cdot HI \quad \text{Eq. 3}$$

Knowing the FOM_{bp} amount, the by-product related carbon input C_{bp} is calculated using the parameters for dry matter content (DM_{bp}) and carbon content in dry matter (CC_{bp}) of the by-product. This amount is added to the soil only if the selected harvest option is ‘harvest, crop res. ploughed (which means by-product left on the field):

$$C_{bp} = FOM_{bp} \cdot DM_{bp} \cdot CC_{bp} \qquad \text{Eq. 4}$$

The contribution from crop residues is also determined in relation to the crop yield. Due to historic reasons (compatibility to the CANDY system), first the residual related N-pool (N_{res}) is calculated in dependence of the crop yield. Afterwards, the adequate C amount of the crop residues (C_{res}) is identified from the substrate specific C/N ratio γ_{fom}:

$$N_{res} = yield \cdot N_{cont} \cdot F_{res} + K_{res} \qquad \text{Eq. 5}$$

$$C_{res} = N_{res} \cdot \gamma_{fom} \qquad \text{Eq. 6}$$

C_{res} and N_{res} in kg/ha, Yield: main product yield of the crop (e.g. grain for cereals) with the crop specific DM content (std_DM_{mp}) as given in TS_BEZUG_HP

F_{res}. K_{res}, N_{cont}: crop specific constants describing the yield depending nitrogen amount of crop residues after harvest.

Table 2: CCB input variables that pertain to the supply of fresh organic matter

Variable	Definition	Unit	Name in database	Database table
yield	yield of the main product (e.g. grain for cereals)	dt/ha	*quantity*	**cultivation**
DM_{oa}, DM_{bp}	dry matter content in fresh matter (substrate specific)	-	*ts_gehalt*	**cdyopspa**
CC_{oa}, CC_{bp}	carbon content in dry matter (substrate specific)	-	*c_geh_ts*	**cdyopspa**
HI	harvest index (crop specific)	-	*hi*	**cdypflan**
γ_{fom}	C/N ratio (substrate specific)	-	*cnr*	**cdyopspa**
F_{res}	constant describing the yield dependent nitrogen amount of crop residues after harvest (crop specific)	kg/dt	*fewr*	**cdypflan**
K_{res}	constant describing the yield independent nitrogen amount of crop residues after harvest (crop specific)	kg/ha	*cewr*	**cdypflan**
N_{cont}	nitrogen content of crop yield (crop specific)	%	*n_gehalt*	**cdypflan**
std_DM_{mp}	standard DM content for the main product yield (this is just for information, but may be important to integrate specific data)	-	*ts_bezug_hp*	**cdypflan**

Example:

winter wheat yield=80 dt/ha (reference DM=86%); where straw is left on the field and an amount of 200 dt/ha slurry is added

Required properties: look up Winter wheat in **cdypflan**:

item_ix=9; *ewr_ix*=30; *kop_ix*=553, (the latter both link to *cdyopspa.item_ix*)

cewr=10; *fewr*=0.07, *n_gehalt*=2.7; *ts_bezug_hp*=0.86; *hi*=0.8

Crop residues: *ewr_ix* 30 leads to FOM type „cereals_1“: *cnr*=50

By-product: *kop_ix* 553 leads to FOM type “Straw_C/N115”: *ts_gehalt*=0.908; *c_geh_ts*=0.462

Look up slurry (pig) in **cdyopspa**: *item_ix*=555: *ts_gehalt*=0.1; *c_geh_ts*=0.4

<u>Calculation (analogue to Eq. 2 to 6)</u>

200 dt/ha slurry as organic amendment

C_{oa} = 200 dt/ha * 0.1 * 0.4 * 100 = 800kg/ha (*100 to get kg/ha)

By product: as organic amendment:

(only when action in management is ‘harvest, crop res. Ploughed’ !)

FOM_{bp} = 80 dt/ha * 0.8 = 64 dt/ha;

C_{bp} = 64 dt/ha * 0.908* 0.462 * 100= 2684.7744 kg/ha (*100 to get kg/ha)

crop residues:

N_{res} = 80 dt/ha * 2.7% * 0.07 kg/dt + 10 kg/ha = 25.12 kg/ha

C_{res} = 25.12 kg/ha * 50 = 1256 kg/ha

Table 3 Total FOM-C input

source	FOM-carbon in kg/ha
crop residues (roots and stubble)	1256
By-product (straw) applied if macode=9 (by-prod.left)	2684.7744
organic amendment (slurry)	800.000
sum	4740.7744

3.3 Quantification of site specific turnover conditions

Biologic active time (BAT) is a concept that describes the impact of environmental conditions on biologic activity on soil organic matter (SOM) turnover (Franko et al. 1995). In a given time interval a certain biologic activity in a suboptimal environment will produce a specific turnover result. The same results occur when the time interval is split in BAT and non-BAT. During the BAT interval the microbial activity is only limited by the substrate, while during non-BAT there is no activity at all. In the CANDY model the calculation of the BAT interval includes the effects of soil temperature, soil water and soil aeration.

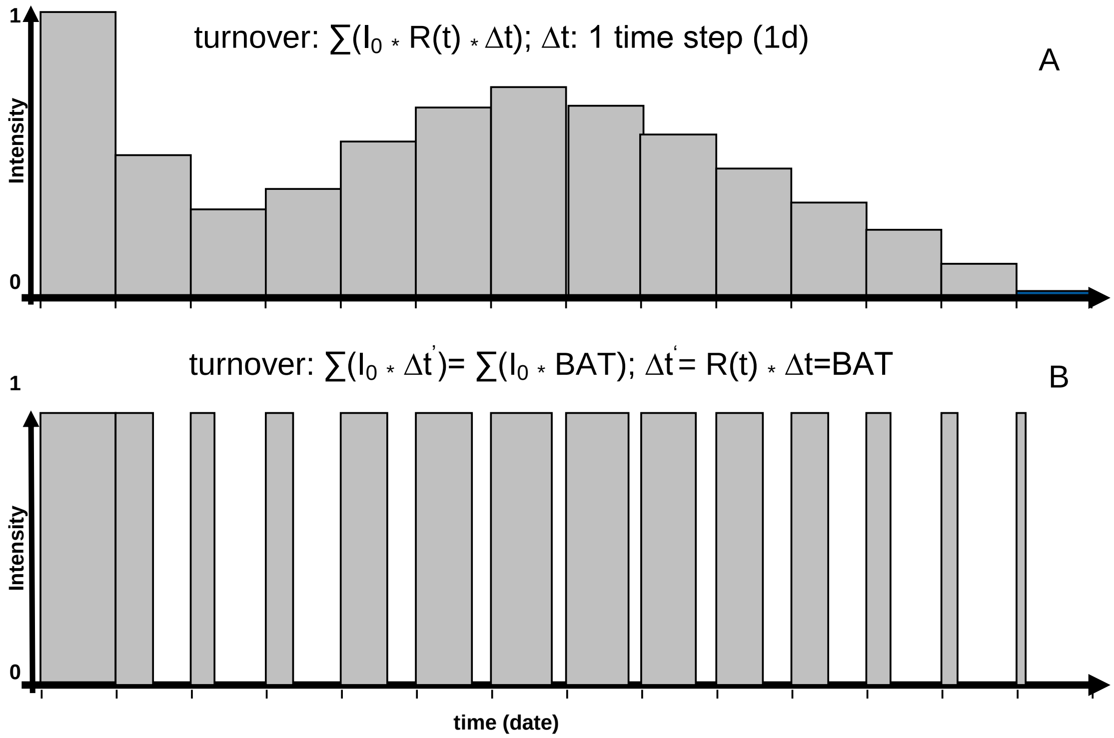


Figure 35: Schematic representation of the turnover calculation by the standard approach (A) and the BAT approach due to transformation of time steps (B)

The scheme in Figure 35 demonstrates the principle how different intensities of uniform time steps (Figure 35 A) are transformed into time steps of different length and uniform intensity (Figure 35 B). The calculated turnover, symbolized by the bar area, will be the same for both approaches, anyway. In the latter case (B) the new calculated time step (Δt‘) is a product of the reduction function R(t) and the origin time step (Δt). In this case the non-BAT time step is represented as the blank space between the BAT bars (Figure 35 B). The CANDY model calculates BAT in daily time steps for each of the 3 top soil layers (0-3 dm). A more detailed description of BAT calculation can be found in the CANDY manual. For the CCB model we use only annual BAT sum as indicator for the potential turnover under the given conditions. The BAT is given as the number of microbial active days (d_{mad}) per year. Based on simulation results with the CANDY model a meta model for the annual sum of BAT was developed by Franko and Oelschlägel (1995) that considers soil texture and annual climate data (air temperature and rainfall) including the annual irrigation amount within the natural rain and an additional adaptation for conservation tillage (no mixing of soil layers).

The following R script may be the best way to explain this simplified BAT calculation as interpolation between different soil types:

```
BAT  <- function(afat, ltem, nied) { # afat is the content of fine particles of your soil
        a <- c(3.3541, 3.1825, 3.0629, 2.1824, 2.1698, 2.0054, 1.8676)
        b <- c(0.015698, 0.01325, 0.003204, -0.009797, -0.02726, -0.03232, -0.03178)
        c <- c(9.0870, 10.2234, 14.5547, 23.0218, 23.6263, 22.9473, 22.9300)
        fattab <- c(6.0, 8.0, 11.5, 15.0, 22.0, 32.0, 44.0) # fattab are soil type classes for the content of
fine particles
        i <- 0
        nied <- min(nied, 700)
        nied <- max(nied, 450)
        repeat {
                i <- i+1
                if ((afat <= fattab[i]) | (i==8)) {   break   }
                        }
 if (i==1) {
                bat <- a[1] * ltem + b[1] * nied + c[1] }  else   {
                if (i < 8) {
                        i1 <- i-1
h1 <- a[i1] * ltem + b[i1] * nied + c[i1]
                        h2 <- a[i] * ltem + b[i] * nied + c[i]
                        p <- (afat - fattab[i1]) / (fattab[i] - fattab[i1])
                        bat <- (1 - p) * h1 + p * h2
                         }
}
        if (i == 8)    {
                bat <- a[7] * ltem + b[7] * nied + c[7]
}
        return(bat)
}
```

<u>Adaptations of BAT for conservation tillage</u>

The general (implicit) assumption in CCB is that the soil is regularly ploughed and the material of the soil is mixed. We understand conservation tillage as a non-mixing operation and hypothesize that this leads to a stratification of SOM because of the missing soil mixing events. In order to acknowledge this effect, we hypothesize that the turnover activity is reduced in deeper soil layers. For ploughed soils this effect will be compensated by mixing the soil layers. If conservation tillage is applied the average turnover conditions should be reduced due to this depth depending reduction of turnover activity. Following the basic principles of the CCB model this effect has to be expressed as a changed value for the Biologic Active Time (BAT).

A reduction factor α was introduced that describes an exponential reduction of turnover activity of the next downward soil layer assuming a layer thickness of 1 dm.

$$\alpha = \exp(\sqrt{F_R \cdot F_D}) \qquad \text{Eq. 7}$$

The factor α depends on two components: a reduction due to reduced gas exchange F_D depending on soil texture that is here represented by the amount of fine soil particles < 6.3 µm (*FP*). The calculation of this factor is taken from the CANDY model as it has been described by Franko et al. (1997):

$$F_D = FP \cdot 0.2844 - 1.4586 \qquad \text{Eq. 8}$$

FP: amount of fine soil particles < 6.3 µm

The second component F_R represents an aggregation of the impacts from soil temperature and soil moisture in relation to optimal conditions and can only be estimated because of the annual time steps in the model. Here is assumed that this factor is aggregated within the annual BAT sum of the tilled system:

$$F_R = \frac{BAT_t}{365} \qquad \text{Eq. 9}$$

If the top soil is annually mixed by ploughing all three assumed soil layers have the same weight G_l=1 in the turnover process.
For no-plough conditions, if the soil layers are not mixed, the (virtual) three top soil layers take part in the turnover with the weight values of 1, $1/\alpha$ and $1/\alpha^2$.
This leads to the relation between the BAT values of a tilled (BAT_t) and a non-tilled (BAT_{nt}) system:

$$BAT_{nt} = \frac{BAT_t}{3} \cdot \left(1 + \frac{1}{\alpha} + \frac{1}{\alpha^2}\right) \qquad \text{Eq. 10}$$

3.4 Soil organic matter turnover

3.4.1 Turnover of carbon

Soil organic matter (SOM) dynamics may be handled by different approaches. The CCB approach uses conceptual pools and describes C and N dynamics as well. As the SOM pools in the CCB model have conceptual character they are not measurable.

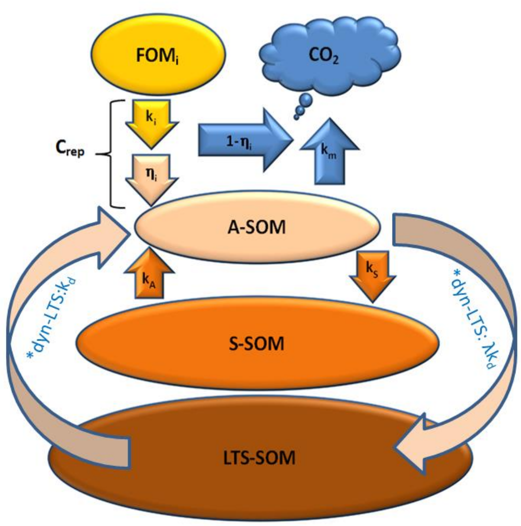


Figure 36: Conceptual pools and fluxes within the soil organic matter module in CCB; *dyn-LTS: only when dynamic LTS-pool is enabled

Organic matter in soil is subdivided into four compartments: (1) fresh organic matter (FOM), (2) biological active soil organic matter (A-SOM), (3) stabilized soil organic matter (S-SOM) and (4) long term stabilized soil organic matter (LTS-SOM). After each time step the resulting pool size for C_{org} can be recalculated from the sum of all SOM pools.

$$C_{org} = C_A + C_S + C_{LTS} + \alpha \cdot C_{FOM} \quad \text{Eq. 11}$$

C_x: carbon content of corresponding compartments of organic matter in soil (C_A = A-SOM, C_S = S-SOM, C_{LTS} = LTS-SOM, C_{FOM} = FOM in kgC ha^{-1})
α substrate specific share of CFOM that is included in standard SOC observations; in most cases α will be zero but certain substrates with long persistence in soil (like peat) are usually not eliminated from the experimental determined SOC value. Only if the parameter record for a given substrate contains a value for *pop* (**p**art of **o**rganic **p**articles in SOC) α is set to this value.

All processes of the C turnover are formulated as first-order reactions (Franko et al. 1995). The decomposition of fresh organic matter is determined by its turnover coefficient k_{FOM}:

$$\frac{dC_{FOM}(t)}{dt} = \dot{C}_{FOM} = k_{FOM} \cdot C_{FOM}(t) \quad \text{Eq. 12}$$

The FOM decomposition results in the creation of A-SOM. The carbon flux from FOM into A-SOM is called C_{rep}. The relation between A-SOM production and FOM decay is described by the synthesis coefficient η_{FOM}:

$$\frac{dC_{rep}(t)}{dt} = \dot{C}_{rep} = \dot{C}_{FOM} \cdot \eta_{FOM} \quad \text{Eq. 13}$$

The turnover of the active SOM pool includes the reproduction flux from FOM (C_{rep}), the mineralization to CO_2 (turnover coefficient k_m) and an internal matter exchange with the stabile SOM pool (turnover coefficients k_a and k_s), using the general parameters k_m=0.00556 d^{-1}, k_a=0.00032 d^{-1}, and k_s=0.0009 d^{-1}:

$$\frac{dC_A(t)}{dt} = \dot{C}_A = \dot{C}_{rep} + k_a \cdot C_S(t) - k_s \cdot C_A(t) - k_m \cdot C_A(t) - \dot{C}_{LTS} \quad \text{Eq. 14}$$

Consequently the carbon turnover of the stable SOM pool is:

$$\frac{dC_S(t)}{dt} = \dot{C}_S = k_s \cdot C_A(t) - k_a \cdot C_S(t) \quad \text{Eq. 15}$$

Table 4: CCB input variables that pertain to the turnover of carbon

Variable	Definition	Unit	Name in database	Database table
k_{FOM}	Turnover coefficient for the decomposition of fresh organic matter	-	*k*	cdyopspa
η_{FOM}	FOM synthesis coefficient determining the relation between the production of A-SOM to the FOM decay (=CO_2 production)	-	*eta*	cdyopspa

So far we have described the biologic driven turnover of the A-SOM and S-SOM pool that both are considered the easy decomposable part of SOM. The SOM that is left has a very low turnover rate that is not so much controlled by biochemical recalcitrance but a result from physical protection in the micro pores of the soil where microbial activity is strongly limited. Following the rationale of the CIPS Model (Kuka et al.2007, Puhlmann et al. 2006) we assume that SOC is distributed over the inner soil surface and quantify the physically protected part in the micro pores from the relation between micro pore related surface to the total inner surface of the soil (see chapter 3.4.3). After an attempt to describe the LTS dynamics only with the change of the micro pore space as driven by changing SOC concentration, explained by Franko and Merbach (2017), we assume a dynamic soil structure where the relation between micro pores and total soil porosity may be constant but with an exchange of the surfaces in the different pore size classes. The underlying process is comparable to the formation and destruction of soil aggregates where inner aggregate matter is transferred to intra aggregate positions and vice versa. This process is not directly related to the microbial turnover and therefore not depending on BAT. We assume that a part of the new formed SOM is captured inside the micro pores while another part is released from the protection/occlusion to take part in the microbial turnover.
Furthermore is considered a matter turnover in the LTS pool. Calculations depend here from the selected mode (with or without saturation).

3.4.2 Model initialization from RepIX

We call the relation of C_{rep} to BAT SOM reproduction index (RepIX) because it describes the formation of new soil organic matter and is an indicator for the SOM stock that will be reached with a given management at steady state. The classification of RepIX into very low, low, normal, high and very high is based on arbitrarily selected steps with breaks at 0.6, 0.9, 1.1, and 1.4 besides upper and lower limits at 0.4 and 1.7 respectively.

3.4.3 Nitrogen fluxes

Nitrogen fluxes modelled by CCB are closely connected to the carbon turnover. The CCB model considers only the N fluxes but not the mineral nitrogen pool itself hypothesizing an unlimited availability of mineral nitrogen in case of nitrogen immobilization (mineral nitrogen is not limiting the OM turnover). In order to provide information about nitrogen mineralization CCB must be able to describe the interaction between SOM turnover and nitrogen fluxes connected with the turnover of the FOM pools and the mineralisation of the active SOM.

The decomposition of FOM also results in a release of mineral nitrogen controlled by the C/N ratio γ_{FOM} of the given FOM pool:

$$\frac{dN_{FOM}(t)}{dt} = \dot{N}_{FOM} = \dot{C}_{FOM} \cdot \frac{1}{\gamma_{FOM}} \qquad \text{Eq. 16}$$

The FOM decomposition results in the creation of A-SOM. The quantity of nitrogen required for the newly formed amount of active SOM depends on the C_{rep} flux and the C/N ratio of the active SOM (γ_A=8.5):

$$\frac{dN_{rep}(t)}{dt} = \dot{N}_{rep} = \dot{C}_{rep} \cdot \frac{1}{\gamma_A} \qquad \text{Eq. 17}$$

The turnover of the active SOM pool also includes the mineralization of A-SOM to CO_2. Hypothesizing that nitrogen mineralisation from SOM is controlled by the dynamics of carbon turnover the nitrogen released from the mineralization process is determined by the C/N ratio of the active SOM (k_m = 0.00556 d^{-1}):

$$\frac{dN_A(t)}{dt} = \dot{N}_A = k_m \cdot C_A(t) \cdot \frac{1}{\gamma_A} \qquad \text{Eq. 18}$$

The total nitrogen flux into (positive values) or out of (negative values) the pool of mineral nitrogen (N_m) results from Eq. 16, Eq. 17 and Eq. 18:

$$\frac{dN_m(t)}{dt} = \dot{N}_m = \dot{N}_A + \dot{N}_{FOM} - \dot{N}_{rep} \qquad \text{Eq. 19}$$

For better illustration of the nitrogen flux calculations in CCB Figure 37 is presenting two examples with respect to FOM decomposition (N_{FOM}) and nitrogen flux from FOM into A-SOM (N_{rep}). Depending on the C/N ratio (γ_{FOM}) of the given FOM pool (10 or 20) the FOM decomposition results in a net N mineralization (+2) or immobilization (-3). A possible mineralization of the A-SOM pool is not considered within this example.

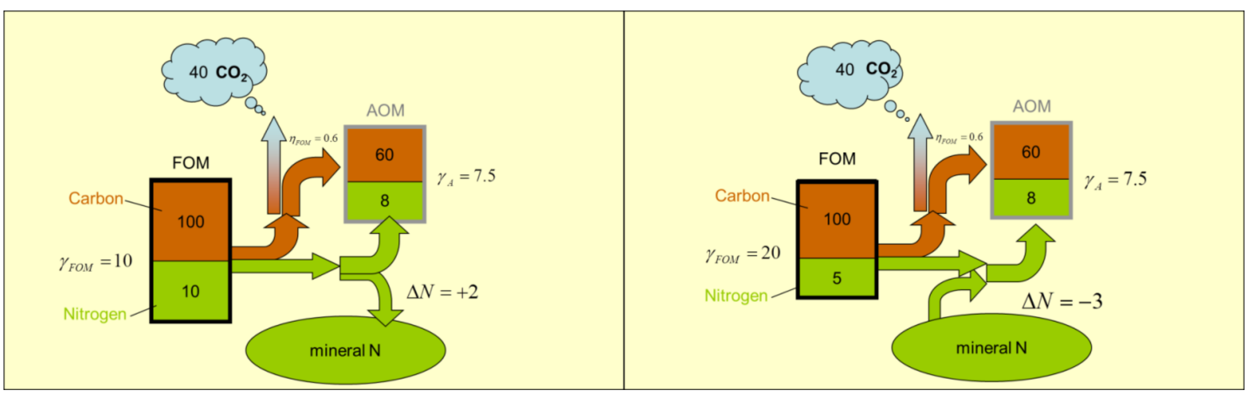


Figure 37: Examples for Net N mineralization and immobilization

Table 5: CCB input variables that pertain to nitrogen fluxes

Variable	Definition	Unit	Name in database	Database table
γ_{FOM}	C/N ratio of the given FOM pool (substrate specific)	-	CNR	cdyopspa

3.4.4 Soil carbon initialization

At runtime the actual sizes for the active, passive and long term stabilised pool must be initialized. This is based on a given value for C_{org} and N_{org} at t=0. The CCB model will use the values from the measurement data that are indicated with year number 0. Generally it is not recommended to take the first real observation value for this purpose because all observation values include an error. Selecting one special observation as initial value would give this result more importance compared to the later observations and the error of the initial value would have an impact on the model results for the following years.

Therefore we recommend to estimate a "virtual" initial value at time t=0 by means of optimisation that gives the model the best fit to the whole set of observations. The sum of squared deviation can be used as a criterion for a good fit and can be minimised by selecting an optimal initial value leaving all other parameters constant.

A practical implementation of this procedure is available with the OPTIMIZER (http://www.ufz.de/index.php?en=39727) that can be easily connected with CCB and is using the Downhill Simplex Method in multi dimensions as described in detail by Press et al. (1989).

The following paragraph describes the initialization algorithm in more detail:

The carbon amounts of active (C_A) and stabile (C_S) SOM together form the decomposable carbon C_{dec}. The initial value of C_{dec} is the difference between C_{org} and C_{LTS} with an upper limit of 2 M% C_{org}:

$$C_{dec}(0) = MIN[2, C_{org}(0) - C_{LTS}(0)] \qquad \text{Eq. 20}$$

The quantification of C_{LTS} is derived from the CIPS model (Kuka et al., 2007) as proposed by Puhlmann et al. (2006). The amount of carbon stored in soil pores related to the permanent wilting point (*PWP*) is expressed by the factor F_{LTS} and is regarded here as stabilized in the long term:

$$C_{LTS}(0) = C_{org}(0) \cdot F_{LTS} \qquad \text{Eq. 21}$$

with

$$F_{LTS-SOM} = \frac{r_2 \cdot r_3 \cdot PWP}{r_1 \cdot r_2 \cdot PV + r_3 \cdot PWP \cdot (r_2 - r_1) + r_1 \cdot FC \cdot (r_3 - r_2)} \qquad \text{Eq. 22}$$

r_i:	pore radius: r_1=5 µm; r_2=10 µm (soil type "L": 12 µm); r_3= 500 µm
PWP:	soil moisture at permanent wilting point in VOL%
FC:	soil moisture at field capacity in VOL%
PV:	soil pore volume in VOL%

The amount of $C_{dec}(0)$ is distributed between C_A and C_S according to the model equations (Eq. 23, Eq. 24) assuming steady state conditions.

$$C_A(0) = C_{dec}(0) \cdot \frac{k_a}{k_a + k_s} \qquad \text{Eq. 23}$$

$$C_S(0) = C_{dec}(0) - C_A(0) \qquad \text{Eq. 24}$$

The C/N ratio of the decomposable SOM is fixed to 8.5. If an initial value for $N_{org}(0)$ is known it is used to calculate the C/N ratio of the LTS pool (γ_{LTS}) from the C/N ratio of the complete SOM (γ_{SOM}).

$$\gamma_{LTS}(t) = \frac{8.5 \cdot \gamma_{SOM}(0) \cdot C_{LTS}}{8.5 \cdot C_{org}(0) - \gamma_{SOM}(0) \cdot C_{dec}(t)} \qquad \text{Eq. 25}$$

3.4.5 Dynamics of the physically stabilized SOM

Following the ideas of the CIPS model (Kuka et al., 2007) there is a highly stabilized SOC pool that is associated with the micro pores in soil. Hitherto CCB and CANDY addressed this pool as long term stabilized (LTS-SOM) and assume this pool as constant because changes of this pool size were expected to be insignificantly small.

Assuming the LTS-SOM dynamic is controlled by soil physics, the pool size calculation is ruled by following equations:

$$SOC = \alpha \cdot (A_\mu + A_m + A_M) \qquad \text{Eq. 26}$$

α: areal specific carbon concentration

A: inner area of micro (μ), meso (m) and macro (M) pores in soil

$$C_{LTS} = \alpha \cdot A_\mu \qquad \text{Eq. 27}$$

$$C_{LTS} = SOC \cdot \frac{A_\mu}{A_\mu + A_m + A_M} = SOC \cdot F_{LTS} \qquad \text{Eq. 28}$$

F_{LTS}: soil structure depending factor relating the LTS pool size to total SOC

Further details of F_{LTS} calculations were given by Kuka et al. (2007), Puhlmann et al. (2006) and Franko et al. (2011).

Implementation of carbon and nitrogen fluxes

In the CIPS model the carbon flux into the micro pore space is restricted to dissolved organic carbon (DOC). Any DOC flux is closely related to microbial activity. The A-SOM pool of the CCB model behaves very similar to soil microbial biomass. Therefore we assume that the flux between time step t_i and t_{i+1} to/from the LTS pool is affecting the A-SOM pool and hypothesize that:

$$\Delta C_{LTS} = -\Delta C_A = C_{LTS}(t_{i+1}) - C_{LTS}(t_i) \qquad \text{Eq. 29}$$

Both pools LTS-SOM and A-SOM have a different C/N ratio (γ) meaning that also a flux (N_{flx}) between the mineral nitrogen and an organic N pool has to be considered:

$$N_{flx} = \Delta C_A \cdot \frac{\gamma_A - \gamma_{LTS}}{\gamma_A \cdot \gamma_{LTS}} \qquad \text{Eq. 30}$$

A growing LTS-SOM pool (N-poor) will withdraw C from the N-rich A-SOM pool and set mineral nitrogen free (meaning prevent the mineral nitrogen from being immobilized during the decomposition of fresh organic matter). A decreasing LTS-SOM pool leads to nitrogen immobilization due to the A-SOM growth and has to be considered as N-sink.

3.5 Calculation of N balance

CCB provides N-balancing for two different schemes. There is the field balance for the nitrogen fluxes that cross the field border and the soil balance that includes also the change of organic N in soil.
There are considered several sinks and sources that are partly different for both balance modes.
In a first step, based on the deposition data in the climate module, the actual N-Deposition is calculated for each year. Further N-sources are (i) the N-Input from mineral fertilizers (from the management data in the cultivation table), (ii) the N-input from seeds (N_{sds}) (using the table **n_saat_input**, linked to **cdypflan** via *nsaat_ix*): $N_{sds} = menge \cdot n\_gehalt/100$ where *menge* and *n_gehalt* are specified in table **n_saat_input**, and the (iii) symbiotic and asymbiotic N-fixation. The symbiotic N-fixation of different crop classes is based on the parameters in table **leg_parm**, linked to **cdypflan** via *leg_ix*. The symbiotic N-fixation N_{sym} of a legume crop with the yield *YLD* (*quantity* in table **cultivation**) is given by $N_{sym} = \max(0, faktor \cdot YLD + konstante)$ where *faktor* and *konstante* are specified in table **leg_parm**.
The asymbiotic N-fixation N_{asy} is calculated depending on the application of mineral N fertilizer (N_{fert}):
$N_{asy} = \begin{cases} 5; N_{fert}>0 \\ 10; N_{fert}=0 \end{cases}$
The source term for the import of nitrogen from organic amendments is different for field and soil balance. The field balance considers the complete N-import (N_{ora}) that is carried onto the field with organic amendments that may as well include inorganic nitrogen (for example in case of slurry).

N_{ora}=QUANTITY*TS_GEHALT*C_GEH_TS/CNR_ALT

The soil related balance considers the change of the mineral nitrogen pool that is known as *n_m_om* from the previous CCB simulation in the table **ccb_nresult** and includes the actual N-flux from the turnover of FOM and SOM as well as the N-flush, that comes with the organic amendments but mainly as mineral nitrogen that is fast available for the crop.

The sink term related to the crop is different for field and soil balance. Therefore, the single components need to be calculated separately using parameters from the table **cydpflan** that in case of crop by-products is linked by the key *kop_ix* to *item_ix* in **cdyopspa**.

Table 6: Calculation of crop related components of the N-balance

Component	Calculation (parameters from CDYOPSPA in bold types)
Crop residues (such as root &stubble)	YLD*N_GEHALT*FEWR+CEWR
Crop main product	YLD*N_GEHALT
Crop by-product	YLD*HI***TS_GEHALT*C_GEH_TS/CNR_ALT**

The field balance includes as sink term the N offtake from the field in terms of main product and –if not left on the field - by-product as well. For the soil balance is important how many N is taken away from the mineral pool with main product, by-product and residues. It is not relevant if they are left on the field because there contribution to the soil balance as N-source is aggregated within the mineralisation flux *n_m_om*.

All components for both types of N-balance are calculated considering the individual *part* as given in **cultivation** and stored as annual values in the table **ccb_n_bilanz**. More insight into the data structure concerning N-balances is given in chapter 4.3 Result tables.

3.6 Estimation of soil parameters

The minimum soil dataset required by the model was limited to clay content (< 2 µm) and soil type (soil textural class) according to the German classification system “Reichsbodenschätzung” (Arbeitsgruppe Boden, 2005; BMJ, 2007; Capelle et al., 2006; Lieberoth, 1982). This requires a number of soil data conversions carried out by pedotransfer functions. If the silt content is known it is not necessary to specify the soil type. If the content of silt is unknown it is calculated from the German soil classification scheme assuming the mean silt content of the given soil class.

Further the fine (≤ 6.3 µm) and medium (6.3 – 20 µm) silt content is calculated using a loglinear interpolation according to Nemes et al. (1999) between clay and silt.

Interpolation of soil texture

$$p(d_x) = p(d_1) + (\ln(d_x) - \ln(d_1)) \cdot \frac{p(d_2) - p(d_1)}{\ln(d_2) - \ln(d_1)} \quad \text{Eq. 31}$$

d_i: diameter of particle class

$p(d_i)$: cumulative amount of particles with $d \le d_i$

Soil bulk density

It is possible to calculate soil bulk density using Eq. 32 and Eq. 33 following the approach of standardized bulk density TRD_s (Ruehlmann and Körschens, 2009) to find an appropriate value for the parameter b.

$$TRD = TRD_s e^{-b \cdot C_{org}} \qquad \text{Eq. 32}$$

$$TRD_s = 2.684 + 140.943 \cdot b \qquad \text{Eq. 33}$$

Following the results of Rühlmann and Körschens (2009) we can express the standardized bulk density as a function of soil clay content:

$$TRD_s = 1.78345 - 0.0081 \cdot clay \qquad \text{Eq. 34}$$

The combination of the last both equations leads to an approach to get b from clay content:

$$b = (1.78345 - 2.684 - 0.0081 \cdot clay)/140.943 \qquad \text{Eq. 35}$$

$$b = -0.00639 - 5.747 \cdot 10^{-5} \cdot clay \qquad \text{Eq. 36}$$

Soil particle density

The particle density (ρ_p) is required in order to calculate the pore volume (*PV*). An useful equation for this purpose was published by Rühlmann et al. (2006):

$$\rho_p = \frac{1}{\frac{Q_{om}}{\rho_{om}} + \frac{1 - Q_{om}}{\rho_m}} \qquad \text{Eq. 37}$$

$\rho_{m:}$ density of mineral component in g cm^{-3}

$\rho_{om:}$ density of organic matter component in g cm^{-3}

where

$$\rho_m = 2.659 + 0.003 \cdot clay \qquad \text{Eq. 38}$$

and

$$\rho_{om} = 1.127 + 0.373 \cdot Q_{om} \quad \text{with} \quad Q_{om} = \frac{C_{org}}{55} \qquad \text{Eq. 39}$$

Hydrological properties

The combination of bulk density and particle density provides the pore volume of the soil:

$$PV = (1 - \frac{\rho_b}{\rho_p}) \cdot 100 \qquad \text{Eq. 40}$$

PV: pore volume in VOL%

In the standard approach (with constant soil physical properties) the values of field capacity (Eq. 41) and permanent wilting point (Eq. 42) are calculated from soil texture using the pedotransfer function published by Lieberoth (1982).

$$FC = 3.40 + 0.85 \cdot ABT \qquad \text{Eq. 41}$$

FC: field capacity in VOL%

ABT: settleable components less than < 10 µm

$$PWP = 1.23 + 0.74 \cdot clay \qquad \text{Eq. 42}$$

PWP: moisture at permanent wilting point in VOL%

The characteristic values *PV*, *FC* and *PWP* of a specific water retention curve are required to calculate the amount of long-term stabilised carbon with the F_{LTS} parameter.

For the simulation of dynamic soil physical properties a more complex approach is used in order to reflect the impact of SOC and BD on hydrological parameters. Generally, the widely used model of Van Genuchten (1980) can be used to predict soil moisture at characteristic matric potential (h=50000 hPa (pF=4.7) for PWP and h=63 hPa (pF=1.8) for FC)

$$\Theta(\Psi) = \Theta_r + \frac{\Theta_s - \Theta_r}{(1 + (\alpha \cdot |\Psi|)^n)^m} \qquad \text{Eq. 43}$$

α	van Genuchten parameter	[cm^{-1}]
n	van Genuchten parameter	[-]
m	van Genuchten parameter	[-]
Ψ	matric potential	[hPa]
Θr	residue water content	[0..1]
Θs	saturation water content	[0..1]

The parameters of the van Genuchten model are calculated with another pedotransfer function from Vereecken et al. (1989), which calculates the van Genuchten parameters using USDA7 texture classes.

$$\Theta_s = 0.81 - 0.283 \cdot BD + 0.001 \cdot T \qquad \text{Eq. 44}$$

$$\Theta_r = 0.015 - 0.005 \cdot T + 0.014 \cdot C_{org} \qquad \text{Eq. 45}$$

$$\alpha = e^{\left(-2.486+0.025\cdot S-0.351\cdot C_{org}-2.617\cdot BD-0.023\cdot T\right)}T \qquad \text{Eq. 46}$$

$$n = e^{\left(0.053-0.009\cdot S-0.013\cdot T+0.00015\cdot S^2\right)} \qquad \text{Eq. 47}$$

$$m = 1 \qquad \text{Eq. 48}$$

3.7 Benchmarks

Benchmarks for a successful evaluation of carbon turnover models have not been established yet. However, one could expect to have values of RMSE, $RMSE_{rel}$, ME, ME_{rel}, SEM and the value of (1-r) as close to 0 as possible.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}} \qquad \text{Eq. 49}$$

$$RMSE_{rel} = \frac{100}{\bar{O}} \cdot \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}} \qquad \text{Eq. 50}$$

$$ME = \frac{\sum_{i=1}^{i=n}(O_i - P_i)}{n} \qquad \text{Eq. 51}$$

$$ME_{rel} = \frac{100}{\bar{O}} \cdot \frac{\sum_{i=1}^{i=n}(O_i - P_i)}{n} \qquad \text{Eq. 52}$$

$$EF = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O_\iota})^2} \qquad \text{Eq. 53}$$

$$SEM = \sqrt{\frac{\sigma^2}{n}} \qquad \text{Eq. 54}$$

$$r = \frac{\sum O_i \cdot P_i - \frac{1}{n} \cdot (\sum O_i) \cdot (\sum P_i)}{\sqrt{\left[\sum O_i^2 - \frac{1}{n} \cdot (\sum O_i)^2\right] \cdot \left[\sum P_i^2 - \frac{1}{n} \cdot (\sum P_i)^2\right]}} \qquad \text{Eq. 55}$$

O_i:	observed value at time step i	M%
P_i:	predicted value at time step i	M%
N:	number of measurements	-
RMSE, $RMSE_{rel}$:	root mean square error	M% or %
ME, ME_{rel}:	mean error	M% or %
SEM:	standard error of the mean difference	M%
Σ:	standard deviation of the difference O-P	M%
r:	Pearson correlation coefficient	-

The correlation between O_i and P_i is significant if the value T_0 (Eq. 56) is not lower than the right-tail value of the Student's t-distribution (p=0.95, f=n-2):

$$T_0(r) = |r| \cdot \frac{\sqrt{n-2}}{\sqrt{1-r^2}} \qquad \text{Eq. 56}$$

Statistical measures of model performance have serious limitations as the different datasets show a considerable heterogeneity in terms of their data quality. Graphical displays can be useful for showing trends, types of errors and distribution patterns. In this study the comparison of observed and predicted values in diagrams was also regarded to judge the quality of model performance at specific sites.

For a comparative evaluation of a CCB calibration with other approaches Akaike’s Information Criterion should be calculated in its standard form:

$$AIC = 2 \cdot k + n \cdot ln\left(\frac{\sum (O_i - P_i)^2}{n}\right) \qquad \text{Eq. 57}$$

Or using the corrected version for finite sample sizes:

$$AICc = 2 \cdot k + n \cdot ln\left(\frac{\sum (O_i - P_i)^2}{n}\right) + \frac{2 \cdot k \cdot (k+1)}{n-k-1} \qquad \text{Eq. 58}$$

4 Input-/Output Parameters & Database

4.1 User-data tables

4.1.1 field_description

Content:

Basic information as fixed data with general description of each homogenous simulation object.

attribute	meaning	unit/type
fl_id	Unique identifier	number
herkunft	Data source / project (documentation purpose)	string
soil_id	pointer to soil data (soilproperties)	number
climate_id	pointer to climate (climate_station ➔ climate_data)	number
location	Appears as folder name	string
site_description	Appears as plot name	string
comment	Space for remarks	string
versuch_code	Pointer to table experiments	number
area	Plot area	number
i_con	Type of initial condition (obsval, null, pre managment)	string
repix	Value of the RepIX indicator that is used for i_con=RepIX	number
rep_cnt	Additional rotations for simulations in cycle mode	number
notill	Selected tillage option (0 for allways ploughing, 1 for never ploughing, 2 for manual input of conservation tillage (no mixing of soil layers)	number
mw_bat	Average BAT (updated by the model)	[d a^{-1}]

Remarks:

Depending on the purpose of the model application it is recommended to extend the table to store additional information that may be useful for the result interpretation or data organisation.

4.1.2 Climate_station

Content:

Basic information about the location of the climate station and N-deposition.

attribute	meaning	unit/type
climate_id	Unique identifier	number
station	Name of the site	string
breite	Latitude (documentation purpose)	number
laenge	Longitude (documentation purpose)	number
year0_nd	Initial year for calculated N deposition	Number
year1_nd	Last year for calculated N deposition	Number
ndep_0	N deposition rate of the initial year	kg/ha
ndep_1	N deposition rate of the last year	number

4.1.3 Climate_data

Content:

Climate data in annual time steps.

attribute	meaning	unit/type
climate_id	Pointer to climate_station	number
year	Observation year; a 0 indicates a long term average	number
temperature	Average annual air temperature at 2 m	[°C]
precipitation	Annual precipitation sum	[mm]

Remarks:

Day and month are options for future development and now should be given a 0 value.

4.1.4 Cultivation

Content:

Management data.

attribute	meaning	unit/type
cultivation_id	Unique number	number
fl_id	Pointer to field description	number
fl_id_alt	Internal buffer	number
year	Year of activity	number
macode	Action code; Pointer to cdy_action	number
item_ix	Object code; pointer to parameter table	number
sim_quantity	Internal buffer	number
quantity	Amount of input or crop yield	number
part	Spatial weight (in %),linked with 'regional-mode'	number

Remarks:

Day and month are options for future development and now should be given a 0 value

4.1.5 Measurements

Content:

Observed data and initial data for SOC and N_t.

attribute	meaning	unit/type
meas_id	Unique number	number
fl_id	Pointer to field_description	number
m_ix	Property code; pointer to cnd_mwml	number
year	Year of observation	number
year_number	Count of the year; 0 means initial value	number
meas_value	Observed value	number
corg_m	Internal buffer	number
vrnz	Varianz of observed value (optional)	number

Remarks:

m_ix=7: SOC; m_ix=0 : NT

4.1.6 Soilproperties

Content:

Parameters of the (top) soil.

attribute	meaning	unit/type
soil_id	Unique identifier	number
profile	Name shown in the interface	string
ba_rbs	Soil type according to “Reichsbodenschätzung”	string
clay	Clay content [%]	number
silt	Silt content [%]	number
silt_org	y(es) if provided by user	y/n
sand	Sand content [%]	number
sand_org	y(es) if provided by user	y/n
fat	Fine particles (clay + fine silt) content [%]	number
fat_org	y(es) if provided by user	y/n
pwp	Permanent wilting point	number
pwp_org	y(es) if provided by user	y/n
pv	Pore volume	number
pv_org	y(es) if provided by user	y/n
fc	Field capacity	number
fc_org	y(es) if provided by user	y/n
pd	Particle density	number
pd_org	y(es) if provided by user	y/n
bd	Bulk density	number
bd_org	y(es) if provided by user	y/n
cif	Part of LTS carbon	number
cif_org	y(es) if provided by user	y/n
skelett	Stone content [%]	number
fbio	Calibration factor for microbial biomass	number
lmbd	λ_d parameter for LTS dynamics	number
lmbd_org	y(es) if provided by user	y/n
deg	k_d parameter for aggregate destruction	*number*
deg_org	y(es) if provided by user	y/n
max_lts	Maximum size of LTS pool (saturation limit)	number
max_lts_org	y(es) if provided by user	y/n

Remarks:

More attributes may be added for convenience of a study or to support data organisation. Non-bold parameters are only required for LTS-dynamics.

4.1.7 Experiments

Content:

Register of the folder objects (experiments, farms etc.) within the database.

attribute	meaning	unit/type
location	Folder name shown in interface	string
vcode	Unique code	string
exp_id	Unique number	number
herkunft	Description of data origin	string
select	Informal field	number

Remarks:

Don't forget to add a record here if you are manually extending the database.

4.1.8 Site_state

Content:

Formal register of the plot objects within the database - only these objects can be selected for simulation.

attribute	meaning	unit/type
fl_id	Link to field_description	numeric
status	Use for simulation: 1 = use; 0 = skip	numeric
res_val	Informal field	numeric

Remarks:

Don't forget to add a record here if you are manually extending the database.

4.2 Model-parameter tables

Only a selection of the model-parameter tables is described within this CCB-manual. For further information please also see the CANDY-manuals.

4.2.1 cdyaktion

Content:

Description of management actions.

attribute	meaning	unit/type
action	Name of action	string
action_id	Key	integer
unit_intensity	Unit of the quantitative attribute	string
def_intensity	Definition of the quantitative attribute	string

4.2.2 cdyopspa

Content:

Parameters for fresh organic matter turnover.

attribute	meaning	unit/type
item_ix	Index	integer
name	Name	string
od	Separation between external source (specified in cultivation data) and internal generated organic matter (like roots). The internal generated data are in terms of N or C, therefore no parametrisation of TS_TEHALT and C_GEH_TS is required	boolean
k	Decomposition coefficient	$[d^{-1}]$
eta	Synthesis coefficient	number
cnr_alt	Total C/N-ratio C_{org} / (N_{org} + N_{min})	number
cnr	Ratio in organic matter (C_{org} / N_{org})	number
ts_gehalt	Dry matter content	[M. %]
c_geh_ts	C content in dry matter	[M. %]
mor	Ratio of mineral and organic nitrogen N_{min} / N_{org}	number

4.2.3 cdypflan

Content: Parameters for crops, defining the type and amount of fresh organic matter (closely linked to cdyopsa)

attribute	meaning	unit/type
item_ix	Key	integer
name	Name	string
ewr_ix	Pointer to a record in cdyopspa to characterise harvest residues and roots	integer
grd_ix	Pointer to a record in cdyopspa to characterise aboveground biomass after ploughing up (not supported in CCB)	integer
kop_ix	Pointer to a record in cdyopspa to characterise by-products	integer
fewr	factor between N in harvest residues, roots and yield	$[kg\ kg^{-1}]$
cewr	N amount in harvest residues independent from yield	$[kg\ N\ ha^{-1}]$
n_gehalt	N-concentration in yield	$[kg\ N\ dt^{-1}]$
ts_bezug_hp	Dry matter content	[-]
hi	Harvest index	[cm]

4.3 Result tables

4.3.1 ccb_nresult

Content: main result table for C and N;

attribute	meaning	unit/type
fl_id	Pointer to field description	number
year	Year	number
year_num	Count of the year	number
n_m_om	Min.N flux from organic sources incl. N_{flush}	number
n_ops	Remaining N in fresh organic matter	number
c_ops	Remaining C in fresh organic matter	number
c_som	C amount in soil organic matter	number
c_org	Concentration of organic C in soil	number
c_lts	C amount in long term stabilized OM pool	number
n_som	N amount in soil organic matter	number
n_org	Concentration of organic N in soil	number
c_mic	C in microbial biomass (see calibration factor *f_bio* in soil properties)	number
c_rep	Carbon flux from FOM into SOM	number
bat	Biologic active time [d_{mad}/yr]	number
n_flush	Amount of mineral N from organic amendments	number
n_m_fom	Net N-mineralization (>0)/immobilization(<0) from FOM	number
bd	Bulk density [g/cm³]	number
pwp	Permanent wilting point [Vol%]	number
a_age	*Age of A-SOM pool **	number
s_age	*Age of S-SOM pool **	number
l_age	*Age of LTS-SOM pool**	number
c_m_tot	Total C flux into atmosphere	number
c_m_fom	C flux into atmosphere from FOM	number
sc_id	Internal used	number
pset	ID of parameter set	number
haeq	Index for humus production: RepIX=C_{rep}/BAT [kg/ha/d_{mad}]	number
n_free_fom	Gross N-mineralization from FOM turnover	number
c_imp_fom	C input by FOM (before turnover)	number
n_imp_fom	N input by FOM (before turnover)	number

* not yet fully implemented

Remarks: amounts in kg/ha; fluxes in kg/ha/yr, concentrations in %

4.3.2 ccb_n_bilanz

Content: calculated details for N-balance components in annual time steps

attribute	meaning	unit/type
fl_id	Pointer to field description	number
year	Year	number
n_m_om	Min.N flux from organic sources incl. N_{flush}	number
n_org_inp	Input with organic amendments	number
n_kop_inp	Input with by-products (if left on field)	number
n_ewr	Uptake with roots and stubble	number
n_saat	Input with seeds N_{sds}	number
n_dng	Input with min. fertilizer N_{frt}	number
n_entz	Uptake with main-+by- product	number
n_bindung	Symbiotic fixation N_{sym}	number
n_deposition	Atmospheric N deposition	number
asym_nbind	Asymbiotic fixation N_{asy}	number
idx	Index term	text

Remarks: all N amounts in kg/ha/yr

4.3.3 ccb_nsaldo

Content: final balance components from **ccb_n_bilanz** aggregated over time

attribute	meaning	type
fl_id	Pointer to field description	number
n_mindg_inp	Input with min. fertilizer N_{frt}	number
n_orgdg_inp	Input with organic amendments N_{ora}	number
n_ewr_upt	Uptake with roots and stubble	number
n_hukp_upt	Uptake with main-+by- product	number
n_mos_inp	***CCB_N_BILANZ.N_m_om***	number
n_leg_inp	Symbiotic fixation N_{sym}	number
n_asym_inp	Asymbiotic fixation N_{asy}	number
n_depos_inp	Atmospheric N deposition N_{dep}	number
n_saat_inp	Input with seeds N_{sds}	number
n_gratis	$N_{sds} + N_{asy} + N_{sym} + N_{dep}$	number
n_saldo_soil	***N_mos_inp + N_mindg_inp + N_gratis - N_HUKP_upt - N_ewr_upt***	number
n_saldo_plot	***N_orgdg_inp + N_mindg_inp +N_gratis -N_HUKP_upt***	number

4.3.4 nmin_saldo

Content: components of soil N-balance

attribute	meaning	type
fl_id	Pointer to field description	number
n_pflanze_out	Uptake with main + by- product+residues: ***n_entz + n_ewr***	number
n_mindg_inp	Input with min. fertilizer N_{frt}	number
n_mos_inp	Min.N flux from organic sources incl. N_{flush} ***; n_m_om***	number
n_leg_inp	Symbiotic fixation N_{sym}	number
n_asym_inp	Asymbiotic fixation N_{asy}	number
n_depos_inp	Atmospheric N deposition N_{dep}	number
n_saat_inp	Input with seeds N_{sds}	number
n_saldo_nmin_soil	***N_mos_inp +*** $N_{frt} + N_{sds} + N_{asy} + N_{sym} + N_{dep}$ ***- n_entz - n_ewr***	number
anz	*Number of considered years*	number

4.3.5 nt_saldo

Content: components of field N-balance

attribute	meaning	type
fl_id	Pointer to field description	number
n_abfuhr	Offtake from field with main + by- product: ***n_hukp_upt***	number
n_mindg_inp	Input with min. fertilizer N_{frt}	number
n_mos_inp	***ccb_n_bilanz.n_m_om***	number
n_leg_inp	Symbiotic fixation N_{sym}	number
n_asym_inp	Asymbiotic fixation N_{asy}	number
n_depos_inp	Atmospheric N deposition N_{dep}	number
n_saat_inp	Input with seeds N_{sds}	number
n_saldo_plotl	$N_{ora} + N_{frt} + N_{sds} + N_{asy} + N_{sym} + N_{dep}$ ***- n_entz***	number

For further information on the result tables please see the sections '2.4.4 Results' (esp. regarding error statistics) and '2.5.2 Checking results'.

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