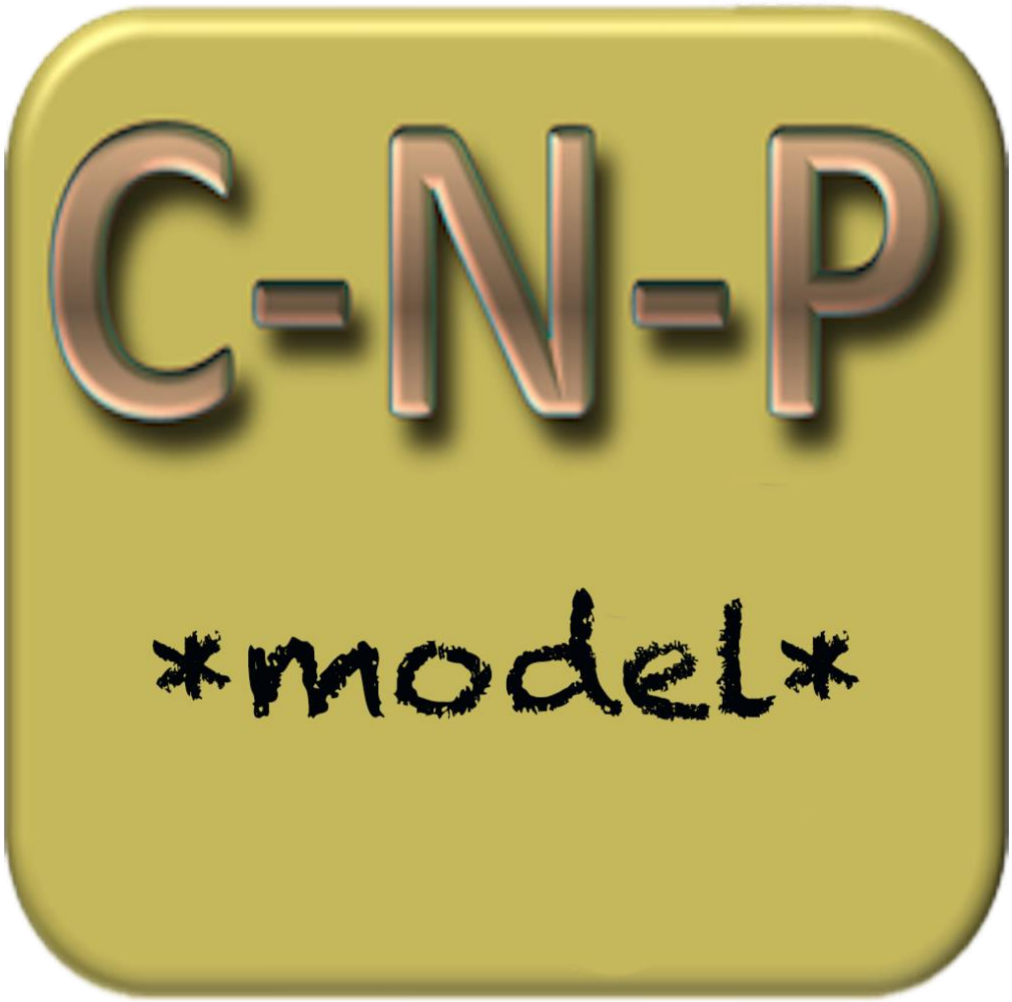
CNP Manual



based on postgresql

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1 Introduction

1.1 Development of CNP (purpose)

CNP is a more recent and extended version of the model CCB (CANDY carbon balance) that itself started as a simplified version of the carbon dynamic model in CANDY. CNP describes the turnover of soil organic carbon, nitrogen, and phosphorus in monthly time steps considering site conditions and depending on crop yields, input rates of fresh organic matter, and the initial organic carbon content of the soil. The biologic active time, as a main feature, is estimated from site conditions (soil texture of the topsoil, tillage system, rainfall and air temperature). Outputs of CNP include dynamics of total organic carbon, SOM reproduction, Nitrogen mineralization and the dynamics of plant available phosphorus.

The former CCB 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, several 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 were based on single datasets from long term field experiments: the consideration on conservation tillage (Franko & Spiegel, 2016), 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) and changes in P dynamics in several long-term experiments (Gasser et al., 2023).
Therefore, the CNP model is considered applicable for advisory service for arable fields on a wide range of site conditions.

1.2 Overview of CNP

The CNP 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 monthly time step
- Simulation of soil nitrogen and phosphorus dynamics (esp. mineralization from fresh organic matter and soil organic matter) on monthly 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

The following chapters contain a user guide for the program interface and then provide a more detailed description of the algorithms implemented in CNP together with an explanation of the model parameters (‘35 Theoretical ’). The description of the program interface is based on a standard workflow. Finally, section ‘58 Input-/Output Parameters & Database’ describes the CNP Database and its manipulation.

2 Interface of CNP

2.1 Install Interface / Initialization

CNP requires a database on a **postgresql** server. This can be installed after downloading from https://www.postgresql.org/. This installation comes with a simple administration tool called **Pgadmin**. For more flexibility it is recommended to install **dbeaver** (https://dbeaver.io/download/) as well.
If you are starting with no previous data, it is best to run **cnp_prepare** first, which will install a demo database that comes with this tool, as well as the cnp4pg.ini file that will be needed to run the CNP software.

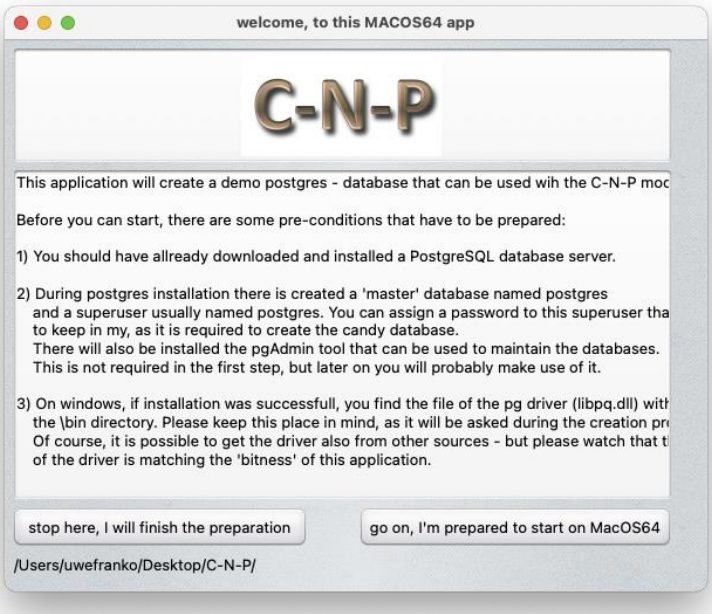

Figure 1: preparation of the first CNP database

If postgres is available, you need to know some basic information in order to proceed with *cnp_prepare*. Creating a new database and (if desired) a new user requires an account (username and password) with these privileges. You created this account during the postgres installation. The next step is to find the driver library for postgres with the correct bitness (32 or 64). This must match the version of the postgres server as well as the bitness of the CNP application (W32 or W64). It is preferable to use 64 bit technology. On a Windows system, the driver library is called libpq.dll and can be found in the postgres installation directories (i.e. c:\Program Files\PostgreSQL\<versionnumber>\lib). But be careful if you have multiple installations of postgres, there is a problem with the bitness of the library on Windows systems. It has the same name for 32 and 64 bit.
On MAC it is libpq.x.yz.dylib (where x, y and z are numbers). It may be useful to copy this library to a location where it can be accessed by the CNP software. It is possible to click on the search button, giving only part of the path to the driver, and if it is found, double click on it in the text box.

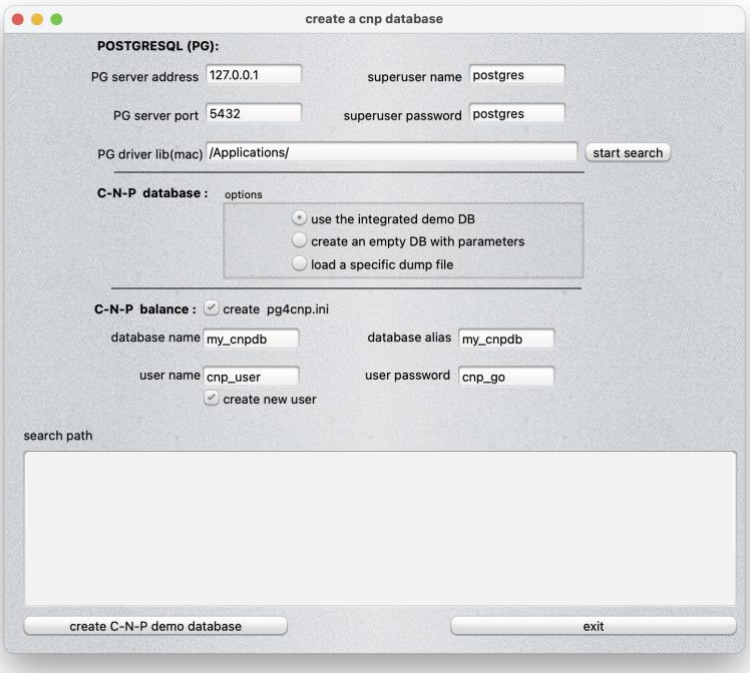

Figure 2: create the demo database

Now it will be easy to complete the next step. Fill in the form similar to the example above. You can choose to install the built-in demo database or another database from a dump file you have obtained elsewhere. Either way, please give the database a name and assign it to a user account. If this user already exists, uncheck the 'create new user' option. As this is probably your first contact with CNP, you should leave the 'create pg4cnp.ini' option checked, as this file is essential for CNP to run. Click on the 'Create' button and wait for it to finish. You can then use your pgadmin tool to check the database and connect to the dbeaver application if you wish.

The structure of the ini file can be seen in the contents of the text box in Figure 3. You can see that there are two entries for a database identifier. The first one in the [databases] section is an alias, which you can see in the drop-down menu where you can switch between them. Then, for each alias, there is a section with connection

parameters where the database name is given as it is defined on the server. This allows you to manage databases with the same name on different servers.

```
[driver]

w32= c:\...\libpq.dll

w64=c: :\...\libpq.dll


[databases]

cnptemplate = 1

my_cnpdb0 = 2


[cnptemplate]

dbname=my_cnpdb0

host=127.0.0.1
```

Figure 3: structure of pg4cnp.ini

Now you can start the user interface (cnpx_GUI) in the same directory as the ini file. The result should look similar to Figure 4

The database that is used by the app can be activated from the popdown menu (red framed). To see the content of this database you have to inflate the tree view clicking its root (green framed). Then you will see optional folders that contain the actual fields. Activate a field and go on with data processing as described in the following chapters. More databases can be connected from the menu point “add existing databases” which activates a form (Figure 5) to define an existing databases connection. Here is an option to import a dump from a third-party source (I. e. to exchange data between different local postgres servers). It is easy to create a dump using the backup tool of the Dbeaver software. On import of such dump, it may occur that the import routine reports several errors while the database is still working fine. To avoid these errors, it is recommended to Exclude (comment) following lines:

CREATE SCHEMA public;

COMMENT ON SCHEMA public IS 'standard public schema';

SET default_table_access_method = heap;

and to make sure that last character of the script is ; (no empty lines at the end that are no sql commands)

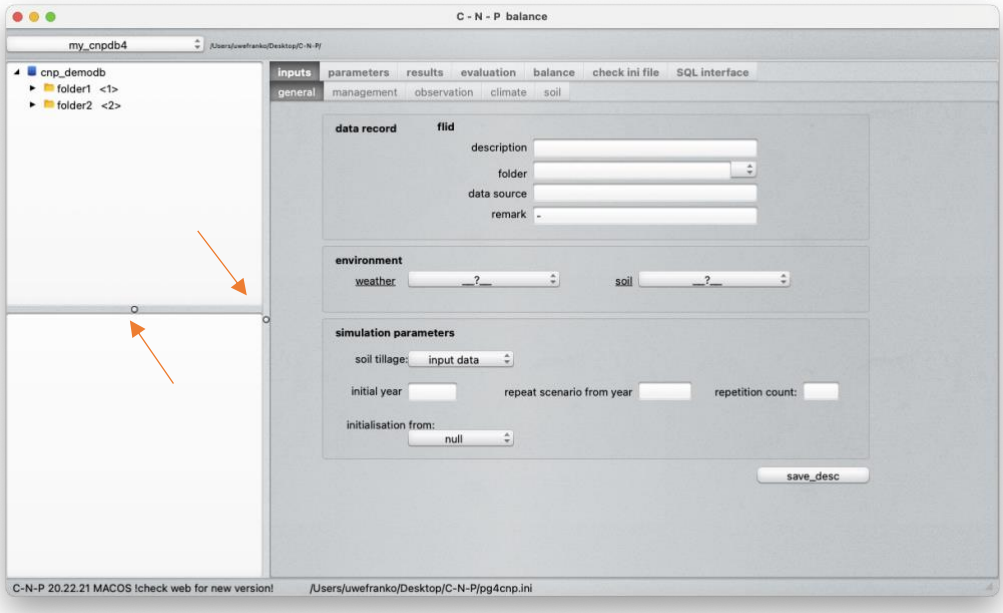

Figure 4: edit the general field description; individual subframes can be adapted throwing at the marked points (red arrows)

2.2 pop-up menus

The main menu at the left top of the form contains three items:

add existing database

A new database connection can be established providing the details to connect with the server. Please specify the file name and click the load button if there is a dump file available for this new database. It is also possible to create an empty database checking the appropriate option (Figure 5). In the latter case it is recommended to create a new folder after the new created database is shown in the tree view.

Figure 5: describe a new DB connection

export a folder to SQLITE

This is an option to easily exchange datasets. After selecting a folder all required data data including the used parameter records are written as an SQLITE database that is represented by one single file in the working directory. The message window shows the successful processed tables. In case of an error, the suspect sql command will be saved as ***x****error_comand.sql* in the working directory where **x** is a running number. If the error was caused by a missing field in the source data, the name of this field will be shown in the message window. Missing fields can easily be added using the sql interface using the command : *alter table <tablename> add <fieldname> <fieldtype>*

Attention: The export will only involve fields of the standard CNP data structure. Any additional field added by the user will not be included.

As a standard, only the climate and soil data that are used within the selected folder will be included in the export. If required, more data records concerning climate and soil can be selected in an additional step.

import from CNP-SQLITE

After selecting a SQLITE file the included tables have at first to be moved into a new created trans schema of the active database. Afterwards, all successful transferred tables can be imported one after one into their corresponding tables in the public schema. It is recommended to import first soil properties, climate_station, experiments and field_description in this order and import the other tables after them. It is checked if the same item (identified by name) is already existing in the destination and the user can decide to overwrite the existing record or to cancel the import for this table. If required the index field (fl_id, climate_id, soil_id) will be adapted to prevent double definitions.

import from CANDY-SQLITE

This is similar to the previous point but will transform data from the CANDY model to the more simple structure of CNP.

2.3 Plot selection from the Tree view

The tree-view helps to structure the data at three levels: database, folders, plots – each with a special pop-up menu:

A right-click on a tree-view item opens a pop-up menu specific for the given level.

On top level (database):

- add a folder : inserts a new folder after editing a name
- run simulations : runs simulations for all plots
- refresh connection : re-connects the database

On folder level:

-add new plot : inserts a new plot named ‘new’

- multiplot simulation : runs simulations for all plots in the folder

On plot level:

-delete active plot : removes **all data of the active plot** from the database

-run simulation : runs simulation for the active plot

2.4 Tabs of the user interface

There is most of functionality packed in one form where you see the fields and folders of your database on the left hand side. All other features are organised in a number of tabs on this main form with the structure: Inputs, parameters, results, evaluation and balance. This will be explained in the following chapters

2.5 Tab *inputs* (user data input)

This tab has a sub-structure of tabs for general data, management data, observation data, climate data and soil parameters. The content of these sub-tabs relates usually but not only to the active field in the treeview.

2.5.1 General field description

The data in CNP are usually organised as fields or *plots* within one folder Each folder may contain numerous plots and one database can contain several folders.

The information on this tab relates to the table field_description and is used to organise the data set. Each record ha a unique field ID (fl_id) and is more detailed characterised by a name (description) that is convenient to communicate, the folder (location) where it is associated to and a data source for documentation purpose. These are all visible in the upper panel ‘data record’. The panel ‘environment’ shows the names of the climate station and the soil profile that are linked with this field. Finally, the lower panel hold information concerning the planed simulation run. Soil tillage can be specified generally for the whole time interval or specified within the management data. The initial year is detected automatically depending on the initial data specified within observations. The initialisation is usually based on observation data – but other approaches are also possible. A scenario can be repeated several times starting at any year.

A right click on an item of the tree view is opening a context menu where a new item (folder or field) can be created. A new created folder includes already an empty field record. Existing fields can easily be reorganised in different folders changing the folder property. Moreover, it is possible to create a copy of the active plot including management and observation data.

There is an option to repeat the management scenario if more climate data is available. The results are then linked to the date of climate data. The repetition count is an integer, but it is possible to stop the simulation at an ultimate year when the ini file has in section [setting] the entry lcyr=<ultimate year> i.e. lcyr=2045 to stop the simulation at the end year 2045.

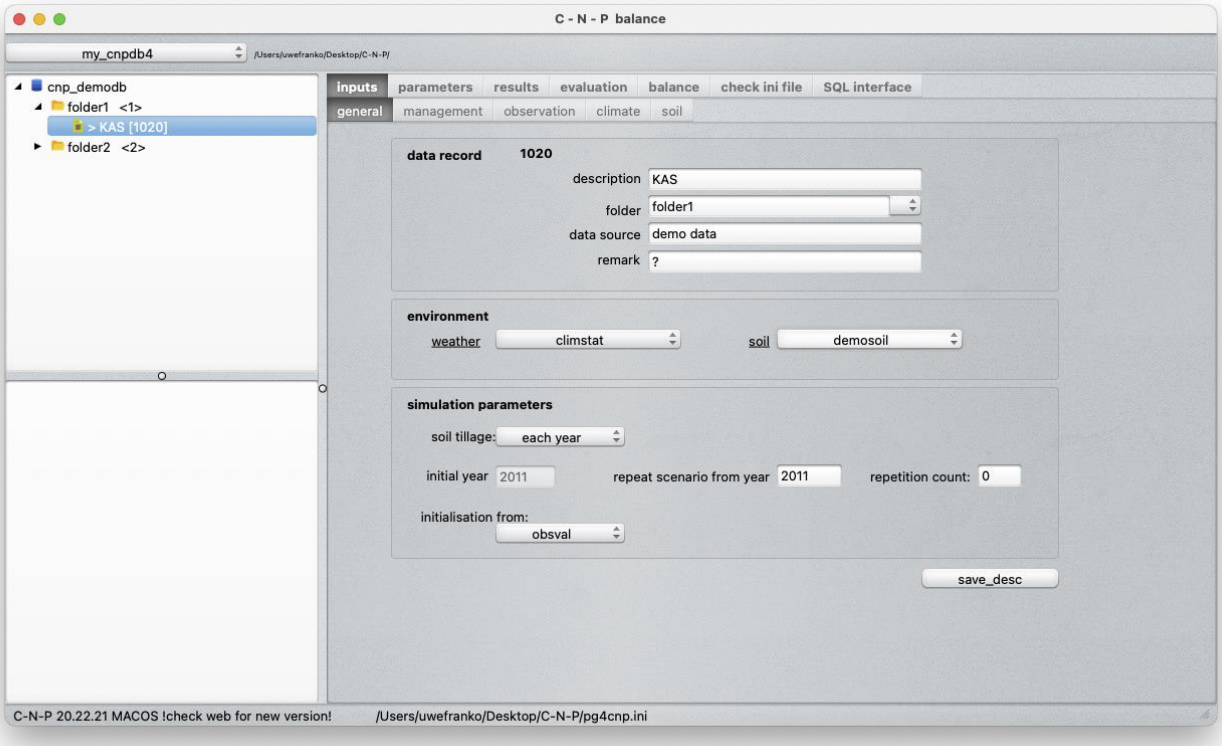

Figure 6: general field description with activated tree view

2.5.2 Management data

The management tab shows all management events for the selected plot to check and change data if required. For this purpose, it is possible to switch (red marker) between update (change the current record) and insert (add a new record) mode. For better overview check the filter items (green marker) in the lower part of the form more detailed explanations.

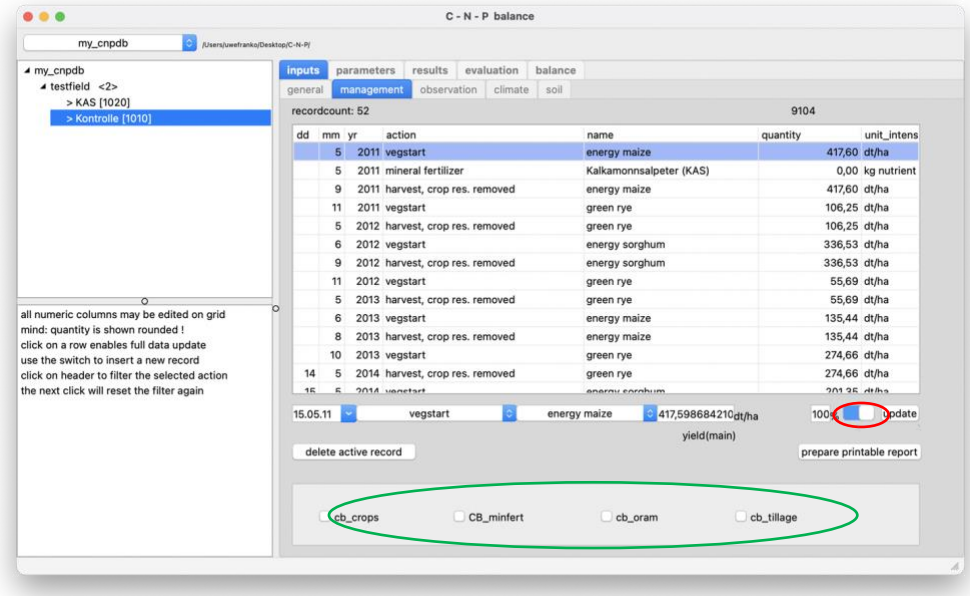

Figure 7: Editing management data at the appropriate tab

date:	Only the year and month are significant – if known, day can be given to have a better documentation and keep data records in a proper order
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 “*tillage*”) - after that please select the related object (crop, fertilizer …) - edit the intensity (yield or amount). - and finally edit the relative area (in %) where this action is applied’).
delete record:	Only the current record is deleted
prepare printable report:	Output of management data on 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. There is a specific action ‘start grassland’ (with yield =0) to include permanent grassland in the scenario. The repeated harvest actions are then ‘cutting grassland’ where the individual yields should be given. The permanent grassland will be stopped by ‘ploughing up’.

It is possible to include catch crops (identified by a name with the attached ‘(ZF)’) without knowing the yields. In this case *yield=0* must be specified.

2.5.3 Observations

CNP works with data about C_{org} (mandatory) and some other optional indicators like N_t (see following table) and Pavl (plant available phosphorus). These elements require to specify an initial value checking the appropriate box (green marker). 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. As a standard assumption the initial SOC amount will be distributed assuming all pools are in equilibrium. The additional input (beside SOC) of Cmic or pS will shift the equilibrium between C-AOM and C-SOM accordingly. P_{avl} is determined as P_{cal}. The following transformation can be used, for data records where only P_{DL} is available: $P_{cal}=0.61*P_{DL}+0.8$.

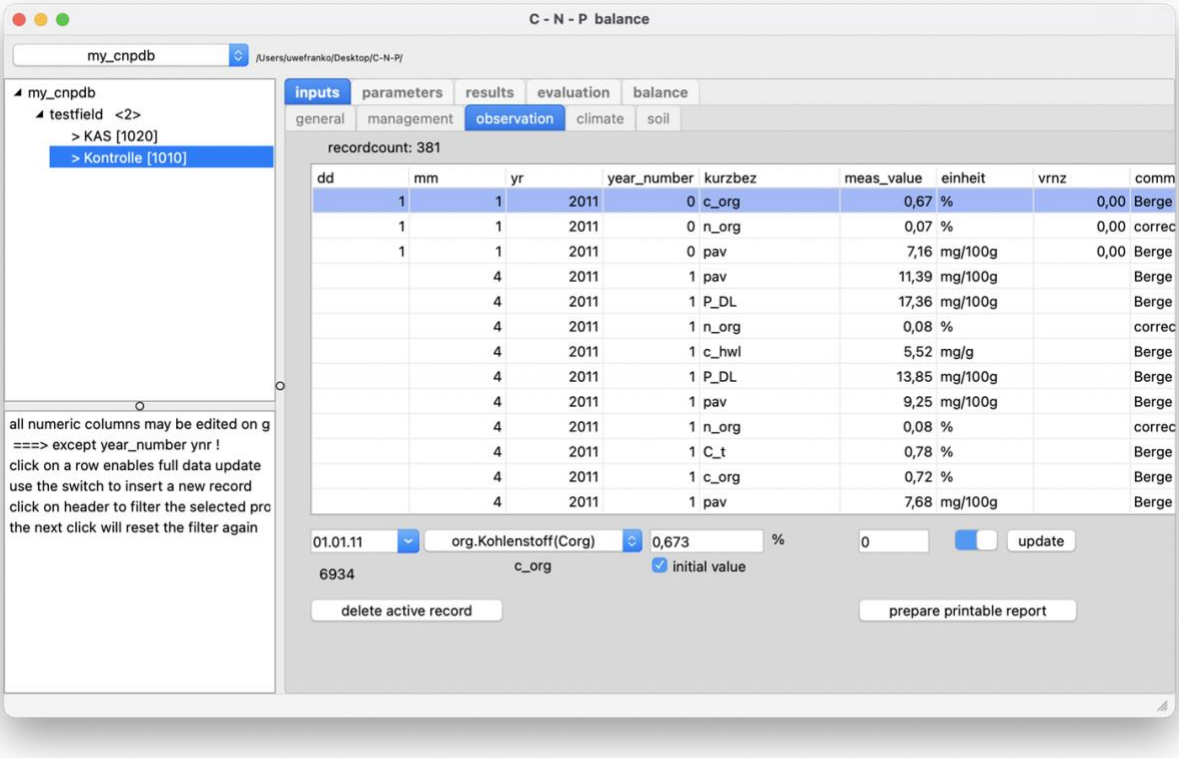

Figure 8:Editing observation data

Also in this sheet you find the options *„insert" and „update"* similar like in the management tab.

sampling date:	Only month and year is required day and day is ignored by the model.
observation:	Select the property
initial value:	Only one is allowed for N_t , P_{avl} ,C_{org} Cmic and pS
value:	Add the observation in correct units
variance:	Insert variance (optional)
printable report:	Print or send the data to a PDF-file

2.5.4 Climate data

Soil and climate data for each plot are specified by dropdown menus at the environment panel in the ‘general-’-tab of ‘inputs’. The drop-down menu will show you all climate stations stored in the CNP database. To add additional climate data, you can go to the ’climate’ tab.

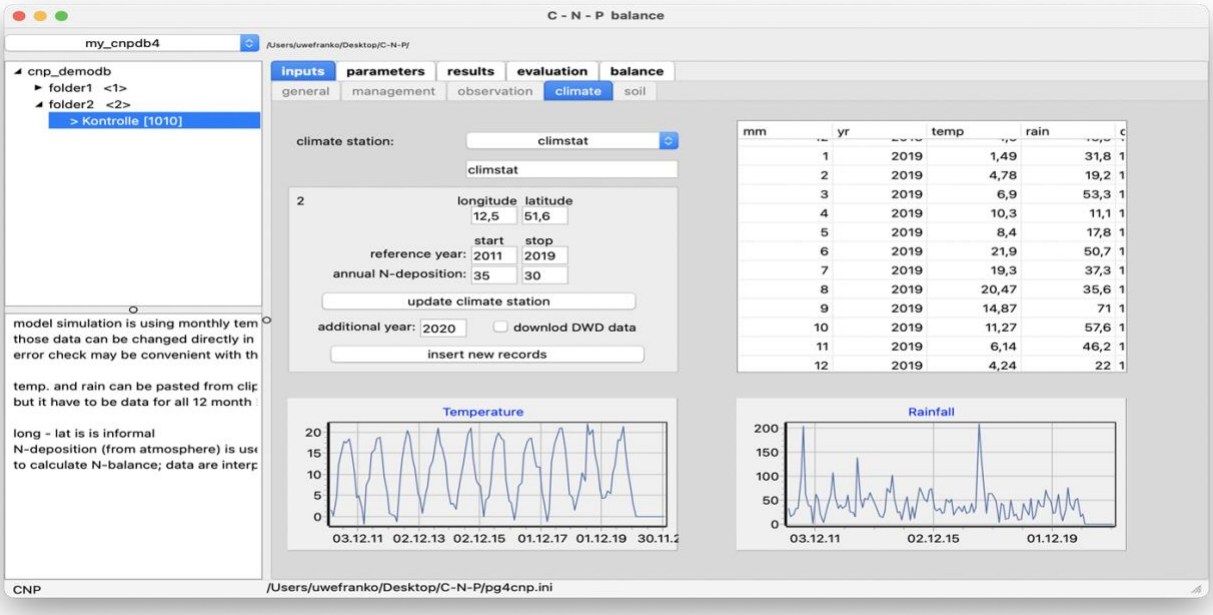

Figure 9: checking and adding climate data

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The climate data is stored separately and can be assigned to any plot. CNP is using monthly climate data. Please check to avoid gaps or obvious errors. To implement a new climate station, select this feature from the drop down menu, add the basic information especially the name for this station and click ‘save new climate station’. Edit the year and click ‘insert new records’ to add data records for this one year. For German sites the data can be downloaded for individual years from a DWD server where temperature and precipitation is available on a 1x1 km grid. If large datasets are already available, it may be convenient to do an update with database tools.
Here is the content of the table climate_station:

climate_ID	Unique value	[-]
station	Name	[-]
temp	Annual average	[°C]
rain	sum of precipitation	[mm]
annual N-deposition	Is linear interpolated from start to stop year when calculating the N balance	[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.

Click on ‘insert new records’ to add climate data manually. There will be shown the data table for this new year with empty cells for temperature and precipitation. These gaps can be filled one by one or copy-paste them from another source (like MS EXCEL). To do so, mark two columns and 12 lines in the excel sheet and copy them into the clipboard. The right click on an empty cell in the climate table and select paste. All 24 numbers will be added to the table and the graphics will update immediately.

2.5.5 Soil data

You have to select the soil data for your corresponding plot in the ‘general’-tab of the ‘inputs’. The drop-down menu will show you all soils stored in the CNP database. To add additional soils, you can either directly use the database (see section ‘58 Input-/Output Parameters & Database’) or select ‘new soil description’ from the drop down menu.

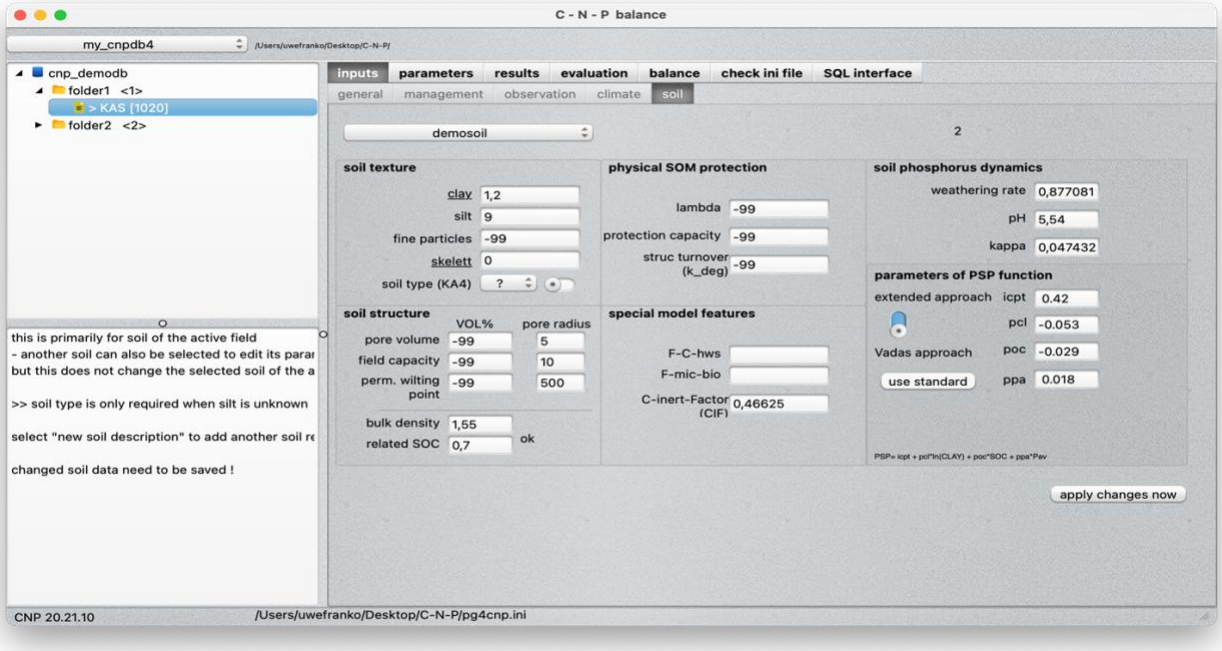

Figure 10: Editing soil data

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CNP 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. Empty fields or input of -99 are both understood as ‘missing value’. Parameters in the panel ‘soil phosphorus dynamics’ are only required if this should be simulated which would require (and is switched on by) an initial value for the plant available P. The part of plant available P depends on

the value of the PSP function. The model can use two different approaches for calculation, that are selected by a switch. A click on the button [use standard] fills the input fields for these PSP parameters.

Specification of a soil type is only necessary when silt is unknown. The model will only then use the average silt content of this soil type. For more flexibility users can select between KA4 ("Kartieranleitung") and RBS ("Reichsbodenschätzung" types using the little switch beside the pop down box.

2.6 Tab parameters

The four sub-tabs quick check, consistency check, inventory, and -import interface contributing to the parameter workflow.

2.6.1 Quick check

A selection of model parameters can quickly be checked and altered in this tab. For more comprehensive tasks it is recommended to use database tools to edit the tables. Select from the drop down menu:
cnpvcdyaktion: content of table cdyaktion – with the selectable management activities
cnpvcdyaparm content of table cdyaparm – with general parameters
cnpvcdymindg: content of table cdymindg – with the selectable mineral fertilizers and their composition
cnpvcdyopspa: content of table cdyopspa – with the parameters for all fresh organic matter entities
cnpvcdypflan: content of table cdypflan – with the parameters for all available crops

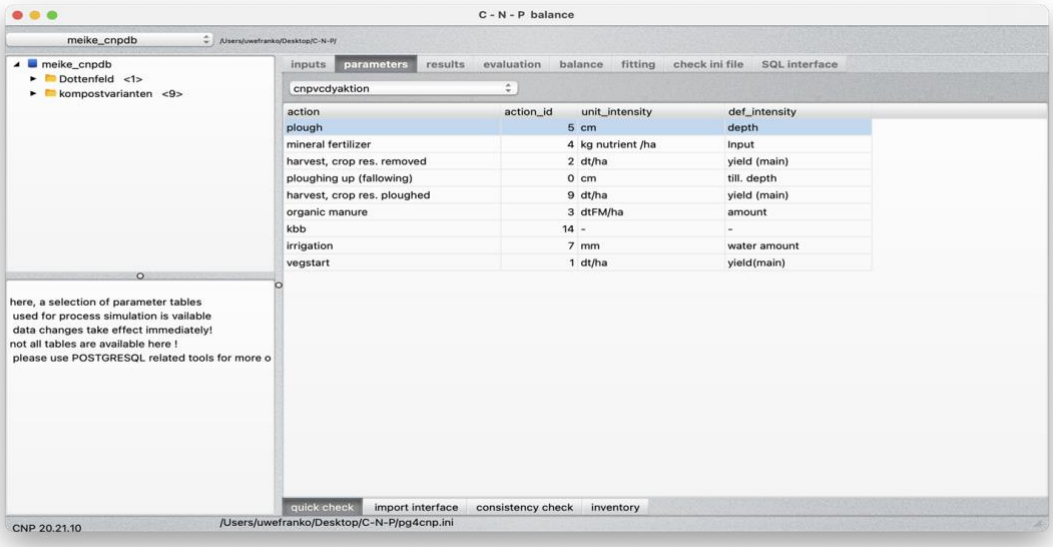

Figure 11: Optional check of most important parameter tables.Table will be sorted after clicking the header of any column

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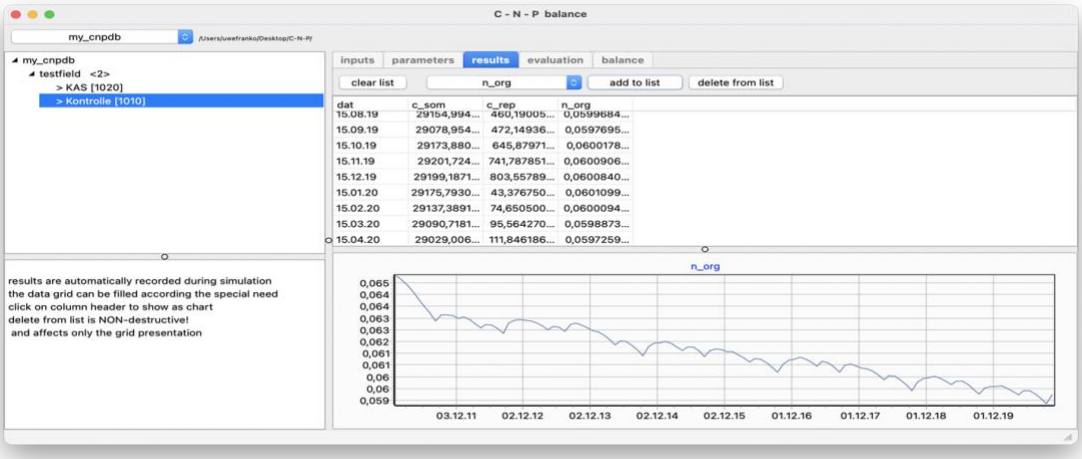


Figure 12: Results tab

2.6.2 consistency check

The active database is checked for inconsistencies. A number of views is generated in the public schema of the active database - and announced to the user - If this option is used for the first time

First, checking the existence of all used objects in cultivation in their related parameter table (crops in cdypflan, organic amendments in cdyopspa and mineral ferttilisers in cdymindg). Second, checking the definition of root (rt_ix), shoot (sh_ix), and green material (gm_ix) from cdypflan to item_ix in cdyopspa. If these both steps find inconsistencies the simulation run will be erroneous, or the model may crash at run time.

The third check is relevant for the balance calculation. Missing balance parameters should be amended before the balance calculation is started.

2.6.3 Inventory

This option supports the compilation of the used parameter set based by the content of the cultivation table. The result is a text file in sql format with insert statements for all used parameter records. This may be used for documentation purpose or the pass on the parameters to another database.

2.6.4 import interface

Over time there will be developed a GIT based parameter repository wherefrom parameters can be downloaded. Internet connection is required if the remote repository shall be used. The local repository has to be defined in the ini file.

2.7 Tab results

The ‘Results’ allows flexible analysis of simulation results. Select any item from the drop down menu and add to (or delete it from) the list of shown data. The last selected item is shown as a chart. The data compiled in the grid can be copied (mouse click) and pasted into other applications for further processing.

This is for a quick overview - the results are stored in the table **CNP_results** and can easily be processed with other tools (i.e. R scripts). The content of the haeq field may be changed specifying the appropriate settings in the ini file:

- report of Crep values : heaq=crep
- report of haeq according to VDLUFA method: haeq=haeq

2.8 Tab evaluation

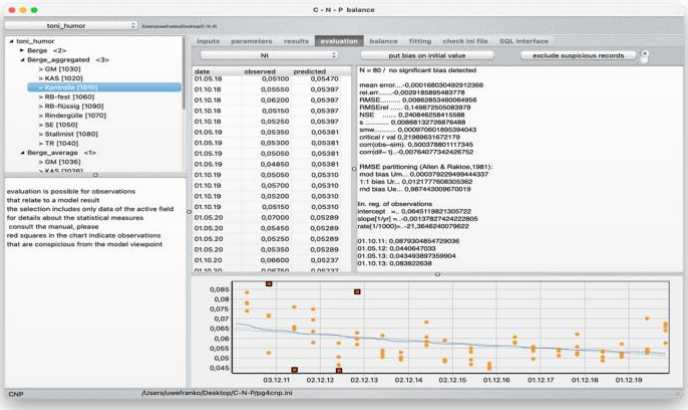


Figure 13: evaluation tab

The drop down menu provides access to all properties where observations and model results can be compared. These data records are shown as a table and simultaneously as chart. A statistic analysis providing indicators to asses the model performance. A potential bias can easily be used to change the initial values, may be with some replications until no bias can be detected. The meaning of the individual indicators is as follows:

mean error	med = residue= difference between model and observation
rel.err	Relative error = med/mean(observations)
RMSE	root mean square error
RMSErel	Rrelative RMSE mse/mean(observations)
efficiency	Nash-Suttcliffe model efficiency coefficient
s	standard deviation of the (hypothetical) normal distribution of residues (square root of variance)
smw	standard error of the residues ($\sqrt{\sigma^2/n}$)
critical r value	Critical r value (significance limit – here available only if N<60)
cor(obs~sim)	correlation between observation and simulation results
cor(dif~t)	correlation between med (mean error) and time
RMSE partitioning:	
Um	model bias part of RMSE
Ur	bias from 1:1 line part of RMSE
Ue	random bias part of RMSE

The partitioning of RMSE into Um, Ur and Ue is based on Allen and Raktoe (1981) and illustrates the reason of model deviation as shown here:

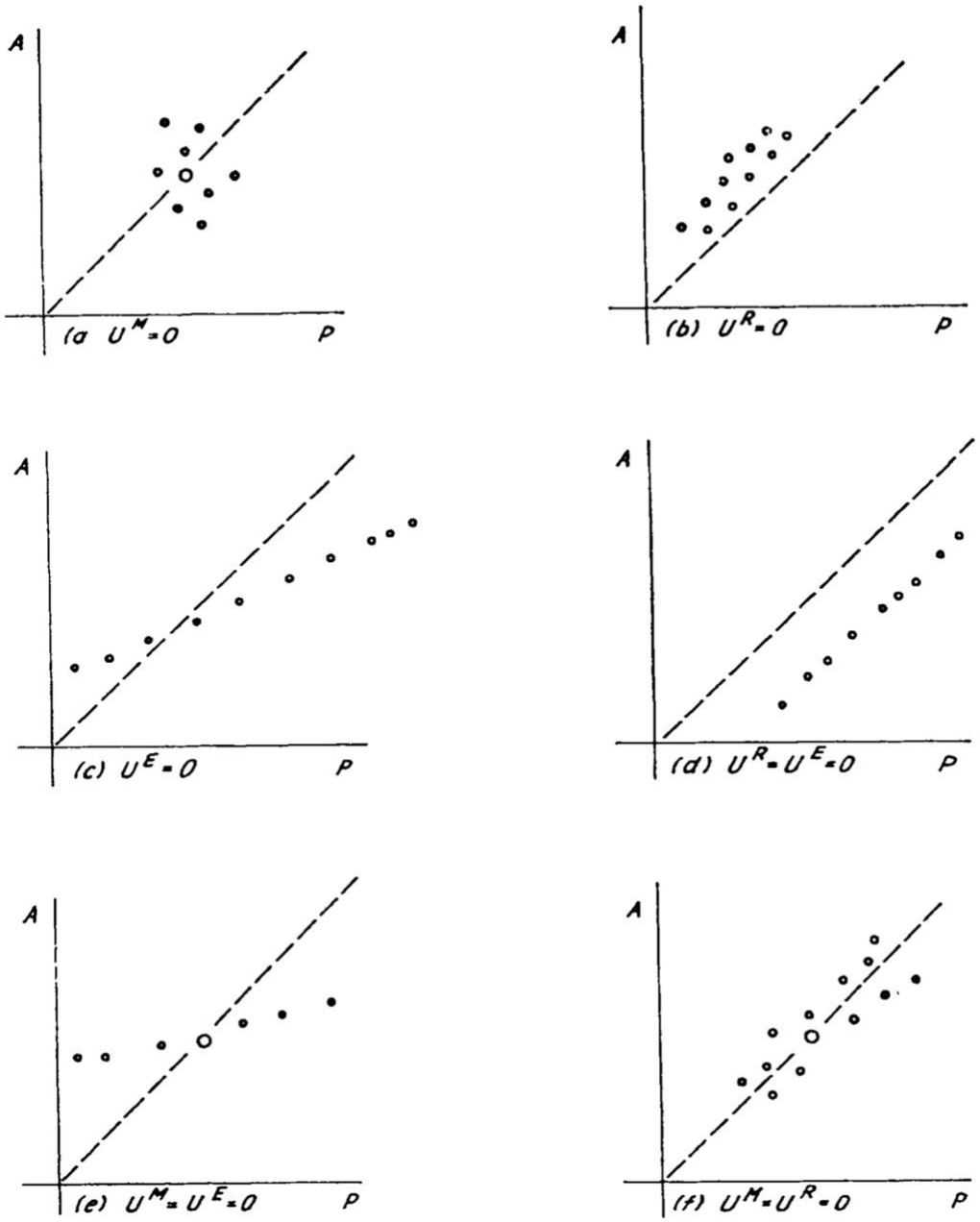


Figure 14: RMSE partitioning. Copy of figure 3.1 from Allen and Raktoe(1981) with“schematicrepresentation of some special cases” of the normalized RMSE-components

Furthermore, the evaluation also shows the result of a linear regression between the selected observation variable and time. Conspicuous values are indicated as red squares in the evaluation chart. This is calculated according to the selected reference system (as setting in the ini file). The conspicuous records can be eliminated from the evaluation by setting the m_ix to 900+m_ix. Therefore, this is easily reversible using the appropriate switch setting.

2.9 Tab balance

A balance calculation includes simulation results and is therefore dependent on the validity of the model for this special data record. The balance is calculated only for the selected treatment. There is for each year a detailed balance sheet for each of the elements available where all fluxes are compiled. This includes data that are only used for this analysis and don't affect the process simulation (i.e., symbiotic N fixation, element concentration in and amount of seeds etc.). Finally, there is an input-output analysis presented as table and as chart. Here are compared the annual averages of inputs, off-takes, changes of storage in SOM and the balance. Table data can be copied to the clipboard and pasted to other applications.

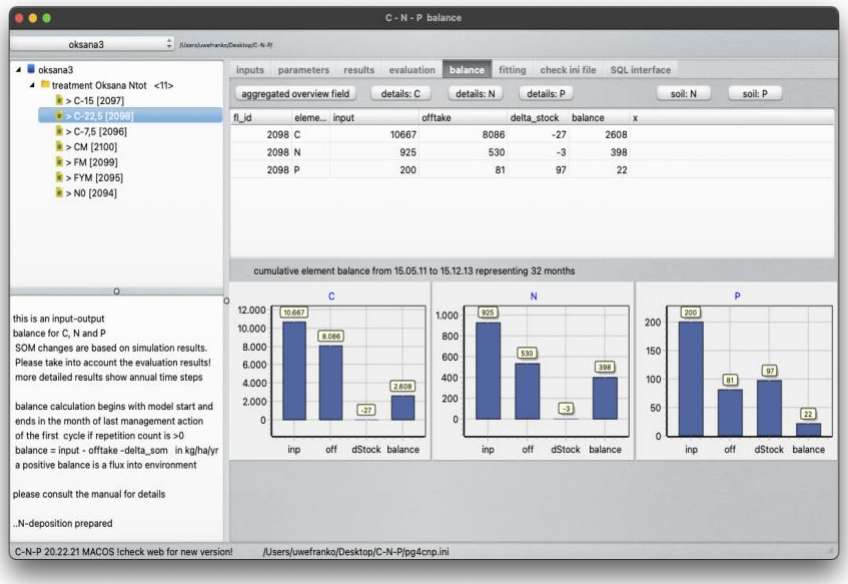


Figure 15: balance tab

The main result is an aggregated input-output balance that does not include but informs about the change of SOM storage. Users can view more detailed results in annual timesteps that are explained at the end of this section. The aggregated balance covers the simulated time interval and may contain incomplete years at the beginning and the end of the scenario. Therefore, the results are presented as sum values in kg/ha for the complete time interval.

The calculation scheme is:

balance= input – offtake

The stock changes for C and N relate to SOM only while for P the change includes also mineral forms.

It is recommended to build scenarios for complete years (from 1.1. to 31.12.) to get balance results that can be better compared with flux rates that are given on an annual base.

The standard presentation shows the field balance (aggregated, detailed and as graphic) but there is an additional option to calculate the soil balance (or crop availability) for N and P (presented only as table) to identify potential nutrient shortage. The calculation scheme here is:

balance= supply – demand

C-balance, columns of the detail table:

	informal
fl_id	plot identifier
dt_mm	time interval (number of months)
yr	balance time step
idx	unique indicator: str(FL_ID) + "_" + str(year) (plot_year)
c_som	C in SOM (kg/ha)
	sources
c_oram_in	total C input with organic amendments (manure, compost etc.)
c_byp_in	C input with by-products left on field
c_seed	seed bound C input (table saat_input)
	sinks
c_resid	C bound with the crop residues (stubble+root)
c_uptake	Total bound C by crop (main + by-product+stubble+root)
c_offtake	C taken away with the products from field

N-balance, columns of the detail table:

	informal
fl_id	plot identifier
dt_mm	time interval (number of months)
n_som	N in SOM (kg/ha)
yr	balance time step
idx	unique indicator: str(FL_ID) + "_" + str(year) (plot_year)
	sources
n_m_om	N mineralisation/imobilisation from turnover of organic compounds (SOM &FOM)
n_oram_in	total N input with organic amendments (manure, compost etc.)
n_byp_in	N input with by-products left on field
n_seed	seed bound N input (table N_SAAT_IMP)
n_fert	N-input with mineral fertilizer
n_symfix	symbiontic N fixation of legume crops (table LEG_PARM)
n_deposition	atmospheric N.deposition (from climate data)
asym_nfix	asymb. N-fixation (depends on application rate of min. N.fert.)
	sinks
n_resid	N uptake of the crop residues (stubble+root)
n_uptake	total N-Uptake by crop (main + by-product+stubble+root)
n_offtake	N taken away with the products from soil plant system

P-balance, columns of the detail table:

	informal
fl_id	plot identifier
dt_mm	time interval (number of months)
yr	balance time step
mp_t	Total P (org+min) in soil (kg/ha)
mpav	Plant available P in soil (kg/ha)
p_t	Concentration of total P (org+min) in soil (mg/100g)
pav	Concentration of plant available P in soil (mg/100g)
idx	unique indicator: str(FL_ID) + "_" + str(year) (plot_year)
	sources
p_min_os	P mineralisation/imobilisation from turnover of organic compounds (SOM &FOM)
p_oram_in	total P input with organic amendments (manure, compost etc.)
p_byp_in	P input with by-products left on field
p_seed	seed bound P input (table N_SAAT_IMP)
p_fert	P-input with mineral fertilizer and weathering
	sinks
p_resid	N uptake of the crop residues (stubble+root)
p_uptake	total N-Uptake by crop (main + by-product+stubble+root)
p_offtake	N taken away with the products from soil plant system

2.10 Tab fitting

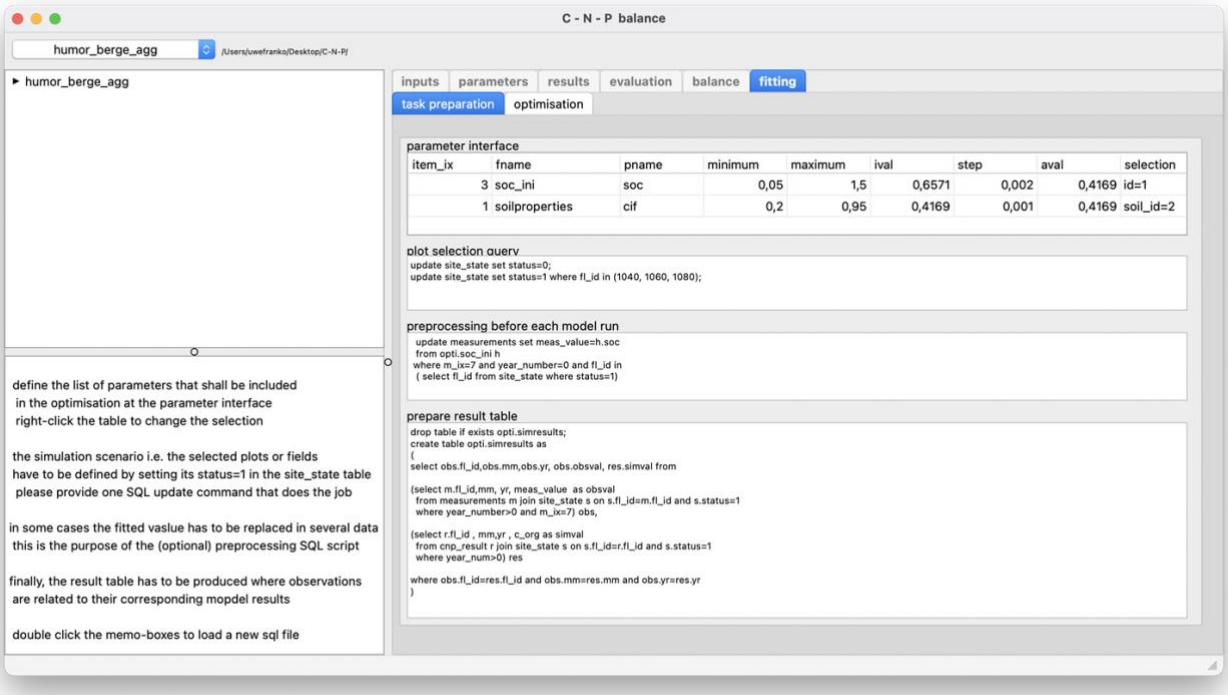


Figure 16: fitting tab - providing an optimiser interface

This tab is shown if the database contains the schema *opti*. It implements the main routines of the standalone app (W32 only) optimizer. With an own manual for more detailed explanations. Here we find a data grid for the parameters that shall be fitted and three boxes where sql scripts can be loaded. These scripts must perform following tasks:

- mark the records (plots, fields) that must be included i the simulation run by setting the corresponding *status* in table *site_state* to 1. The example shows that three fields are included.
- the preprocessing step is executed before each simulation run and may be not required in all cases. In this example we want to find a unique initial value for all tree plots. Therefore, an additional table was implemented (outside off this script) to store this value which is distributed by the preprocessing script to the individual initial values of the tree plots in this example.
- The optimisation algorithm compares two data rows where finally should be only a minimum difference between them. The third script has to produce this dataset as table named opti.simresults containing the fields obsval (the observations), simval (model results) and – depending on the chosen error function – a potential indicator to build groups of data.

The scripts should be tested separately and can be loaded from text files after clicking the individual boxes.

2.11 Tab check ini file

There are usually not many occasions where users must check and change the ini file as new database connections can be added automatically. But sometimes it may be reasonable to alter content in or even add a new [setting] section. Each setting is on a separate line written as label=value. Available options are:
(options are separated by a slash, default values are written in bold letters.)

P_details=**none** / txt # txt: output into tmp_result.txt
M_details=**none** / txt # txt: output into tmp_manact.txt
lcyr=**9999** / <last year for periodic simulation runs> # optional
haeq= **haeq** / crep # crep: heaq column in cnp_result contains C_{rep} values in kg/ha
fcmic=**gener** / spec # C_{mic}/C_{aom} parameter from cdyaparm (gener) or the soil specific (spec) value
refsys=**cnp**/linreg # reference system to identify potential outliers
lim_lts=**y** / n # limit the C accumulation of LTS pool
mod_lim= **wm** / wz # select the algorithm to calculate the saturation limit
save_state=y/**n** # y: to save the final state in som_state and fom_state
ltsstep=**y**/m # y: adapt LTS only at the end of each year
struc=**Vereecken /** Rühlmann # switch between PTFs
scrdir=**script_rep** / <?> # sub directory to store sql-scripts downloaded from GIT
repdir=**data_rep** / <?> # sub directory to store GIT downloads for parameter updates

Here is the explanation for the header of tmp_result.txt:

mm	current month
yr	current year
nmo	running month, useful for quick graphic presentation without conversion of mm & yr into a date
bd	bulk density
mpsom	P in SOM (kg/ha)
mpfom	P in FOM (kg/ha)
p_s2m	flux from SOM-P to mineral P
p_f2m	flux from FOM-P to mineral P
p_f2s	flux from FOM-P to SOM P
mp_av	plant available P (kg/ha)
mp_na	non-available, mineral P (kg/ha)
a_ppu	P uptake into plant
spmin	P mineralization (p_s2m+p_f2m)
pfert	P input with mineral fertilizer
pfom	P input with FOM
pwth	P input by weathering
kav2sa	k value for transfer from available to non-available mineral P
ksa2av	k value for transfer from non-available to available mineral P
psp	PSP value

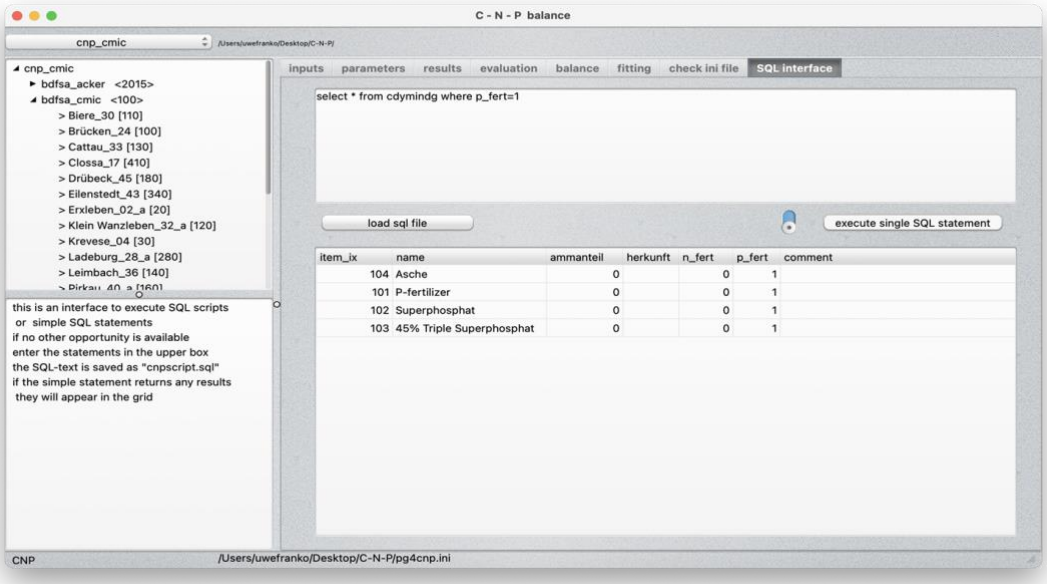


Figure 17: Example for using the SQL interface; use the switch (red circle) to change between single statement and SQL script.

2.12 Tab SQL interface

Sometimes it may be reasonable to execute SQL statements directly from the C-N-P user interface. If they have been already prepared as text files they can be loaded and adapted o completely new written. Before execution the content of the memo box is saved as *cnpscript.sql*. An already existing file with this name will be overwritten without warning. Single select statements will produce a result that is shown afterwards. If a script is executed there will be no result produced. Generally, if complex problems have to be solved, it is recommended to use more comprehensive tools like pgAdmin or Dbeaver.

A new option is implemented that allowsadditonal to the free selection of local files the download of SQL scripts from a central GIT repository.

2.13 Special application cases

In most cases the model will be initialized from real or virtual observation values (initialisation from ***obsval***). Other options are ***null*** (assuming a 'normal' humus management according to the SOM level=0 of the indicator based initialisation described in next paragraph), ***ReplX*** (see 2.13.1), ***state*** (see 2.13.2) and ***pgl*** (applicable for permanent grassland if no SOC observations are known)

2.13.1 Indicator based initialisation

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 an indicator (select ***ReplX*** as shown in Figure 18) that describes the OM management like the Humus-Balance method of VDLUFA (VDLUFA,2014) where the actual state is characterized by 5 classes from A (very low) to E (very high). The 'optimal' or normal state is class C. In relation to the balance approach of the VDLUFA method the indicator value is 0 for class C, has negative values for low levels and positive values for high levels. For even more flexibility a numeric value can be inserted directly ranging from -2.5 up to + 2.5 or using the slider as shown in Figure 19. This option should only be used for special cases and with a critical review of the results.

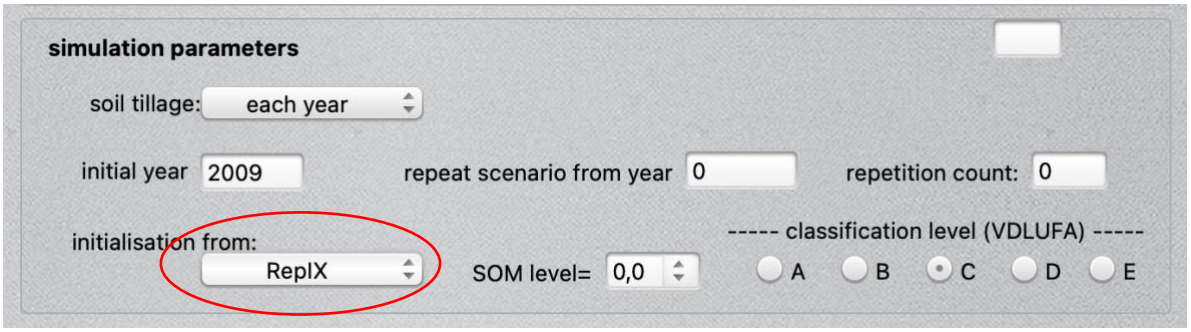


Figure 18: selection of the indicator-mode for model initialisation

Figure 19: click arrows (red marker) to activate slider to indicate an initial SOC level

2.13.2 Explicit setting of initial state

It may be convenient for scenario simulations to set all organic pools initially to a given size. This requires the initial mode *'state'*. Then SOM and FOM pools are set to the values given in tables *som_state* and *fom_state* for the given *fl_id*. The model will save the final distribution of SOM and FOM pool if in the *[setting]* section of the ini-file is specified ***save_state=y*** .

2.13.3 Using the batch mode

CNP 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):

parameter	meaning
GO	automatic start of simulation run
BAL	Start balance calculation after finishing scenario (only working together with the *GO* parameter)
PPQ=<preprocessing sql script>	Preprocessing sql script useful to prepare the next simulation run
POQ=<postprocessing sql script>	Postprocessing sql script, useful for automated result processing
DB=<db name>	name of the database incl. complete path
INI=<ini file with DB parameters>	exit from application after finishing the simulation run
STSAVE	Save the final SOM and FOM state
STEP	the simulation scenario as defined in site_state is repeated for a list of single steps as defined in table *step_list*. PPQ and POQ script are called before and after each single simulation step
ID=<fl_id>	Alternative option to set status=1 for <fl_id> in table *site_state* and force the simulation of this entity

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 '58 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. At first an example for starting CNP in batch mode without using the STEP option:

On Windows:
cnp.exe DB= cnp_sample_DB PPQ=use_all.sql go

On MacOS
open -a cnpx_GUI.app --args DB=cnp_sample PPQ=use_all.sql GO

with 'use_all.sql':

```
UPDATE site_state SET status = 0;
UPDATE site_state SET status = 1  from field_description fd
WHERE site_state.fl_id=fd.fl_id
AND fd.exp_id= 16;  -- select all plots of a certain experiment
```

The STEP option is intended to simulate various scenarios that have some common features. The simulation is controlled by the table step_list that should have at least the columns step and simtag (both integers). The model will perform a run for each record in step_list where simtag=0. The item simtag signals the current state: 0 means simulation has still to be done; -1 means simulation is currently running; 1 means simulation is finished. If the model finds a record with simtag=-1 at startup it will replace this item with -99. Furthermore, there can be created a table step_parm with the same length as step_list and having a number of columns beside the item step
The pre- and postprocessing scripts can relate to these table and alter the inital values or other parameters and collect the results as required for each step. The table step_list may contain additional fields that are used to modify (override) the simulation task at runtime:

climate_id	replaces the climate data of the selected record in field_description
soil_id	replaces the soildata of the selected record in field_description
fl_id	replaces the management data of the selected record in field_description with the management of the specified fl_id
obs_id	replaces the observation data of the selected record in field_description with another field given by obs_id

This way it is possible to create a simulation scenario as combination of the management of a given plot with several different climates and/or soils etc.

Here is an example where 17 climate datasets are applied to explain this in more detail. The climate data are already in the database and should have been checked to avoid inconsistencies. In this case we have to prepare only the table step_list containing the field step, climate_id and simtag

This command builds a table with all available climate stations:

```
create table step_list as
select row_number () over() as step, climate_id ,  0 as simtag from climate_station
```

The following batch call will simulate the plot with fl_id 41 in the database cnp_gcef using the original data formanagement, soil and initial conditions in combination with each of the climate data from the step_list and collect the SOC results from each run using the post-processing query in the file my_step_poq.sql that should be located in the working directory of CNP

```
cnpx_gui.exe DB=cnp_gcef  STEP ID=41 GO POQ=my_step_poq.sql
```

The content of my_step_poq.sql is intended to collect the amount of Csom at the end of each simulation year within the table my_step_results (please don't forget to create this table beforehand):

```
insert into my_step_results (step,yr,c_som)
select step,yr,c_som
from cnp_result rs, site_state ss ,step_list sl
where rs.fl_id = ss.fl_id and mm=12 and sl.simtag=-1
and ss.status = 1
order by yr
```

Another application of the STEP mode will be demonstrated in the following with the implementation of a sensitivity analysis.

The task is to analyse the sensitivity of the initial values for SOC0, total (P_t0) and available Phosphorus (Pav0) on the Pav over time. To this end the table step_parm is generated containing a list of steps (1..150) each with a random sample of the initial parameters. Further, the table step_list contains the same list of step where each record has a simtag that signals the current state: 0 means simulation has still to be done; -1 means simulation is currently running; 1 means simulation is finished. If the model finds a record with simtag=-1 at startup it will replace this item with -99. The pre- and postprocessing scripts can relate to these tables and alter the inital values and collect the results as required for each step.

```
# generation of table step_parm
# clean up
rm(list=ls())
# load libraries
library(RPostgres)
library(ggplot2)
library(lhs)
set.seed(10534)
x<-data.frame(randomLHS(n=150,k=3))
print(summary(x))
x$soc<-qnorm(x$X1,mean=0.832 , sd=0.05)
x$p_t<-qnorm(x$X2,mean=54.663, sd=0.05)
x$pav<-qnorm(x$X3,mean=2.5   , sd=0.05)
print(cor(x$soc,x$pav))
print(cor(x$soc,x$p_t))
print(cor(x$pav,x$p_t))
# DB Verbindungen herstellen
cn1<-dbConnect(RPostgres::Postgres(),host='127.0.0.1',port='5432',user='cnp_user', password='cnp_go',dbname='meike_cnpdb')
mytab<-x
mytab$step<-0
for (i in 1 : length (x$X1) ) {
  mytab$step[i]<-i
}
dbWriteTable(cn1,"step_parm",mytab)
dbDisconnect(cn1)
```

STEP_PARM:

step	X1	X2	X3	soc	p_t	pav
[NULL]	0.7120462482	0.685141719	0.057335571	0.8599686266	54.6871062915	2.42112296
2	0.4725980326	0.2641728434	0.5278315808	0.8285629678	54.6314733322	2.5034910057
3	0.2693786447	0.6789365128	0.004170811	0.8012653353	54.6862363497	2.3681039925
4	0.441448005	0.5432366399	0.043965344	0.8246350492	54.6684295613	2.4146792092
...						
142	0.5847981068	0.2707157484	0.8079687801	0.8427091863	54.6324675138	2.5435217762
143	0.8983002428	0.2094244426	0.5097802185	0.8955962857	54.6225790037	2.5012258914
144	0.2243876264	0.4282084945	0.6047133689	0.7941270778	54.6539531476	2.5132783137
145	0.3796029309	0.3905848237	0.7815284814	0.81667381	54.6491102446	2.5388682855
146	0.8890686284	0.7596891274	0.5224787734	0.8930794959	54.6982651459	2.5028187889
147	0.9669105811	0.3489316927	0.9388505987	0.9238605211	54.643589686	2.5772598122
148	0.8196944505	0.0109914411	0.052775993	0.8777100633	54.5484668241	2.4190743264
149	0.7490645912	0.961976229	0.6376095514	0.8655774529	54.7517047184	2.5176038246
150	0.7673161353	0.8103412184	0.2225983176	0.8685018368	54.7069577202	2.4618276312

STEP_LIST: (steps 1..144 are finished; 145 is currently in process and 146..149 will be processed and 150 was crashed in a previous run; to create the table execute: create table step_list as select step, 0 as simtag from step_parm

step	simtag
1	1
2	1
3	1
4	1
....	
142	1
143	1
144	1
145	-1
146	0
147	0
148	0
149	0
150	-99

Further we need a table to collect the results for all steps:

```
CREATE TABLE public.step_results (
        fl_id int4 NULL, mm int4 NULL,yr int4 NULL, year_num int4 NULL,   n_m_om float8 NULL,
        n_ops float8 NULL, c_ops float8 NULL, c_som float8 NULL, c_org float8 NULL,
        c_lts float8 NULL, n_som float8 NULL, n_org float8 NULL, c_mic float8 NULL,
        c_rep float8 NULL, bat float8 NULL, n_flush float8 NULL, n_m_fom float8 NULL,
        bd float8 NULL,  pwp float8 NULL, a_age float8 NULL, s_age float8 NULL, l_age float8 NULL,
        c_m_tot float8 NULL, c_m_fom float8 NULL, sc_id int4 NULL, pset int4 NULL, haeq float8 NULL,
        n_free_fom float8 NULL,  c_imp_fom float8 NULL, n_imp_fom float8 NULL, p_min_os float8 NULL,
        pav float8 NULL, p_t float8 NULL, mpav float8 NULL, mp_t float8 NULL, step int4 NULL
         );
```

The preprocessing sql script transfers the values from step_parms into measurements to provide for each step different initial conditions. In the example shown below the simulation scenario is restricted to the plot with fl_id= 11

```
update measurements set meas_value = step_parm.p_t
from step_parm,step_list
where fl_id=11 and year_number=0 and m_ix=2    --Pt
and  step_parm.step=step_list.step
and  step_list.simtag=-1;

update measurements set meas_value = step_parm.pav
from step_parm,step_list
where fl_id=11 and year_number=0 and m_ix=1    --Pav
and  step_parm.step=step_list.step
and  step_list.simtag=-1;

update measurements set meas_value = step_parm.soc
from step_parm,step_list
where fl_id=11 and year_number=0 and m_ix=7    --soc
and  step_parm.step=step_list.step
and  step_list.simtag=-1;
```

The postprocessing sql script moves the results into table step_results:

```
INSERT INTO public.step_results
(fl_id, mm, yr, year_num, n_m_om, n_ops, c_ops, c_som, c_org, c_lts, n_som, n_org, c_mic, c_rep, bat, n_flush, n_m_fom, bd, pwp, a_age, s_age, l_age,
c_m_tot, c_m_fom, sc_id, pset, haeq, n_free_fom, c_imp_fom, n_imp_fom, p_min_os, pav, p_t, mpav, mp_t, step)
select fl_id, mm, yr, year_num, n_m_om, n_ops, c_ops, c_som, c_org, c_lts, n_som, n_org, c_mic, c_rep, bat, n_flush, n_m_fom, bd, pwp, a_age, s_age,
l_age, c_m_tot, c_m_fom, sc_id, pset, haeq, n_free_fom, c_imp_fom, n_imp_fom, p_min_os, pav, p_t, mpav, mp_t, step from cnp_result, step_list
where fl_id in (select fl_id from site_state where status=1)  and step_list.simtag=-1
order by step,fl_id,yr,mm;
```

To make sure that the proper field is included in simulation, the table site_state has to be prepared (in this example :set status=1 for fl-ID=11). With all preparations finished, we can start the model:

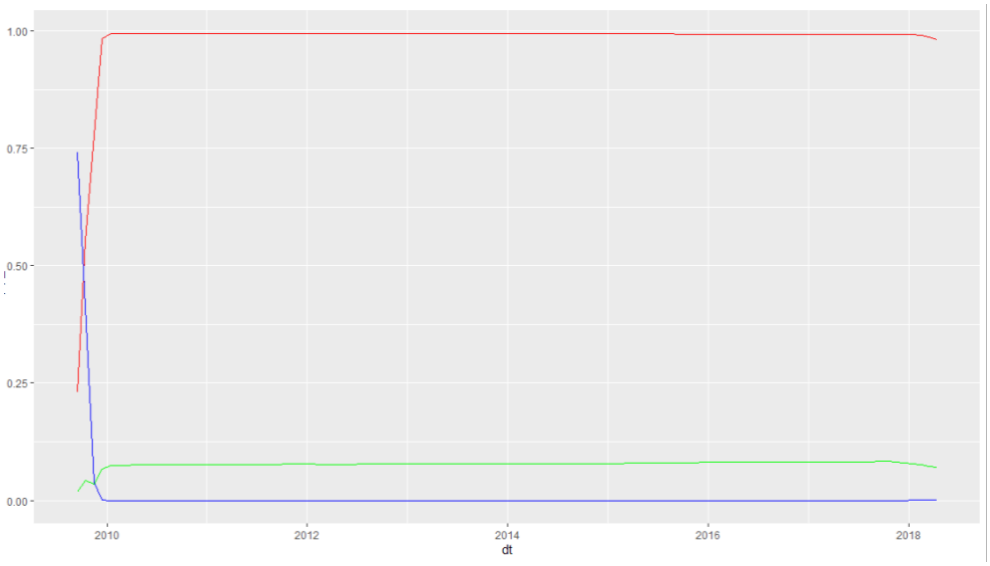
On Windows:
cnpx_gui.exe DB=my_database GO STEP PPQ=chk_ppq.sql   POQ=chk_poq.sql

On MacOS
open -a cnpx_GUI.app --args DB=my_database GO STEP PPQ=chk_ppq.sql   POQ=chk_poq.sql

In the results there is a table step_results with all result records that can be used to calculate the sensitivities with the following R script:

```
# analyse the results
#clean up
rm(list=ls())
# load libraries
library(RPostgres)
library(ggplot2)
 # DB Verbindungen herstellen
cn1<-dbConnect(RPostgres::Postgres(),host='127.0.0.1',port='5432',user='cnp_user', password='cnp_go',dbname=my_database')
 sql<-" select distinct mm, yr,'15'||'-'||mm::text||'-'||yr::text  as t from step_results order by yr, mm"
sds<-data.frame(dbGetQuery(cn1,sql))
sds$qssoc0<-0
sds$qspav0<-0
sds$qsp_t0<-0
sds$dt<-as.Date(sds$t,"%d-%m-%Y")
n<- length(sds$yr)
for (i in 1 : n ) {
amm<-as.character(sds$mm[i])
ayr<-as.character(sds$yr[i])
sql <- paste0( " select r.yr,r.mm, '15'||'-'||mm::text||'-'||yr::text as t, r.pav, r.p_t,p.soc as soc0,p.p_t as p_t0,p.pav as pav0 from step_parm p,
step_results r
    where r.year_num>0 and  r.step=p.step and r.mm=",amm," and r.yr=",ayr)
 cds<-data.frame(dbGetQuery(cn1,sql))
cds$dt<-as.Date(cds$t,"%dd%mm%yyyy")
## for sensitivity analysis using linreg compare paragraph 4.4 in Borgonovo & Plischke, 2016
lr<-lm(data=cds,pav~soc0+pav0+p_t0)
print(summary(lr))
sx1<-sd(cds$soc0)
sx2<-sd(cds$pav0)
sx3<-sd(cds$p_t0)
sy<- sd(cds$pav)
## sensit auf SOC change:
sens_csoc0<-(lr$coefficients[2]*sx1/sy)
sens_cpav0<-(lr$coefficients[3]*sx2/sy)
sens_cp_t0<-(lr$coefficients[4]*sx3/sy)
qsc_soc0<-sens_csoc0^2
qsc_pav0<-sens_cpav0^2
qsc_p_t0<-sens_cp_t0^2
sds$qssoc0[i]<-qsc_soc0
sds$qspav0[i]<-qsc_pav0
sds$qsp_t0[i]<-qsc_p_t0
}
dbDisconnect(cn1)
gs1<-ggplot(sds)+geom_line(aes(x=dt,y=qsp_t0*10),color="green") + geom_line(aes(x=dt,y=qssoc0),color="red")+
        geom_line(aes(x=dt,y=qspav0),color="blue")
print(gs1)
```

The chart shows the temporal course of the sensitivity of SOC (red), Pav (blue) and P_ (green) – where the latter is enlarged by factor 10. Obviously SOC0 is dominant for Pav while its initial value is of less importance and also P_t has only very little influence



Here is another example (shell script for MacOS) that demonstrates how to simulate first all plots within the database with following balance calculation. The balance results are show in the terminal and, for C balance; exported into a CSV file that is then opened with the excel application.

```
#!/bin/zsh
adb=oksana3
port=5432

#prepare the site_state table
psql  -h 127.0.0.1 -p $port  -U cnp_user -d $adb -c "update site_state set status=1"

# run the model
open -W ./cnpx_GUI.app --args DB=$adb GO BAL

# show n-Balance results in terminal
psql  -h 127.0.0.1 -p $port  -U cnp_user -d $adb -c "select * from nbil.general_balance where element='N' order by fl_id"

# export C-balance results as csv file ...
psql  -h 127.0.0.1 -p $port  -U cnp_user -d $adb -c "\copy (select * from nbil.general_balance where element='C') to 'svoutput.csv' with CSV DELIMITER ';' HEADER"
#... and open it in excel
open -a /Applications/Microsoft\ Excel.app ./svoutput.csv
echo "script finished"
```

2.14 Backup and restore the database on system level

It is recommended to regularly produce copies of the database. There are different ways to do so. In the following we describe the steps on system level.

Open a terminal (on Mac) or a cmd (on windows) window.

On windows should be executed following steps (that may have to be adapted to the actual conditions:

set pgr="c:\Program Files\PostgreSQL**15**\bin\"

set PGPASSWORD=**cnp_go**

set dbname=**your_database**

%pgr%pg_dump -d %dbname% -f ***%dbname%_dump.sql*** -h ***127.0.0.1*** -p ***5435*** -U ***cnp_user***

On mac there is only one step required:

pg_dump -d ***db_name*** -f ***db_dump.sql*** -h ***127.0.0.1*** -p ***5435*** -U ***cnp_go***

In the result you get an SQL-file that can be used to restore the complete database

To restore the database on a windows system under a new name the steps are as follows:

set pgr="c:\Program Files\PostgreSQL**15**\bin\"

set PGPASSWORD=**cnp_go**

%pgr%createdb -U ***cnp_user*** -h ***127.0.0.1*** -p ***5432*** -T template0 ***new_db***

%pgr%psql -U ***cnp_user*** -d ***new_db*** -h ***127.0.0.1*** -p ***5432 < db_dump.sql***

..and similarly on mac:

createdb -U ***cnp_user*** -h ***127.0.0.1*** -p ***5432*** -T template0 ***new_db***

psql -U ***cnp_user*** -d ***new_db*** -h ***127.0.0.1*** -p ***5432 < db_dump.sql***

3 Theoretical Background

3.1 Model structure

The general construction of the CNP model is shown in **Error! Reference source not found.**. 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 several FOM pools that are characterized by the origin of organic matter (OM).

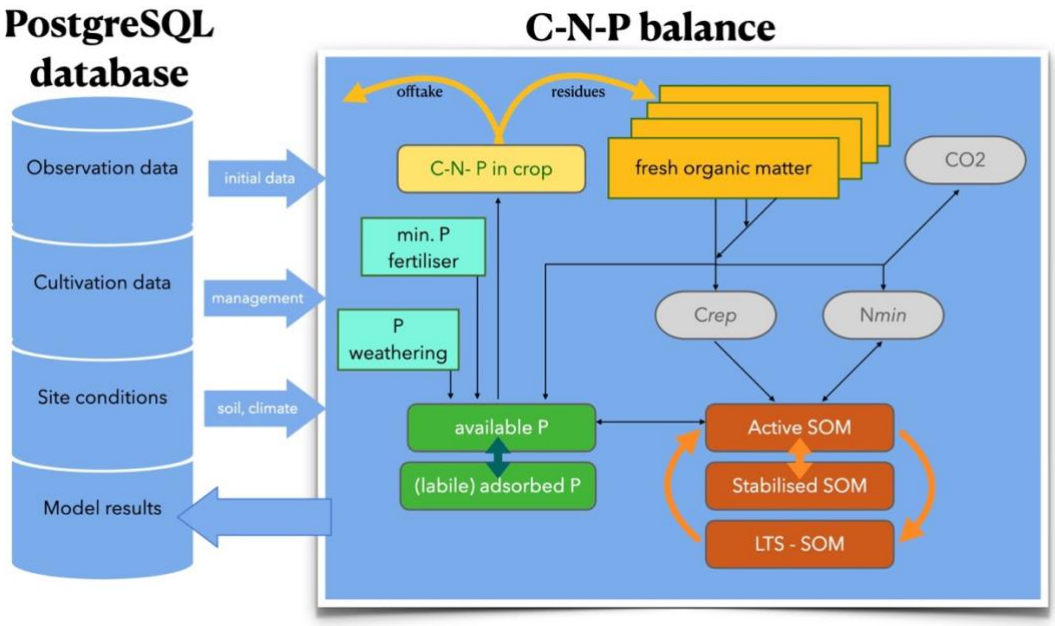


Figure 20: C.N-P general approach.

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 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 topsoil layer to transform the units.

Generally, a topsoil 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:

$$M = CONC \cdot \rho_B \cdot h \cdot (1 - \frac{GC}{100}) \cdot 10^4 \qquad \text{Equation 1}$$

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: CNP 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 additionally characterize 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:

- organic amendments (OA)
- by-products that are left on the field after harvest such as straw and leafs (BP)
- crop residues such as roots and stubble (RT and ST)
- ploughing up of intercrop

For a mustard intercrop is a routine available to estimate the grown biomass if -99 is specified as yield. In this case the vegetation should be finished with a 'ploughing up' action. The calculation of aboveground biomass is based on the results of Koch et al. 2017 who found

$$BM = -2.937 + 1.16 * R + 0.021 * T$$

With

R : average rainfall in mm d^{-1}(original from sowing day to 30.09.)

CNP approach: $R = (0.5 * R_8 + R_9)/45$ ($R_{8,9}$ Rainfall of August and September)

T : sum of air temperature (original from day 19 to 31 after sowing)

CNP approach: $T = T_9 * 12$ (T9 : average temperature in September)

Within a 'ploughing up' event BM (as shoot) together with the calculated root biomass are added to soil.

The amount of fresh organic matter input from organic amendments (OA_{fm}) given in the scenario data is multiplied with the according dry matter content.

$$OA_{dm} = OA_{fm} * DM_{oa}$$ Equation 2

For the other both pathways, we start with basic definitions to calculate the mass fluxes that will be expressed in kg/ha from the given yield data that is given in dt/ha:

$$MP_{dm} = Y_{mp} * dm_{mp}$$ Equation 3

where

MP_{dm} : dry matter yield of the main product (dt/ha)

Y_{mp} : yield of main product with defined dry matter content (dt/ha)

dm_{mp} : defined dry matter part of the main product [0..1]

The amount of root mass is defined by a linear equation:

$$RT_{dm} = FIX_r + BIX * MP_{dm}$$ Equation 4

where

FIX_r: yield-independent part of root dry matter (dt/ha)

BIX: Belowground index. Yield-dependent part of root dry matter (-)

Similar to root dry matter, we assume also for the dry mass of stubble a linear relation to dry matter yield. We have a constant part of Stubble dry matter (FIX_s), a yield dependent factor for the total above ground residue dry mass (RIX) and a factor for the stubble part of this yield dependent growth (STIX). The dry-matter of by-products is however completely yield dependent:

$$ST_{dm} = FIX_s + RIX * STIX * MP_{dm}$$ Equation 5

$$BP_{dm} = RIX * MP_{dm} - ST_{dm}$$ Equation 6

where

ST_{dm} : dry matter of stubble (dt/ha)

BP_{dm} : dry matter of by-product (dt/ha)

FIX_s : part of stubble dry matter, independent on yield result (dt/ha)

RIX represents the relation between the yield dependent part of aboveground residues to the dry matter yield of the main product and STIX represents the yield dependent part of stubble in relation to the yield dependent part of all aboveground residues.

For each organic matter input XX (where XX may be OA, BP, ST or RT) the actual element fluxes for C follows from the product of the dry matter amount with the dry matter C concentration of this compartment (C_{dm}) while the C/N (CNR_{om}) and C/P (CPR_{om}) ratio are additionally used to quantify the fluxes for N and P, respectively.

$$C_{om} = XX_{dm} \cdot C_{dm}$$ Equation 9

$$N_{om} = XX_{dm} \cdot C_{dm}/CNR_{om}$$ Equation 10

$$P_{om} = XX_{dm} \cdot C_{dm}/CPR_{om}$$ Equation 11

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; rt_ix=30; sh_ix=553, (the latter both link to cdyopspa.item_ix)
for crop item 9 we find in cdypflan:
fix_r=11.628; bix=0.116; fix_s = 0; rix=0.941; stix=0.15;
for root item 30 we find in cdyopspa:
c_dm= 0.42 cnr=41 cpr=53
for residue (and stubble) item 1001 we find also in cdyopspa:
c_dm=0.45 cnr=77.58 cpr=109
the organic amendment with slurry requires the look up of item 555 (slurry (pig)) in **cdyopspa**: *item_ix* to find : dm=0.1; c_dm=0.4 ; cnr=13 ; cpr=120

Calculation (analogue to Eq. 2 to 10)
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*' ! otherwise MP_{dm}=0)
MP_{dm} = 80 dt/ha * 0.86 = 68.8 dt/ha

Stubbles:
ST_{dm}= 0 + 0.941 * 0.15 * 68.8 dt/ha = 9.711 dt/ha
C_{st} = 9.711 dt/ha * 0.45 * 100 ≈ 437 kg/ha (*100 to get kg/ha)
Straw:
BP_{dm} = 68.8 dt/ha * 0.941 – 9.711 dt/ha ≈ 55 dt/ha;
C_{bp} = 55 dt/ha * 0.45 * 100 ≈ 2476 kg/ha (*100 to get kg/ha)
Roots:
RT_{dm}= 11.629 + 0.116 * 68.8 dt/ha = 19.61 dt/ha
C_{rt} = 19.61 * 0.42 * 100 ≈ 824 kg/ha (*100 to get kg/ha)

Table 2 Total FOM-C input

source	FOM-carbon in kg/ha
roots	824
stubble	437

By-product (straw) applied if macode=9 (by-prod.left)	2476
organic amendment (slurry)	800
sum	4537

3.2.1 Permanent grassland

Other than in arable crops, for permanent grassland a continuous flux of organic material is assumed. The model considers two sources: roots and green biomass as continuous litter fall. The monthly amount is given in fix_r (rhizodeposition) and fix_s (litter fall). In both cases the parameter values are considered as dry matter. The carbon input is calculated using the parameters from cdyopspa which is related via rt_ix and gm_ix to cdypflan.
A crop of permanent grassland starts with a specific action (start grassland; action_id=12) and will process cutting actions (action_id=6) to get yield data that are required for P dynamics and also used for the element balance.
On request, C-N-P can be extended to include also livestock grazing. The SQL-script to change the data base can be downloaded from GIT using the SQL-interface of the model. After executing the script and restarting the model it is possible to up- and down-force cattle units to/from the grassland.

3.2.2 Catch crops

Catch crops that don't require yield information in the management data are identified by a '(ZF)' as part of the name. If the management data show yield=0 for such a catch crop, the model will calculate a yield using monthly values of air temperature T_m and rain R_m (which includes irrigation water) that are transformed into AET_m using the empirical equation: $AET_m = 1.44*T_m + 0.44*R_m$
In the next step, the dry matter yield YLD_{dm} is calculated using an equation given by Knoblauch (2022)

$$YLD_{dm} = 0.524*\Sigma\ AET_m - 40.3$$

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.

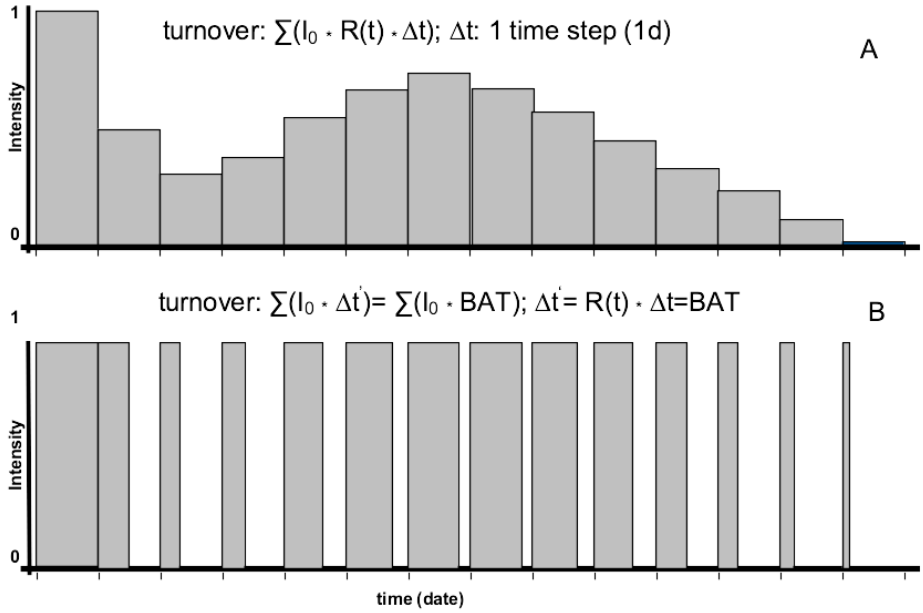


Figure 21: Schematic representation of the turnover calculation by the standard approach (A) and the BAT approach due to transformation of time steps (B)

The scheme in **Error! Reference source not found.** demonstrates the principle how different intensities of uniform time steps (**Error! Reference source not found.** A) are transformed into time steps of different length and uniform intensity (**Error! Reference source not found.** 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 (**Error! Reference source not found.** 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 CNP 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)
}
```

C-N-P is working in monthly time steps. Therefore, the annual value of BAT (BAT_{yr}) is disaggregated into monthly values (BATm) using a temperature function (F_T) to generate the weights for each month based on the average air temperature (T_m) of this month: $BAT_m = BAT_{yr} * \frac{F_T(T_m)}{\sum_{m=1}^{m=12} F_T(T_m)}$; $F_T = \max\left(1, Q_{10}^{\frac{T-35}{10}}\right) with\ Q_{10} = 2.1$

Adaptations of BAT for conservation tillage

The general (implicit) assumption in CNP 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 CNP 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.

$$\alpha = \exp\left(\sqrt{F_R \cdot F_D}\right) \qquad \text{Equation 12}$$

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):

$$F_D = FP \cdot 0.2844 - 1.4586$$ Equation 13

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:

$$F_R = \frac{BAT_t}{365}$$ Equation 14

If the top soil is annually mixed by ploughing all three assumed soil layers have the same weight G_t=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/α and 1/α^2.
This leads to the relation between the BAT values of a tilled (BAT_t) and a non-tilled (BAT_{nt}) system:

$$BAT_{nt} = \frac{BAT_t}{3} \cdot (1 + \frac{1}{\alpha} + \frac{1}{\alpha^2})$$ Equation 15

3.4 Soil organic matter turnover

3.4.1 Turnover of carbon

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

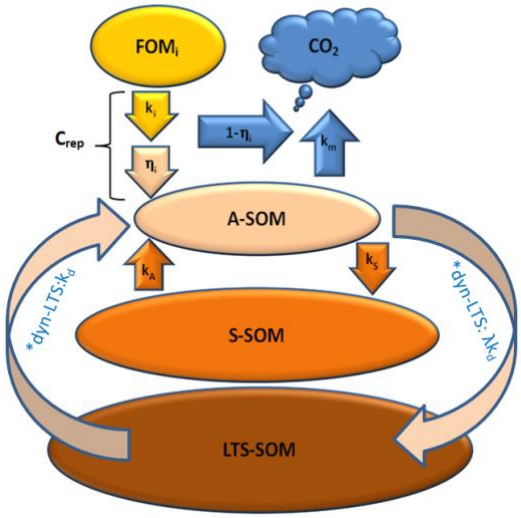


Figure 22: Conceptual pools and fluxes within the soil organic matter module in CNP.

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.

$$C_{org} = C_A + C_S + C_{LTS} + \alpha \cdot C_{FOM} \qquad \text{Equation 16}$$

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 C_{FOM} 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 (for model version > 20.22.27). For α *>0* also the result values of *n_som, n_org, p_t,* and *mp_t* are affected by the remaining FOM.

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}:

$$\frac{dC_{FOM}(t)}{dt} = \dot{C}_{FOM} = k_{FOM} \cdot C_{FOM}(t) \qquad \text{Equation 17}$$

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}:

$$\frac{dC_{rep}(t)}{dt} = \dot{C}_{rep} = \dot{C}_{FOM} \cdot \eta_{FOM} \qquad \text{Equation 18}$$

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}:

$$\frac{dC_A(t)}{dt} = \dot{C}_A = \dot{C}_{rep} + k_a \cdot C_S(t) - k_s \cdot C_A(t) - k_m \cdot C_A(t) - \dot{C}_{LTS} \qquad \text{Equation 19}$$

Consequently, the carbon turnover of the stable SOM pool is:

$$\frac{dC_S(t)}{dt} = \dot{C}_S = k_s \cdot C_A(t) - k_a \cdot C_S(t) \qquad \text{Equation 20}$$

Table 3: CNP 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 on the selected mode (with or without saturation).

3.4.2 Model initialization from RepIX

We call the relation of C_{rep} to BAT "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. Data from several long term experiments where so called "optimum" values for SOC content was published were used to transform this SOC content into the corresponding RPX value. An analysis revealed that these characteristic RPX_{opt} values are closely related to soil texture.

Following the approach of Franko&Rühlmann(2022) we can express the C reproduction flux for this optimum SOM level as: $C_{rep}^{opt} = 1386.62 + 7.76 * (clay + silt) - \frac{396397}{BAT^2}$.

Similar to the VDLUFA approach, it is possible to assign a C flux difference ($\Delta C_{rep} = C_{rep} - C_{rep}^{opt}$) between actual and optimal C-flux (analogue to the HAEQ balance) to the different VDLUFA classification levels.

The *ΔCrep* value can be used to assess the SOC level in the same way as the management in the VDLUFA balance using the classification rules in Table 2.

Table 1. VDLUFA classification and corresponding ranges of HAEQ and Crep (Crep = 1.6 x HAEQ).

VDLUFA classification	HAEQ balance	C flux difference ΔC_{rep}
A: very low	< -200	< -320
B: low	-200...-75	-320... -120
C: normal (optimum)	-75...100	-120... 160
D: high	100...300	160... 480
E: very high	> 300	> 480

In CNP is this mode activated when the option 'initialize from RepIX was selected. For more convenience, here is used a real number that varies between -2.5 and +2.5 instead of strict classification borders. When RepIX (the SOM level indicator) is set to 0 it indicates the 'optimum' level. Negative and positive values describe levels below or above this optimum.

The resulting *ΔCrep* value is calculated accordingly as $\mathrm{MIN}(500, 273.9 * RepIX * \exp(RepIX * 0.0482))$ and reflects the ranges shown in the table above.

3.4.3 Nitrogen fluxes

Nitrogen fluxes modelled by CNP are closely connected to the carbon turnover. The CNP 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 CNP 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:

$$\frac{dN_{FOM}(t)}{dt} = \dot{N}_{FOM} = \dot{C}_{FOM} \cdot \frac{1}{\gamma_{FOM}} \qquad \text{Equation 21}$$

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):

$$\frac{dN_{rep}(t)}{dt} = \dot{N}_{rep} = \dot{C}_{rep} \cdot \frac{1}{\gamma_A}$$ Equation 22

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}):

$$\frac{dN_A(t)}{dt} = \dot{N}_A = k_m \cdot C_A(t) \cdot \frac{1}{\gamma_A}$$ Equation 23

The total nitrogen flux into (positive values) or out of (negative values) the pool of mineral nitrogen (N_m) results from Equation 21, Equation 22 and Equation 23:

$$\frac{dN_m(t)}{dt} = \dot{N}_m = \dot{N}_A + \dot{N}_{FOM} - \dot{N}_{rep}$$ Equation 24

For better illustration of the nitrogen flux calculations in CNP (Figure 23) 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.

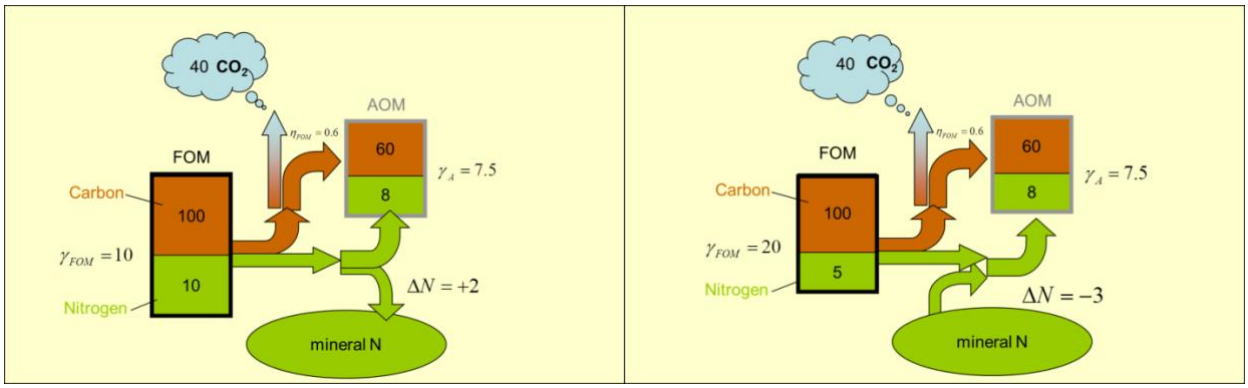


Figure 23: Examples for net-N-mineralization and - immobilization.

Table 4: CNP 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

Organic amendments like slurry contain both, organic and inorganic nitrogen. While the organic part processed as described above, is the inorganic part an immediately available nutrient source for the crop, comparable to mineral fertilization. Therefore, the parameter set of organic compounds (in CDYOPSPA) contains several data related to C/N ratio in order to separate both forms. The C/N ratio of the organic part (CNR), the (alternative)

C/N ratio of the substrate (CNR_ALT) and additionally MOR describing the relation of mineral nitrogen to organic nitrogen in the substrate. There is redundancy within these three parameters as $MOR = \frac{CNR}{CNR_{ALT}}$ -1. Or, depending on what data are provided: $CNR = CNR_{ALT} * (1 + MOR)$.

3.4.4 Phosphorus fluxes

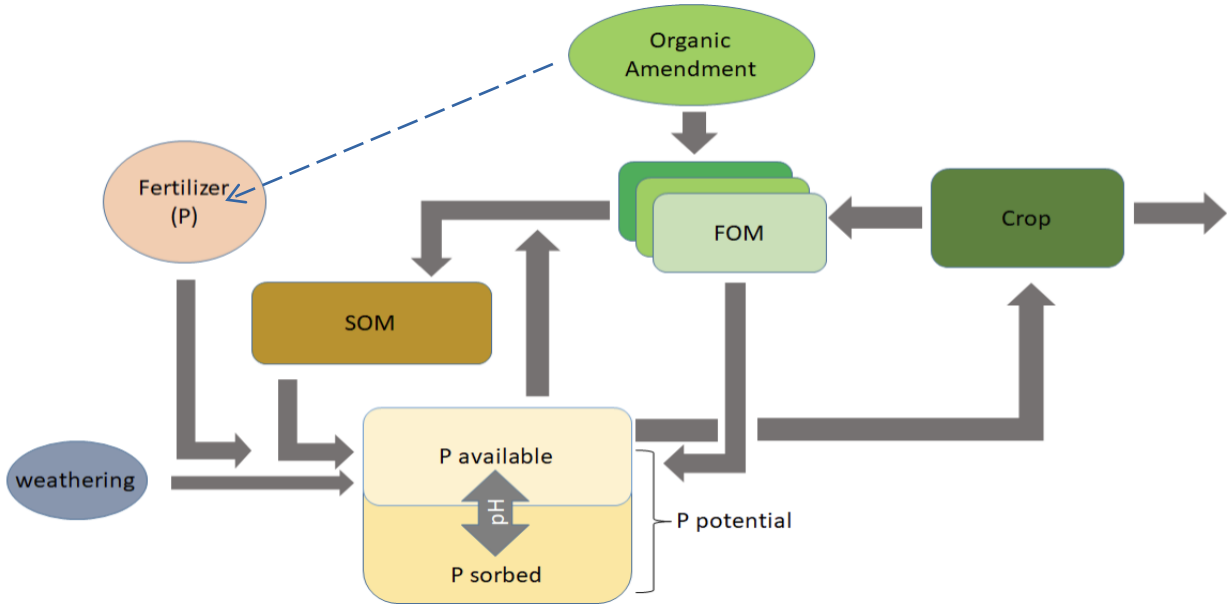


Figure 24: Schematic representation of P-Fluxes

Beside the P amount bound in SOM (P_{org}), the CNP model considers the potential plant available phosphorus (P_{pot}) is split into a plant available (P_{avl}) and a sorbed pool that is not available for plant uptake (P_{nav}). The plant available fraction P_{avl} is represented by the P extracted with the calcium acetate lactate method (CAL) and comprises P in solution and the easily plant available P species. P_{avl} and P_{nav} are both are connected to each other via a pH dependent sorption/desorption exchange process that is striving for a steady state. Another experimental value considered in CNP is the total amount of P (P_{tot}) as sum of P_{pot} and P_{org} and is analogue to P extracted with the HNO_3+ HCl method. Here is ignored the amount of P within the FOM pools assuming that at times of soil sampling the FOM stock is negligible small. The amount of P_{org} is given from the C amount of each SOM pool and the specific C/P ration of the soil organic matter.
Phosphorus can be added to soil as organic amendment or as mineral fertilizer. Organic substrates may contain a part of their phosphorus in mineral form. Therefore, an organic amendment is handled as a combination of adding a pure organic compound plus a pure mineral P addition similar to mineral fertilisation. All mineral P is added to the P_{avl} pool and then a subject of further processes.

The dynamics between pools is given by following equations:

$$\dot{P}_{avl} = k_{nav2avl} * P_{nav} - k_{avl2nav} * P_{avl} \quad \text{Equation 25}$$

$$\dot{P}_{nav} = k_{avl2nav} * P_{avl} - k_{nav2avl} * P_{nav} \quad \text{Equation 26}$$

where k_{x2y} is the rate constant for the flux from pool x to pool y

Further, we follow the approach of Coleman at al. (2017) where both k values are modified according to the soil pH value:

$$dP_{a2n} = \hat{k}_{avl2nav} * P_{avl}(t) \quad \text{Equation 27}$$

$$dP_{n2a} = \hat{k}_{nav2avl} * P_{nav}(t) \quad \text{Equation 28}$$

$$\hat{k} = \frac{k*pH}{7}; pH \leq 7 \quad \text{Equation 29}$$

$$\hat{k} = k * (2 - \frac{pH}{7}); pH > 7 \quad \text{Equation 30}$$

Furthermore, we define the indicator for P availability following the approach of Vadas et al. (2012) as PSP

$$PSP = \frac{P_{avl}}{P_{avl}+P_{nav}} \quad \text{Equation 31}$$

but with a modified pedotransfer function that was derived from datasets from german experiments.

$$PSP = pcl * Clay + ppa * P_{avl} + poc * SOC + pcloc * Clay * SOC + pavoc * SOC * P_{avl} + icpt \quad \text{Equation 32}$$

with

icpt	= 0.0919667	pcl	= -0.0080484	poc	= -0.0473169
ppa	= 0.0237138	pcloc	= 0.0055262	pavoc	= -0.0066461

This relation can be used to initialize the amount of P_{tot} that is here taken as sum of P_{org} and P_{pot} and also the other pools assuming a steady state between all three pools:

$$P_{pot} = (P_{nav} + P_{avl}) = \frac{P_{avl}}{PSP} \quad \text{Equation 33}$$

To make the model operational it is necessary to provide a value for $k_{sac2avl}$ (kappa).

The missing $k_{nav2avl}$ value can be derived from the steady state condition between both pools considering the actual size of P_{avl} as well as the actual value of PSP calculated from the pedotransfer function as f(clay,soc,P_{avl})

$$k_{avl2nav} = \frac{k_{nav2avl}*(1-PSP(t))}{PSP(t)} \quad \text{Equation 34}$$

The overall P dynamics include the turnover of any pool in SOM or FOM. During the turnover of each OM pool the matter transfer is described by C-dynamics (see 3.4.1) while P fluxes are calculated according to the C/P ratios resulting in a similar pattern as shown for the N flux in Figure 24. Any net P transfer (dP_{trf}) from mineralization ($dP_{trf}>0$) or immobilization ($dP_{trf}<0$) is connected with P_{avl} , the available P-pool.

Other considered processes that affect the P_{avl} amount are a constant weathering rate (dP_{wth}), plant related P-uptake (dP_{upt}) that is evenly distributed over all vegetation time and application of fertilizer (dP_{frt}) at the specified month. Because organic amendments may also include a specific amount of easily plant available P, there is one more flux, that we call P-flush (P_{fls}), that is treated like mineral fertiliser. The amount of P_{fls} is calculated from the added C amount (C_{aom}), the relation between mineral and organic P (PMOR), and the C/P-ratio in the organic part (C_{org}/P_{org}) of the added substrate. The total amount of added P (P_{add}) is given by $P_{add} = \frac{C_{aom}*(1+PMOR)}{CPR}$ and the mineral part P-flush is represented by $P_{fls} = \frac{P_{add}*PMOR}{(1+PMOR)} = \frac{C_{aom}*PMOR}{CPR}$.

These fluxes from outside affect only the P_{avl} pool. Therefore, before the internal re-distribution between P pools the available pool is updated:

$$P_{avl}(t) = P_{avl}(t-1) + dP_{wth} + \sum dP_{trf} + dP_{frt} + dP_{fls} - dP_{upt}$$ Equation 35

In agricultural data there is sometimes given the P amount in terms of P2O5. The transfer factor from P2O5 to P is 0.436 according to the German fertilizer regulation (DVO from 5.12.2012)

3.4.5 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 CNP 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 integrated to CNP and also available with the OPTIMIZER (http://www.ufz.de/index.php?en=39727) that can be easily connected with simulation models 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}:

$$C_{dec}(0) = MIN[2, C_{org}(0) - C_{LTS}(0)]$$ Equation 36

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:

$$C_{LTS}(0) = C_{org}(0) \cdot F_{LTS}$$ Equation 37

with

$$F_{LTS-SOM} = \frac{r_2 \cdot r_3 \cdot PWP}{r_1 \cdot r_2 \cdot PV + r_3 \cdot PWP \cdot (r_2 - r_1) + r_1 \cdot FC \cdot (r_3 - r_2)}$$ Equation 38

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 (Equation 39, Equation 40) assuming steady state conditions.

$$C_A(0) = C_{dec}(0) \cdot \frac{k_a}{k_a + k_s}$$ Equation 39

$$C_S(0) = C_{dec}(0) - C_A(0)$$ Equation 40

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}).

$$\gamma_{LTS}(t) = \frac{8.5 \cdot \gamma_{SOM}(0) \cdot C_{LTS}}{8.5 \cdot C_{org}(0) - \gamma_{SOM}(0) \cdot C_{dec}(t)}$$ Equation 41

So far, this is a description of initializing all pools in equilibrium. While this is the standard procedure, it may be required to put the pools out of balance at initial time specifying additional information to initialise the SOC pools. One option is the input of an initial Cmic value that is the internally transformed into the related C-AOM and C-SOM is calculated as difference: C-SOM= SOC – C-LTS – C-AOM. The other option is the input of a pS value to characterise the imbalance between A- and S-SOM:

$$pS_{dec} = \log_{10}\left(\frac{C_{A-SOM}}{C_{S-SOM}}\right) - \log_{10}\left(\frac{k_{S2A}}{k_{A2S}}\right)$$ (42)

pS : indicator for the distance of the unprotected SOM-amount to its steady state

Assuming $z = 10^{(pS_{dec})}$, R=k_{S2A}/k_{A2S} and D= $C_{A\text{-}SOM}+C_{S\text{-}SOM}$ = SOC-C_{lts} we calculate the pool sizes:

$C_{S\text{-}SOM}$= D* R/(R+z) and $C_{A\text{-}SOM}$=D*z/(z+R)

3.4.6 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, CNP 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:

$$SOC = \alpha \cdot (A_\mu + A_m + A_M)$$ Equation 43

α: areal specific carbon concentration

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

$$C_{LTS} = \alpha \cdot A_\mu$$ Equation 44

$$C_{LTS} = SOC \cdot \frac{A_\mu}{A_\mu + A_m + A_M} = SOC \cdot F_{LTS}$$ Equation 45

F_{LTS}: factor depending on soil structure, 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).

The amount of C_{LTS} may be limited. After this point all SOC increase results only from C accumulation in the decomposable part. If LTS-limitation should be considered, the option *lts_lim=y* has to be specified within the settings section of the ini-file. The standard algorithm follows the paper of *Wiesmeier et al. 2014* but can be changed to *Wenzel et al. 2022* with *mod_lts=wz*.

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 CNP 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:

$$\Delta C_{LTS} = -\Delta C_A = C_{LTS}(t_{i+1}) - C_{LTS}(t_i) \qquad \text{Equation 46}$$

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:

$$N_{flx} = \Delta C_A \cdot \frac{\gamma_A - \gamma_{LTS}}{\gamma_A \cdot \gamma_{LTS}} \qquad \text{Equation 47}$$

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 element balances

We can calculate the element balance in two ways:

(i) Input -output balance of the field neglecting the turnover processes in soil.
(ii) demand – supply balancing the nutrient demand of the growing crop and the available nutrients from plant available inputs including nutrient mobilization from organic sources.

While input-output balances make sense for C, N and P the demand -supply calculation is reasonable only for N and P because the C demand of the growing crop can be supplied from atmosphere without a sensible limit.

Input-output balance

CNP provides C, N and P-balancing for aggregated and annual values.
The final balance expresses how much of the element in question is left on field with the general approach:
field balance= input-output

For an extended balance calculation, it may be reasonable to include the stock change as well:

Extended field balance= input-output-Δstock

The individual parts of the carbon balance calculation are:

C_{MP} – carbon in main product
C_{ByP} – carbon in by-product
C_{St} – carbon in stubbles (or similar plant residues)
C_{root} – carbon in root material
C_{seeds}– carbon added with seeds
C_{OrAm} – carbon added with organic amendments
C_{Off} – total carbon offtake from field with biomass
dC_{SOM} – change of carbon in soil organic matter

Depending on the farming strategy, the by-product may be used (_u) or left (_l) on field and is therefore split in two parts : $C_{ByP}= C_{ByP\_u}+ C_{ByP\_l}$

The total input from crop residues includes a (potential) part of the by-product, the stubbles and the roots: $C_{CrRes}= C_{ByP\_l} + C_{St} + C_{Root}$

Beside crop residues (C_{CrRes}), the overall input (C_{in}) consists of organic amendments (C_{OrAm}) and seeds (C_{seeds}): $C_{in}= C_{CrRes} + C_{OrAm} + C_{seeds}$.

The biomass offtake consists of the main product and a (potential) part of the by-product: $C_{Off}= C_{MP} + C_{ByP\_u}$ while the uptake includes also the amount of stubble and roots.

Finally, the SOM change can be calculated from the model results: $dC_{SOM}= C_{SOM}(t_1)-C_{SOM}(t_0)$

For the N balance, we use the same elements as described above, replacing C with N. In addition, N deposition from the atmosphere, symbiotic and non-symbiotic N-fixation and N inputs from mineral fertilizers are considered. N deposition and non-symbiotic N-fixation is corrected regarding the actual time interval (if not the whole year is covered by the scenario).

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 **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*. Parameter values can be found at Stein-Bachinger et al. (2004).

The symbiotic N-fixation N_{sym} of a legume crop with the yield *YLD* (*quantity* in table **cultivation**) is given by $N_{sym} = ndfa \cdot legshr \cdot N_{biomass}$ where *ndfa* and *legshr* have to be specified in table **leg_parm**. $N_{biomass}$ represents the nitrogen in below- plus above-ground parts of the crop at harvest.

The non-symbiotic N-fixation N_{nsy} is calculated in kg/ha/yr depending on the application of mineral N fertilizer (N_{fert}):

$$N_{nsy} = \begin{cases} 5; N_{fert} > 0 \\ 10; N_{fert} = 0 \end{cases}$$

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*DM*C_DM/CNR_ALT

The P balance is based on the similar elements as the C balance but also considers P weathering (defined as a constant rate within soil properties, but here corrected to the actual time interval if only a part of a year is covered by the scenario) as fertilizer input.

Demand-supply balance for N and P

The soil related demand-supply balance considers the nutrient flux from mineralisation that is known as *n_m_om* or p_min_os plus the N_flush from organic amendments from the previous CNP simulation in the table **CNP_nresult** and includes the actual fluxes from the turnover of FOM and SOM as well as the N-flush, that comes with the organic amendments as mineral nitrogen that is fast available for the crop.

The total crop demand is higher than the offtake from field balance and considers the nutrition of the whole crop including all parts that will be left on the field. All 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**.

The supply is calculated as the sum from mineralization flux and the n_flush between the last harvest events of individual years plus the added nutrients from external sources other than organic amendments.

More insight into the data structure concerning N-balances is given in chapter 4.3 Result tables.

Table 5: Calculation of crop related components of N-balance (*replace CNR_ALT with CPR_ALT to get P-balance*)

Component	Calculation (parameters from CDYOPSPA in bold types, parameters from CDYPFLAN in italics)
roots crop residues stubble	(*FIXr*+*BIX**YLD**DM_MP*)*YLD***C_DM/CNR_ALT** (YLD**DM_MP***RIX***STIX*+*FIXs*)***C_DM/CNR_ALT**
Crop main product	YLD**DM_MP***N_MP*
Crop by-product	YLD*(*RIX**(1-*STIX*))***C_DM/CNR_alt**

Beginning with model version 20.22.21, it is possible to start the balance calculation immediately after the scenario simulation, if the model is called from a batch file using the call parameter *BAL*. This works only together with the *autostart* parameter *GO* but includes also multiplot scenarios. The annual results of this balance calculations are recorded in the tables *nbil.gen_c_bilanz*, *nbil.gen_n_bilanz*, and *nbil.gen_p_bilanz* that have the same structure as the ccb_***x***_bilanz tables but collect the results from more than one plot. The aggregated balance results are compiled in table *nbil.general_balance.*

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

$$p(d_x) = p(d_1) + (\ln(d_x) - \ln(d_1)) \cdot \frac{p(d_2) - p(d_1)}{\ln(d_2) - \ln(d_1)}$$ Equation 48

d_i: diameter of particle class

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

Soil bulk density

It is possible to calculate soil bulk density using Equation 49 and Equation 50 following the approach of standardized bulk density TRD_s (Ruehlmann and Körschens, 2009) to find an appropriate value for the parameter b.

$$TRD = TRD_s e^{-b \cdot C_{org}}$$ Equation 49

$$TRD_s = 2.684 + 140.943 \cdot b$$ Equation 50

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

$$TRD_s = 1.78345 - 0.0081 \cdot clay$$ Equation 51

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

$$b = (1.78345 - 2.684 - 0.0081 \cdot clay)/140.943$$ Equation 52

$$b = -0.00639 - 5.747 \cdot 10^{-5} \cdot clay$$ Equation 53

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):

$$\rho_p = \frac{1}{\frac{Q_{om}}{\rho_{om}} + \frac{1 - Q_{om}}{\rho_m}}$$ Equation 54

ρ_m: density of mineral component in g cm^{-3}

ρ_{om}: density of organic matter component in g cm^{-3}

where $\rho_m = 2.659 + 0.003 \cdot clay$ Equation 55

and $\rho_{om} = 1.127 + 0.373 \cdot Q_{om} with Q_{om} = \frac{C_{org}}{55}$ Equation 56

Hydrological properties

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

$$PV = (1 - \frac{\rho_b}{\rho_p}) \cdot 100$$ Equation 57

PV: pore volume in VOL%

In the standard approach (with constant soil physical properties) the values of field capacity (Equation 58) and permanent wilting point (Equation 59) are calculated from soil texture using the pedotransfer function published by Lieberoth (1982).

$$FC = 3.40 + 0.85 \cdot ABT$$ Equation 58

FC: field capacity in VOL%

ABT: settleable components less than < 10 µm

$$PWP = 1.23 + 0.74 \cdot clay$$ Equation 59

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).

$$\Theta(\Psi) = \Theta_r + \frac{\Theta_s - \Theta_r}{(1 + (\alpha \cdot |\Psi|)^n)^m}$$ Equation 60

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

$$\Theta_s = 0.81 - 0.283 \cdot BD + 0.001 \cdot T$$ Equation 61

$$\Theta_r = 0.015 - 0.005 \cdot T + 0.014 \cdot C_{org}$$ Equation 62

$$\alpha = e^{(-2.486+0.025 \cdot S - 0.351 \cdot C_{org} - 2.617 \cdot BD - 0.023 \cdot T)} T$$ Equation 63

$$n = e^{(0.053 - 0.009 \cdot S - 0.013 \cdot T + 0.00015 \cdot S^2)}$$ Equation 64

$$m = 1$$ Equation 65

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.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{n}}$$ Equation 66

$$RMSE_{rel} = \frac{100}{\bar{O}} \cdot \sqrt{\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{n}}$$ Equation 67

$$ME = \frac{\sum_{i=1}^{i=n} (O_i - P_i)}{n}$$ Equation 68

$$ME_{rel} = \frac{100}{\bar{O}} \cdot \frac{\sum_{i=1}^{i=n} (O_i - P_i)}{n}$$ Equation 69

$$EF = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O}_i)^2}$$ Equation 70

$$SEM = \sqrt{\frac{\sigma^2}{n}}$$ Equation 71

$$r = \frac{\sum O_i \cdot P_i - \frac{1}{n} \cdot (\sum O_i) \cdot (\sum P_i)}{\sqrt{[\sum O_i^2 - \frac{1}{n} \cdot (\sum O_i)^2] \cdot [\sum P_i^2 - \frac{1}{n} \cdot (\sum P_i)^2]}}$$ Equation 72

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 (Equation 73) is not lower than the right-tail value of the Student's t-distribution (p=0.95, f=n-2):

$$T_0(r) = |r| \cdot \frac{\sqrt{n-2}}{\sqrt{1-r^2}}$$ Equation 73

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 CNP calibration with other approaches Akaike's Information Criterion should be calculated in its standard form:

$$AIC = 2 \cdot k + n \cdot \ln(\frac{\sum (O_i - P_i)^2}{n})$$ Equation 74

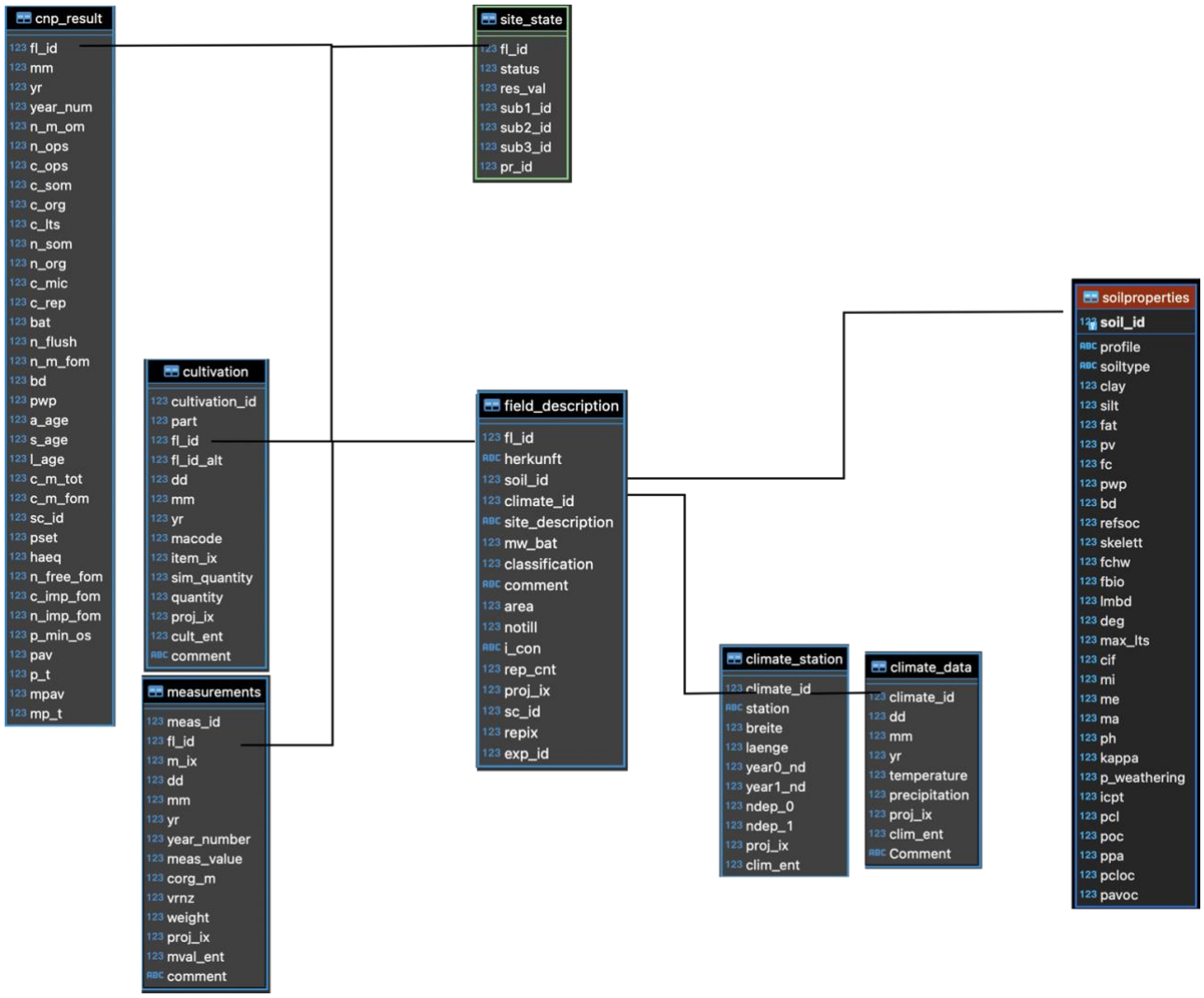
or using the corrected version for finite sample sizes:

$$AICc = 2 \cdot k + n \cdot \ln(\frac{\sum (O_i - P_i)^2}{n}) + \frac{2 \cdot k \cdot (k+1)}{n-k-1}$$ Equation 75

4 Input-/Output Parameters & Database

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.

4.1 User-data tables



4.1.1 Experiments

Content:

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

attribute	meaning	unit/type
location	Folder name shown in interface	string
exp_id	Unique number	number

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

4.1.2 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
site_description	Appears as plot name	string
comment	Space for remarks	string
exp_id	Pointer to table experiments	number
area	Plot area	number
i_con	Type of initial condition (obsval, null, pre management)	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 always 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.

4.1.3 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

4.1.4 Climate_data

Content:

Climate data in monthly time steps.

attribute	meaning	unit/type
climate_id	Pointer to climate_station	number
mm	Month: 1..12	number
yr	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.

4.1.5 Cultivation

Content:

Management data.

attribute	meaning	unit/type
cultivation_id	Unique number	number
fl_id	Pointer to field description	number
dd	Day of activity (to indicate time sequence)	number
mm	Month of activity	number
yr	Year of activity	number
macode	Action code; Pointer to cdy_action	number
item_ix	Object code; pointer to parameter table	number
quantity	Amount or yield	number
part	Spatial weight (in %), linked to 'regional-mode'	number

Remarks: Day is an option for better documentation l and may be given a 0 value

4.1.6 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
dd	Day of activity (to indicate time sequence)	number
mm	Month of observation	number
yr	Year of observation	number
year_number	Count of the year; 0 means initial value	number
meas_value	Observed value	number
vrnz	Varianz of observed value (optional)	number

Remarks: m_ix=7: SOC; m_ix=0 : NT

4.1.7 Soilproperties

Content: Parameters of the (top) soil.

attribute	meaning	unit/type
	----- general -----	
soil_id	Unique identifier	number
profile	Name shown in the interface	string
soiltype	Soil type according to KA4/RBS, used to get silt content	string
fbio	Calibration factor for microbial biomass	number
fhws	Calibration factor for hot water soluble carbon	
	---- soil texture ----	
clay	Clay content [%]	number
silt	Silt content [%]	number
fat	Fine particles (clay + fine silt) content [%]	number
skelett	Stone content [%]	number
	---- soil structure -----	
pv	Pore volume	number
fc	Field capacity	number
pwp	Permanent wilting point	number
bd	Bulk density	number
refsoc	Reference SOC value relating to the soil physical parameters	number
	----- LTS dynamics ----	
cif	Part of LTS carbon	number
mi	Micropore dimension; default r=5	
me	Mesopore dimension; default r=10	
ma	Makropore dimension; default r=500	
lmbd	λ_d parameter for LTS dynamics	number
deg	k_d parameter for aggregate destruction	*number*
max_lts	Maximum size of LTS pool (saturation limit)	number
	----- P dynamics -----	
pH	pH value: affects P adsorption dynamics	number
p_weathering	anual rate of P weathering	kg/ha/yr
kappa	turnover constant for P flux	number
icpt		number
pcl		number
poc		
ppa		number
pcloc		
pavoc		kg/ha/yr

Remarks:

More attributes may be added for convenience of a study or to support data organisation.

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

4.2 Model-parameter tables

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

4.2.1 cdyaparm

Content: General parameters (selectable at program start).

4.2.2 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

4.2.3 cdyopspa

Content: Parameters for fresh organic matter turnover.

attribute	meaning	unit/type
item_ix	Key, Index	integer
name	Name, label	string
oram	Separation between external source (specified in cultivation data) and internal generated organic matter (like roots)	boolean
k	Decomposition coefficient	[d^{-1}]
eta	Synthesis coefficient	[0..1]
c_dm	C content in dry matter	[kg C dt^{-1}] = [M%]
dm	Standard DM (only for organic amendments)	[0..1]
cnr	C/N ratio in organic matter (C_{org} / N_{org})	[-]
cpr	C/P ratio of organic matter (C_{org}/P_{org})	[-]
cnr_alt	Total C/N-ratio C_{org} / (N_{org} + N_{min})	[-]
mor	Ratio of mineral and organic nitrogen N_{min} / N_{org}	[-]
pmor	Ratio of mineral and organic phosphorus P_{min} / P_{org}	[-]
ros_ix	Pointer to a record in vdlufa_oram to characterize the humus equivalent	integer

4.2.4 cdypflan

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

attribute	meaning	unit/type
item_ix	Key, Index	integer
name	Name; label	string
stix	(DM stubble-FIX) / (DM stubble +DM by-product)	[0..1]
rix	(DM stubble +DM by-product) / DM main product	[0..1]
fix_s	Intercept in linear function to calculate the DM amount of stubble	[dt ha^{-1}]
fix_r	Intercept in linear function to calculate the DM amount of roots	[dt ha^{-1}]
bix	Slope in linear function to calculate the DM amount of roots from main product	[0..1]
c_mp	C-concentration in DM of main product	[kg C dt^{-1}] = [M%]
n_mp	N-concentration in DM of main product	[kg N dt^{-1}]
p_mp	P-concentration in DM of main product	[kg P dt^{-1}]
dm_mp	Standard DM of main product	[0..1]
rt_ix	Pointer to a record (item_ix) in cdyopspa to characterise harvest residues from roots	integer
sh_ix	Pointer to a record (item_ix) in cdyopspa to characterise harvest residues from shoot	integer
gm_ix	Pointer to a record (item_ix) in cdyopspa to characterise aboveground biomass after ploughing up (not supported in CNP)	integer
seed_ix	Pointer to a record in n_saat_input to characterise nutrients in seeds	integer
leg_ix	Factor between N in harvest residues, roots and yield	[kg kg^{-1}]
ros_ix	Pointer to a record in ros_pflan to characterize the humus equivalent	[HÄQ]
organic	Item for organic farming	True/false

4.3 Parameter tables

4.3.1 cdymindg

Content:

Definition of the mineral fertilizers

attribute	meaning	unit/type
item_ix	Key, Index	integer
name	Name; label	string
ammantanteil	The amount of ammonium in N-fertilizer	%
herkunft	Description of data origin	string
n_fert	Nitrogen-fertilizer	True/False
p_fert	Phosphorus-fertilizer	True/False

4.3.2 cnd_mwml

Content: Definition of measurements of soil properties (only actually used parameters are shown)

attribute	meaning	unit/type
m_ix	pointer from table measurements	integer
merkmal	definition	string
bezeichnunung	definition displayed in cnp model	string
kurzbez	abbreviated definition	string
einheit	unit	string

4.3.3 ros_od

Content: Parameters of organic amendments according to the German VDLUFA method of humus balance

attribute	meaning	unit/type
ros_ix	pointer from cdyopspa	string
ts_proz	Dry matter content	string
c_hum	Humus equivalent (VDLUFA)	string

4.3.4 ros_pflan

Content: Crop parameters according to the German VDLUFA method of humus balance

attribute	meaning	unit/type
ros_ix	pointer from cdypflan	string
name	Crop group	string
ros_ug, ros_og	Humus reproduction/demand (lower/upprer value)	string

4.3.5 n_saat_input

Content: element input with sowing

attribute	meaning	unit/type
seed_ix	Pointer from cdypflan	integer
name	Description seed input	string
menge	Amount of seed input	kg/ha
c_gehalt ***n_gehalt*** ***p_gehalt***	Amount of C, N, P in seeds	%

4.3.6 leg_parm

Content: Parameters for symbiotic N-fixation from atmosphere (only actually used parameters are shown)

attribute	meaning	unit/type
id	Unique identifier	integer
leg_ix	Link to cdypflan	integer
ndfa	Part of nitrogen in crop derived from atmosphere (0..1)	float
legshr	Part of legumes in crop mixture (0..1)	float

4.4 Result tables

4.4.1 CNP_results

Content: main result table for C, N and P;

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
pset	ID of parameter set	number
haeq	Index for humus production [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
p_min_os	P mineralization	
pav	Concentration of availaible P (equivalent to CAL extraction)	mg/100g soil
p_t	Concentration of total P (equivalent to HNO_3 HCL extraction)	mg/100g soil
mpav	Amout of availiable P	??????
mp_t	Amount of total P	???????

* not yet fully implemented

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

4.4.2 nbil.ccb_c_bilanz

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

attribute	meaning	unit/type
fl_id	Pointer to field description	number
dt_mm	time interval (number of months)	number
yr	Year , balance time step	number
c_som	C amount in SOM	number
c_orgd_inp	Input with organic amendments	number
c_kop_inp	Input with by-products (if left on field)	number
c_ewr	C in biomass of roots and stubbles	number
c_saat	Input with seeds C_{sds}	number
c_entz	C-in biomass of main-+by-product	number
c_offtake	C-offtake from field with biomass	number
idx	Index term	text

Remarks: all C amounts in kg/ha/

4.4.3 nbil.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
dt_mm	time interval (number of months)	number
yr	Year, balance time step	number
n_som	N amount in SOM	bumber
n_m_om	Min.N flux from organic sources incl. N_{flush}	number
n_orgd_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_offtake	N-Offtake from field	
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

4.4.4 nbil.ccb_p_bilanz

attribute	meaning	type
fl_id	Pointer to field description	number
dt_mm	time interval (number of months)	number
yr	Year, balance time step	number
mpav	Plant available P (mass)	number
mp_t	Total P (mass)	number
pav	Plant available P (concentration	number
p_t	Total P (concentration	number
p_min_os	Min P flux from organic sources	number
p_orgd_inp	Input with organic amendments	number
p_kop_inp	Input with by-product (if left on field)	number
p_ewr	Uptake with roots and stubble	number
p_saat	Input with seeds	number
p_dng	Input with fertilizers	number
p_entz	Uptake with main+by-product	number
p_offtake	Offtake from field	number
idx	Unique index	varchar

Remarks: all P amounts in kg/ha

Temporary tables used in balancing

nbil.tmp_n_bilanz

attribute	meaning	type
Fl_id	Pointer to field description	
part		
mm		
Year_		
macode		
kpoff		
Crop_ix		
Name_		
C_hp		
N_hp		
P_hp		
C_kop		
N_kop		
P_kop		
C_stp		
N_stp		
P_stp		
C_root		
N_root		
P_root		

nbil.tmp_rep_cnt

attribute	meaning	type
Fl_id	Pointer to field description	
Rep_cnt		
ayear		
eyear		
ycnt		

nbil.tmp_ndeposit

attribute	meaning	type
climate_id	Pointer to climate station	
yr	year	
N_dep_y	Annual N deposition	

nbil.nbil_n_dng

attribute	meaning	unit/type
fl_id	Pointer to field description	number
yr	year	
n_dng	N input with fertiliser	
idx	index	

nbil.nbil_p_dng

attribute	meaning	unit/type
fl_id	Pointer to field description	number
yr	year	
p_dng	P input with fertiliser	
idx	index	

nbil.nbil_cnp_yield

attribute	meaning	unit/type
fl_id	Pointer to field description	number
yr	year	
c_offt	C offtake from field	
n_offt	N offtake from field	
p_offt	P offtake from field	
c_entz	C in main- and by-product	
n_entz	N in main- and by-product	
p_entz	P in main- and by-product	
c_kopp	C in by-product	
n_kopp	N in by-product	
p_kopp	P in by-product	
c_root	C in roots	
n_root	N in roots	
p_root	P in roots	
c_stop	C in aboveground residues (stubble)	
n_stop	N in aboveground residues (stubble)	
p_stop	P in aboveground residues (stubble)	
idx	index	

nbil.nbil_saat

attribute	meaning	unit/type
fl_id	Pointer to field description	number
yr	year	
c_saat	C added with seeds	
n_saat	N added with seeds	
p_saat	P added with seeds	
idx	index	

nbil.nbil_orgd

attribute	meaning	unit/type
fl_id	Pointer to field description	number
yr	year	
c_orgdg	Added C	
n_orgdg	Added N	
p_orgdg	Added P	
typ	‘oram’ or ‘kopp’	
idx	index	

nbil.nbil_nleg

attribute	meaning	unit/type
fl_id	Pointer to field description	number
yr	year	
n_bindung	Amount of symbiotic bound N	
n_bio	Total N in biomass	
fnsym	help factor: ndfa*legshr	
idx	index	

nbil.nmin_saldo

attribute	meaning	unit/type
fl_id	Pointer to field description	number
yr	year	
n_pflanze_out	N uptake by crop	
n_mindg_inp	N input with fertiliser	
n_mos_inp	N input from mineralisation	
n_leg_inp	N input from symbiotic binding	
n_asym_inp	N input from asymbiotic binding	
n_depos_inp	N deposition from atmosphere	
n_saat_inp	N input with seeds	
saldo_nmin_soil	N saldo (mineral fluxes)	
anz	count	

nbil.ccb_nsaldo

attribute	meaning	unit/type
fl_id	Pointer to field description	number
N_mindg_inp	N input with min. fertiliser	
N_orgdg_inp	N input with organic amendments	
N_kop_inp	N in by-product	
N_ewr_upt	N in crop residues	
N_hukp_upt	N in main- and by-product	
N_mos_inp	N input from mineralisation	
N_leg_inp	N input from symbiotic binding	
N_asym_inp	N input from asymbiotic binding	
N_depos_inp	N input from atmosphere	
N_saat_inp	N input with seeds	
N_gratis	N input without charge	
N_saldo_soil	N saldo soil	
N_saldo_plot	N saldo field	

nbil.pavl_saldo

attribute	meaning	unit/type
fl_id	Pointer to field description	number
yr	year	
p_pflanze_out	P offtake by crop	
p_mindg_inp	P input with min. fertilser	
p_mos_inp	P input from mineralisation	
p_saat_inp	P input with seeds	
saldo_pavl_soil	Saldo of plant available P	
anz	count	

nbil.nt_saldo

attribute	meaning	unit/type
fl_id	Pointer to field description	number
yr	year	
n_abfuhr	N offtake with crop	
n_mindg_inp	N input with fertiliser	
n_orgdg_inp	N input with organic amendments	
n_leg_inp	N input from symbiotic binding	
n_asym_inp	N input from asymbiotic binding	
n_depos_inp	N input from atmosphere	
n_saat_inp	N input with seeds	
N_kop_inp	N input with by-product left on field	
N_saldo_plot	N saldo on plot level (field)	

nbil.pt_saldo

attribute	meaning	unit/type
fl_id	Pointer to field description	number
yr	year	
p_abfuhr	P offtake from field	
p_mindg_inp	P input with fertiliser	
p_orgdg_inp	P input with organic amentment	
p_saat_inp	P input with seeds	
p_kop_inp	P input with returned by-products	
p_saldo_plol	P saldo on plot level (field)	

nbil.tmp_som_change2

attribute	meaning	unit/type
fl_id	Pointer to field description	number
dt_mm	Time interval in months	
delta_c_som	SOC	
delta_n_som	SON	
delta_p_som	P in SOM	
delta_mpt	Total P	
delta_mpav	Plant available P	

nbil.tmp_sombalance2

attribute	meaning	unit/type
dat	date	date
fl_id	Pointer to field description	number
mm	month	
yr	year	
year_num	Running (year) number	
c_som	SOC	
n_som	SON	
mp_t	Total P	
mpav	Plant available P	

5 Published CCB/CNP application studies.

First model description and validation:(Franko et al., 2011)

Bare fallow and soil tillage: (Franko & Merbach, 2017)

Soil tillage experiment:(Franko & Spiegel, 2016)

Regional application in Saxony:(Witing et al., 2019)

Sensitivity analysis:(Diel & Franko, 2020)

International set of bare fallow experiments:(Farina et al., 2021)

Very high carbon input rates: (Franko & Schulz, 2021)

Management changes in long term experiment: (Franko et al., 2021)

Transfer lab results into field experiment:(Gasser et al., 2022)

Adding P-dynamics to get the CNP model:(Gasser et al., 2023)

Upscaling of management options:(Witing et al., 2023)

Detailed references:

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6 References in model description

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