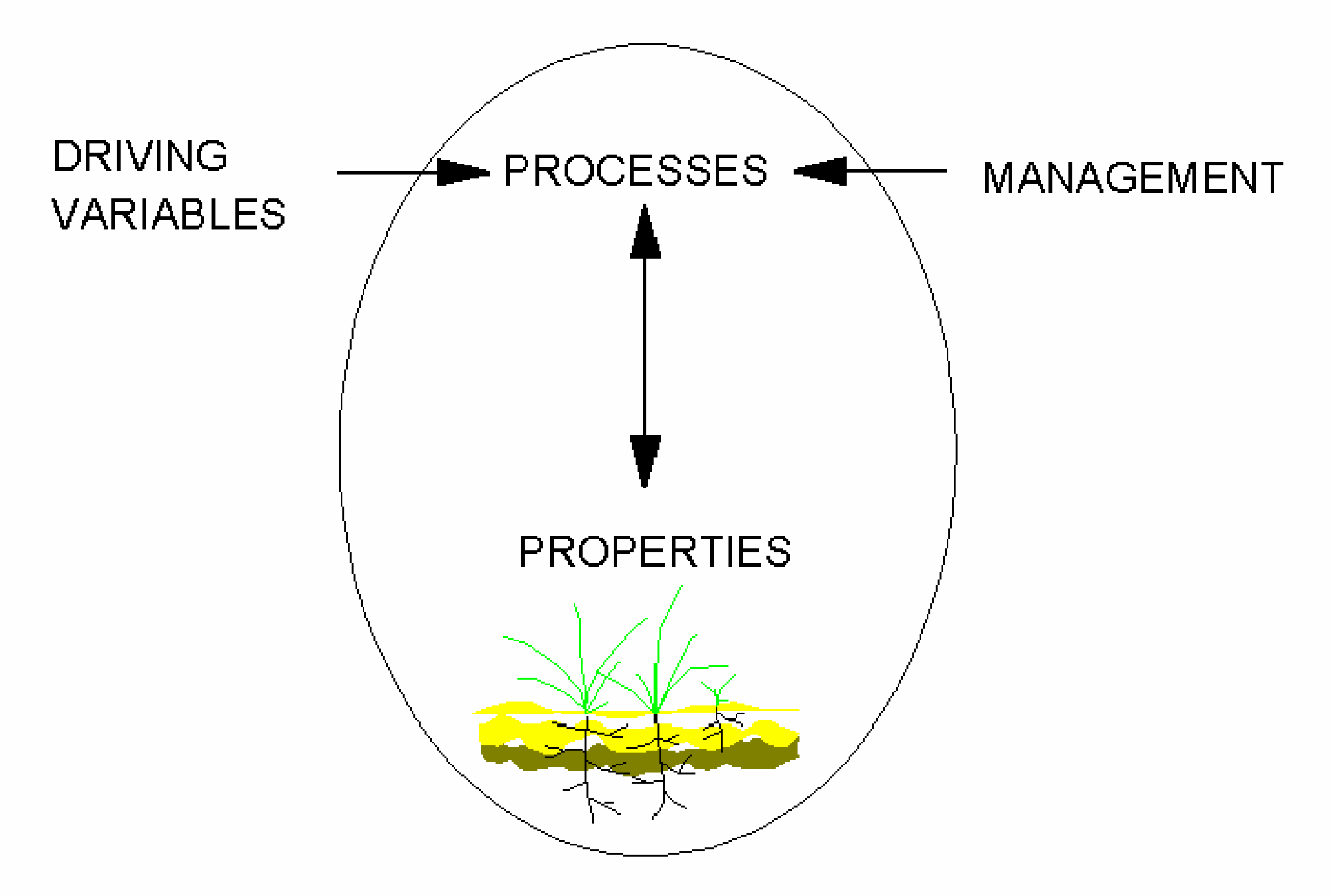
The CENTURY model for SOM levels in Dutch agricultural land uses and land management.



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Content

Summary

Soils contain vast amounts of organic carbon (C) which can be found in soil organic matter (SOM). Land use changes and predicted global warming, through their effects on net primary productivity, the plant community and soil conditions, may have important effects on the size of the soil organic matter pool and directly affect the atmospheric concentration of these trace gases. With accurate information incorporated in model systems, the potentials to sequester C can be reliably predicted. A model's ability can be tested by simulating long-term SOM changes using existing datasets. This can be done under a variety of land uses and in a range of climates within the temperate region, as a means of identifying which SOM models are likely to be most appropriate for future global change impact assessment in different environments. Dutch policy is interested in the reaction of soil C to climatic changes because of its relation to the emission of CO_2 to the atmosphere, which can be linked to the greenhouse gas problems currently investigated in Europe. The Century 4.0 model has been chosen to examine whether soil organic carbon can be predicted in combination with Dutch agricultural land uses, without additional changes to the Century model.

The SOM model simulates the dynamics of C, N, P, and S for different plant production systems such as grassland, arable land, forests, and savannas. It is similar to some other multi-component models and partitions plant residues among structural and metabolic organic pools, based on their lignin/ N ratio. Century distinguishes 3 SOM pools: an active turnover pool, a slow turnover pool and a passive turnover pool.

No articles were found where Century was applied for The Netherlands, but world wide, researchers tested Century and stated that calibration and validation of Century is essential with new [site] conditions. From the two options: (i) Calibration and validation for The Netherlands through Dutch long term datasets, or (ii) Calibration assumed through literature from other researchers in Europe, option (ii) was chosen (§4.3). This option was chosen because in the time span of this study no useful long term Dutch experiments could be found. Calibration with Century was done by other researchers for different European locations and the conclusion was that Century could be used in The Netherlands.

For the model runs, a distinction was made between the runs for the initialisation of Century, and the simulation. The initialization was not to reproduce Dutch reality, but only to reach a steady state for the SOM pools in Century. The initialization was a natural grassland environment which ran for 6000 years under two textures: sand and clay, and with Dutch weather data. The simulations were the runs where actual Dutch agricultural rotations were simulated for 1200 years. Through Dutch literature, two options were chosen as rotations. The first rotation was a grass maize rotation (GM) on sandy soil. The second rotation was a wheat-potato-grass/clover-sugar beet-potato rotation (WPSP) on clay soil. Parameters were adapted according to Dutch

literature data and the time span for the different runs was chosen in order to let all SOM pools be able to respond to the management changes.

The initializations showed a clear distinction between the two textures used. Both runs increased in % C during the run, with clay ending with a higher % C (5.6), than sand (2.7). This signifies a value of ± 4.6% SOM for sandy and ± 9.6% SOM. Both runs were considered to be in a steady state at 5000 years and so this time span was also used for the simulation. For the simulations, Century showed a trend of decreasing soil organic matter decline when simulating Dutch agricultural management for both grass–maize rotation (with a sand texture) and a wheat-potato-clover-sugar beet and potato rotation (with a clay texture). These simulations seemed to end for both soil texture types in steady state conditions, with an end total for the GM rotation of 1.8 % C and 4.1 % C for the WPSP rotation. Though differences of % C can be seen between the years, no answer could be given for the individual response of Century to the crops, since Century did not give output data when specifying for specific months during the rotations. Only the GM rotation shows a clear response of Century to the years with maize (decreasing % C) and to grass (increasing % C). The most distinct difference of unaltered (no parameter adaptations) Century runs which had similar initializations and rotations compared to the adjusted Century runs, is a difference in the initializations of WPSP. The adjusted initialization was very high (5.6 % C), compared to the original run (3.3 % C). This is probably due to the Dutch weather data used. The model responded strongly to the management of ploughing (increasing decomposition) and fertilizers (increasing SOM levels) added to the soil, and showed to have several constrains as far as the model's performance (§ 5.1).

For further recommendations: TAGA is given as a Dutch database where long term Dutch experiments can possibly be found for the calibration of Century, the model responses to soil management and land use have to be checked without seeing the model as a black box, the possibility for combining Century with climate questions should be considered, and the option of using the improved version of century (version 5.0) is given.

1. Introduction

Soils contain vast amounts of organic carbon (C) [Reijneveld *et al.*, 2007] which can be found in soil organic matter (SOM). Land use changes and predicted global warming, through their effects on net primary productivity, the plant community and soil conditions, may have important effects on the size of the soil organic matter pool and directly affect the atmospheric concentration of these trace gases [Batjes, 1996]. On a global scale soil respiration in terrestrial ecosystems is estimated to a total of 50-75 Pg[1] Carbon per year [Houghton and Woodwell, 1989; Schlesinger 1977]. By comparison, fossil fuel burning adds about 5 Pg C/ yr to the atmosphere [ca. 1980-1982, Marland and Rotty 1984]; even a small change in the soil respiration flux may rival the annual fossil fuel loading of the atmospheric carbon dioxide (CO_2). Soil respiration is a major flux in the global carbon cycle, second in magnitude to gross primary productivity, which ranges from 100-120 Pg C/ yr [Box, 1978, Bolin, 1983; Houghton and Woodland, 1989], and equal to or greater then the estimated global terrestrial net primary productivity of 50-60 Pg C/ yr [Box, 1978; Ajtay *et al*., 1979; Bolin, 1983; Olson *et al*., 1983; Houghton and Woodland, 1989]. Despite its importance in the global C cycle, the global magnitude and distribution of soil respiration is poorly quantified. Rates of soil respiration have been measured in a variety of ecosystems to examine rates of microbial activity, nutrient turnover, carbon cycling, root dynamics, and a variety of other soil processes. The understanding of soil respiration rates and factors that influence them therefore has a solid base, according to Raich and Schlesinger (1992).

Croplands (i.e. lands used for the production of arable crops), cover about 1/3 of Europe's land surface and are estimated to be the largest biospheric source of carbon loss to the atmosphere in Europe each year [Smith *et al.*, 2005] with a current best estimate of C changes in European agricultural soils which indicates that croplands are losing 300 Tg C/ yr to the atmosphere, thus largely offsetting the sink in the forest sector (363 Tg[2] C/ yr). The C balance of grassland ecosystems, which was estimated by following exactly the same methodology as for arable soils, may, in contrast to arable soils, constitute a net C sink (101 Tg C/ yr), although the uncertainty surrounding this estimate is larger than the sink itself [Janssens *et al.*, 2003].

The sequestration[3*] potential of a soil depends on the vegetation it supports, its mineralogical composition, the depth of the solumn, soil drainage, the availability of water and air, and the temperature of the soil environment. The sequestration also depends on the chemical characteristics of the soil organic matter* and its ability to resist microbial decomposition. It is possible to predict the potentials of different soils to sequester C, when accurate information for these features is incorporated in model systems. A model's simulation of future events obviously

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[1] *1 Pg C corresponds to 1*10^{15} g C*

[2] ♣ 1 *Tg C corresponds to 10^{12} g C.*

[3] * *Words with a ' * ' can be found in the Terminology chapter.*

cannot be compared to measured data to verify its validity. We can, however, get some measure of performance by testing a model's ability to simulate long-term SOM changes using existing datasets. This can be done by testing the ability of SOM models to simulate the long term dynamics under a variety of land uses and in a range of climates within the temperate region as a means of identifying which SOM models are likely to be most appropriate for future global change impact assessment in different environments. In the future, SOM models will be used to assess the impact of global change on SOM and subsequent feedback effects [Smith *et al.*, 1997a].

A current question in The Netherlands is whether carbon stocks and carbon fluxes in Dutch agriculture are showing a decreasing, a steady state or increasing trend, under the current agricultural land use. Dutch policy is interested in these questions because the soil C can possibly be related to the emission of CO_2 to the atmosphere, which is linked to the greenhouse gas problems currently investigated in Europe. In this report Century 4.0 has been put to the test to run this originally USA-based model under Dutch circumstances, and acquire an insight in what predictions Century gives for the future when testing specific crop rotations and farm management on Dutch agricultural soils.

1.1 Objectives

The reason for working with Century comes from the (policy) question whether the carbon content in Dutch soils is increasing, decreasing or whether it is in a steady state. Century is a complex model, which can model soil organic carbon in soils, with the extensive use of parameters and agricultural management options.

It is thought possible to use Century for Dutch soil and agricultural management conditions.

Hypothesis: Century can be used to simulate carbon storage in Dutch agricultural soils without additional changes to the model.

The changes referred to are parameter changes from the model itself.

This hypothesis can be tested by:

- Evaluating literature about the use of Century in previous experiments and simulations.

If Century can be used without additional changes, it is important to analyse and report the pros and cons of using Century in The Netherlands.

If Century cannot be used without additional changes, the question is whether Century can be used for other circumstances then it was written for. The latter can be done by:

- Evaluating literature about the use of Century in different conditions then it was written for.

Other questions are:

- What kind of results can be found when simulating Dutch agricultural rotations on different Dutch soils, and how do they compare to other found results?
- Determine what the sensitivity of the different initial parameters in the Century model is, and how these parameters influence the C storage in the soil. When possible, a description will be given how to establish extensive land coverage of the carbon stored in Dutch soils in The Netherlands with the use of Century.

1.2 Relevance

Understanding the processes that control soil organic matter dynamics is the key to SOM management [Gerzabek *et al.*, 2006]. Maintaining or increasing soil organic matter is justified both from an agronomic and a climatic perspective because it affects the capacity of the soil to sustain crop growth, is an important factor in decreasing soil compaction and erosion, and is also a source and possible sink of atmospheric CO_2-C [Paustian *et al.*, 1997].

Recently, the European Commission has given a proposal for a European Strategy on Soil. This strategy describes 7 soil threats for the European soils. One of these threats is the decline of organic matter in the soil. The Dutch government is focusing more on preserving ecological services. These services are part of ecosystems, which are of use for humans [Internet link 1, 2007]. One of these important functions is the storage of carbon in the soil. Considering that soil can store carbon in different forms (e.g. stabile, passive carbon and labile, active carbon), it can be essential to use a model to evaluate these long term processes and anticipate on the impact long term changes have on the Dutch ecosystems as a whole.

2. Background

2.1. Soil Organic Matter

Carbon dioxide (CO_2) is produced in soil by roots and soil organisms and to a small extent, by chemical oxidation of carbon-containing materials [Lundegårdh, 1972]. CO_2 is released from soils in the process variably referred to as soil respiration, soil-CO_2 evolution, or soil-CO_2 efflux. The rate at which CO_2 moves from the soil to the atmosphere is controlled by the rate of CO_2 production in the soil (the true soil respiration), the strength of the CO_2 concentration gradient between the soil and the atmosphere, and properties such as soil pore size, air temperature, and wind speed that influence the movement of CO_2 through and out of the soil [Raich and Schlesinger, 1992].

The term soil organic matter is generally used to represent the organic constituents in the soil, including undecayed plant and animal tissues, their partial decomposition products, and the soil biomass. When plant and animal debris is added to soil, it is broken down by macro- and micro-organisms, initially into particulate organic matter, and finally into humus [Internet link 2, 2007]. The term soil organic matter includes [Internet link 3, -]:

- Identifiable, high-molecular-weight organic materials such as polysaccharides (carbohydrates such as cellulose) and proteins,
- Simpler substances such as sugars, amino acids, and other small molecules,
- Humic substances.

Humic substances can be divided into three different groups namely [Internet link 3, -]:

Humic acids - the fraction of humic substances that is not soluble in water under acidic conditions (pH < 2) but is soluble at higher pH values. Humic acids are the major extractable component of soil humic substances. They are dark brown to black in colour.

Fulvic acids - the fraction of humic substances that is soluble in water under all pH conditions. They remain in solution after removal of humic acid by acidification. Fulvic acids are light yellow to yellow-brown in colour.

Humin - the fraction of humic substances that is not soluble in water at any pH value and in alkali. Humins are black in colour.

SOM has a key importance in nutrient availability, soil structure, in the flux of trace gases between land surface and the atmosphere, and thus in improving soil health [Carvalho Leite *et al.*, 2003]. Application of organic matter to the soil adds C, which promotes the growth of beneficial bacteria. Another benefit is when crops grow and demand more nutrients; decomposing organic matter can be used as plant food. When soil is disturbed by turning or tilling, extra oxygen is added to the soil. This increases aerobe microbial activity, which feeds on organic matter. Therefore, soil disturbance can decrease the SOM's reserves. Adding organic matter to a sandy soil can improve the soil fertility and helps the soil to retain more water, whereas adding organic matter to a clayey soil improves the aeration in the soil, giving it a better structure. The raw materials in organic matter can vary greatly in their resistance to breakdown. Woody organic substances like lignins are very resistant, while more simple compounds like sugars are readily utilised. Along the way, microbial populations increase, and in the process they synthesise their own compounds which add to the diversity. These organisms eventually die and are consumed by other organisms. Carbon dioxide is a by-product of this complex chain of processes. Over half of the carbon added to soil is lost as CO_2 during breakdown. Because of their varying reactivity, the turnover times for these different carbon fractions varies from a few months to tens of thousands of years [Internet link 2, 2007].

The main factors that influence the amount of carbon in a soil are [Internet link 2, 2007]:

- **Climate** For similar soils under similar management, the amount of carbon is greater in areas of higher rainfall, and smaller in areas of higher temperature. The rate of decomposition can double for every 8 or 9℃ increase in mean annual temperature.
- **Soil type** Clay helps to protect organic matter from breakdown, either by binding organic matter strongly or by forming a physical barrier which limits microbial access. Clay soils in the same area under similar management will tend to retain more carbon than sandy soils.
- **Vegetative growth** The more vegetative production the greater are the inputs of carbon. Also, the more woody this vegetation is (greater C:N ratio), the slower it will breakdown. So, the crop system can strongly affect carbon concentrations.
- **Topography** Soils at the bottom of slopes generally have higher carbon content then the soils at the top of a slope because these areas are generally wetter and have higher clay contents. Poorly drained areas have much slower rates of carbon breakdown.
- **Tillage** Tillage will increase carbon breakdown. However, the impact of tillage is generally outweighed by the effect of management on the amount of carbon grown and returned to the soil. An exception to this is where tillage leads to increased erosion.

Organic matter can be considered pivotal (i.e. it is an essential component in the soil), because of its role in physical, chemical and biological processes in the soil. Many of these functions interact. For example, the high cation exchange properties of organic matter are a major means by which organic matter is able to bind soil particles together in a more stable structure. SOM influences the water holding capacity and aeration of the soil and this can in return influence the soil temperature [Internet link 2, 2007].

2.2 SOM in models

Due to the slow reaction to changes in e.g. climate or land use management, organic matter is a frequently used and well documented indicator of long term changes of soil in many models. The most important reason for such a model is that through the model's parameters an observation can be made as to what might happen in the future. Several models include a 'climatic influence' where the effect of a higher temperature is being taken into account.

Land use and agricultural management practices such as crop rotation, soil tillage and organic amendments can affect SOM by influencing both the quantity and quality of crop residues that are returned to the soil; they also influence the rate of decomposition of added residues and native SOM [Gregorich *et al*., 1994; Haynes & Beare, 1996], as cited by Gerzabek *et al*. (2006).

The elements C, N (nitrogen), P (phosphorus) and S (sulphur) are central to all biological processes and provide a key to our understanding of changes in the biosphere [Hutchinson, 1970] and systematic study of the interaction of these elements' transformations provides a valuable means of understanding the structure and functioning of ecosystems [Steward, 1984], as cited by Parton (1988).

Soil organic matter is very important in soil modelling, because it is, for example, a crucial source and sink for plant available nutrients in natural and managed ecosystems [e.g., Cambardella and Elliott, 1992], as cited by Parton (1993). The Century model has been tested and used under many conditions [Paustian *et al*. 1992; Gilmanov *et al*. 1997; Romanya *et al*. 2000] and against many long-term data sets and has performed well under temperate conditions, as. This set of simulations reinforces the utility of Century as a tool for predicting SOM dynamics across climates, land-use types, and treatments within sites [Parton *et al*., 1998] as cited by Kelly *et al.* (1997).

2.3. Century model description

The Century SOM model was originally developed and tested on data sets mainly from grassland and wheat–fallow agriculture in the US Great Plains [Parton, 1987, Parton, 1988]. The model simulates the dynamics of C, N, P, and S for different plant production systems such as grassland, arable land, forests, and savannas (with a minimum of 10 years) with a monthly time step [Shibu *et al.*, 2006]. It contains the following sub models: soil organic matter, water budget/soil temperature, N, P, S, and plant production. It is possible to include agricultural influences such as cultivation, fertilization, grazing, irrigation, and different harvesting methods when modelling crops [Paustian *et al.*, 1997]. Century 4.0 was chosen because it was the mostly widely tested version of the model that could be found and it is free for download on http://www.nrel.colostate.edu/projects/century/. Century works with 3 utilities, which help set up Century for a specific run: file100.exe, event100.exe, and list100.exe. The file100 utility helps users adjust, update or create any of the 12 data files used by Century. These data files, which can be recognized by their extension: .100, refer to different files with specific parameters that are used in Century and can be found in annex 1. For example: in crop.100 the different crops (such as wheat, grass, corn, etc) and their common parameters (i.e. the potential aboveground monthly production for crops (g C/ m2), which is set at different values for the different crops) are located. figure 1 can be a helpful visual image.

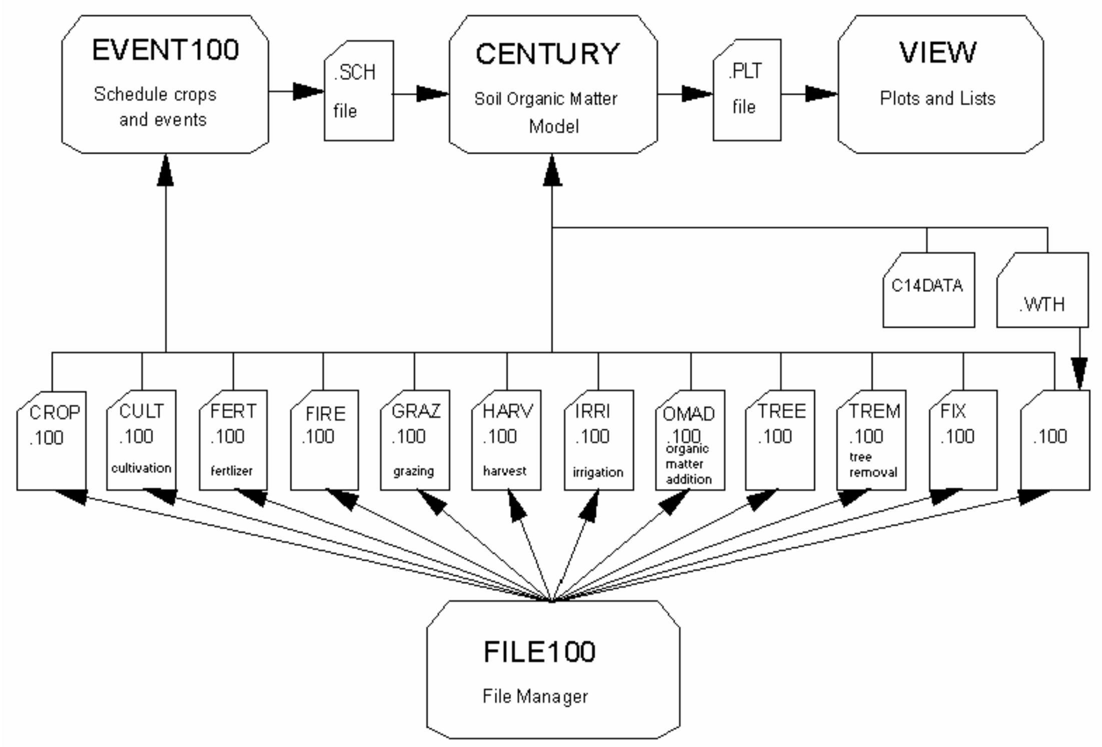

Figure 1, Century file structure and the different relationships between utility programs. List100 is being run as a separate program so output data can be easily accessible for e.g. output in excel.

Beside these 12 data files, file100 can also be used to change the Century environment files. File.100 gives the possibility to alter parameters and their values used. The two most important ones are the fix.100 file and the <site>.100 file. The fix.100 file has fixed parameters primarily related to organic matter decomposition, and the <site>.100 file has specific parameters such as precipitation, soil texture, and initial conditions for soil organic matter. Century 4.0 already has several <site> files included in the software. These <site> files can be used as a basis and can be renamed and altered through file100 to create a specific environment for the land management or rotation needed.

After alterations to the 12 data files have been made, the event100 utility can be used to set up the scheduling part of Century. Event100 manages the (agricultural) plants used, events that occur at specific indicated periods during the simulation (e.g. fertilization, when cultivation takes place, at what time a specific crop is planted and harvested, etc.). These events are saved in a schedule file, recognized by the extension:'*sch*'.

The list100 utility reads the binary output file, created by Century, and generates a file that can be read easily by e.g. excel. List100 also makes it possible to extract data from a small part of a long run. For further instructions see the extended manual from Century [Metherell *et al.*, 1993].

The SOM sub-model of Century is similar to some other multi-component models [Jenkinson and Rayner, 1977, Jenkinson, 1990] and partitions plant residues among structural and metabolic organic pools, based on their lignin/ N ratio. The structural pool is further subdivided into lignin and cellulose components. Metabolic and cellulose C are transferred to the active pool (i.e. microbial biomass), whereas lignin C is transferred directly to the slow pool. The third pool is the passive turnover pool and this pool is very resistant to decomposition. Decomposition of all pools is described according to first-order kinetics with different relative rate constants per pool that vary for different systems like arable crops, grass and forest. The actual relative rate of decomposition for the structural pool is derived from its lignin content, whereas for the active pool it is modified for soil texture, in addition to the modifications for soil temperature and moisture content [Shibu *et al.*, 2006]. In annex 2 several characteristics of the Century model have been joined together.

3. Methodology

Century can be used to simulate soil organic matter under different conditions. In the manual of Century [Metherell *et al.*, 1993], a separate paragraph has been added to describe how the Century model has been calibrated and validated. This has been carried out by fitting the model to long-term soil decomposition experiments where different types of plant material were added to soils with a number of soil textures. The model was officially developed for estimating steady state soil C and N in grassland systems in the Great Plains in The United States of America, but has since then been expanded to croplands and forests systems.

3.1 Literature

When reviewing literature about the use of Century in The Netherlands, no articles were found in The Netherlands for analysed experiments with the Century model. For the continuation of this report, different pathways could be chosen depending on what was found in literature. Since a decision had to be made already in the beginning of the literature review, a short summary is given why the hereafter described method is being used.

World wide, Century has been used by many researchers to verify the model’s reliability, to back up their own (SOM) models output or to compare SOM models with each other. However, one important issue was described in most articles: the constructiveness of any SOM model used in a site, different from what is was calibrated for, depends on the [site] calibration and validation for which the model was tested.

According to Metherell *et al.* (1993) the internal parameters of Century have been determined by fitting the model to soil decomposition experiments (1 to 5 years) where different types of plant material were added to the soils with a number of soil textures. Century is not originally designed to be a plant production model and some parameters may have to be calibrated for specific environments. Bruun *et al.* (2003) mentions that there is a major limitation to the models which are based on the Jenkinson and Rayner (1977) model (Century is one of these models). The size and turnover rate of the various SOM pools used in these models, are based on qualitative concepts, rather than measurable entities and most often model performance can only be verified against measured total-C contents in soil. It is essential that long-term SOM turnover models are tested critically using experiments with widely different soil types, agronomic managements, and land uses. Parton (1987) found that uncertainties, especially the site history, set a limit on the precision that may be expected from the Century model’s regional predictions (….), and when looking at grassland biome worldwide, Parton (1993) stated that Century is useful both as a descriptive and analytic tool (…), but only against a large body of observations and rigorously calibrated. Falloon and Smith (2002) indicated that it may not always be appropriate to use default methods for estimating initial SOC pools, and that specific sites may require adjustment.

Addiscott (1995) specified two important problems when it comes to validating models: (i) The more parameters there are, the less likely that these parameter values can be obtained by direct measurement, (ii) the more parameters; the more likely that a nonlinear problem will occur.
This concluded to belief that before simulating Dutch agronomic land uses, it is important to calibrate and validate Century for Dutch [site] conditions. The following sections describe the possibilities and the adaptation of Century.

3.2 Calibration and Validation of SOM models in The Netherlands

To calibrate* and validate* the Century model, several options (explained in more detail in chapter 4) have been reviewed and compared. These options included articles where Century was calibrated for Dutch land uses, and datasets from Dutch agricultural long term experiments. The datasets are important for running Century with adjusted values found in Dutch literature and experiments, and to see how Century deals with the fact that it is given input data for which the model itself was not originally calibrated. Other models have been calibrated by using mainly fallow long-term experiments, CESAR [Vleeshouwers and Verhagen, 2002], or available long-term experiments, Daisy in Askov, Denmark [Bruun *et al.*, 2003]. Century requires a minimum amount of data input to run the model. These inputs are data on weather, soil plant, animal inputs, and land use and management inputs. Smith *et al.* (1997) already pointed out that the initial starting values can make a difference in performance and that site specific calibration is required.

3.3 Experimental set up

For the model runs, a distinction was made between the runs for the **initialisation** of Century (so initial C pools could be entered later in the simulation) and the **simulation** where varying actual Dutch agronomic management was added to the run. Two options were considered for initialization.
(i) The first option was to obtain data from long-term experiments from Dutch agriculture and to compare the runs made by Century. This could be done by running Century with adapted parameters after which it would be possible to compare the linear regression of observed data versus simulated model results [Parton *et al.*, 1993], or calculating the number of times the difference between Century model prediction and observed data differs by less than a threshold proportion (e.g. 25%) from the observed data, as described by Parton *et al*. (1993).

This gives estimations as to how accurate Century could predict SOM under different conditions than what it was calibrated for. The long-term experiment necessary for a good calibration needed to have several search criteria for fitting Century.

This search profile had the following characteristics:

- The experiment had to be long enough to be able to see organic matter changes in the soil, considering the fact that the passive SOM pool has very slow turnover rates; a time span of at least 40 years is preferred.
- The basic Century input data required. These include weather data (minimum temperature, maximum temperature per month, rain data), soil texture, crop rotations, preferably initial SOM pools for initialisation runs, nutrient input into the soil.
- The experiment needed to have known fertilization additions to the soil during the whole experiment.
- Experiments with crop use similar to that of the used rotations in the runs are necessary.
- If possible, documented land use prior to the beginning of the experiment is present.

(ii) The second option was to continue on what other researchers found when using data from long-term experiments from Western Europe for the calibration of Century. Several experiments were used for testing the Century model in the past. Considering climatic similarity and soil characteristics within Europe, it could be legitimate to assume different locations within Europe have little variability so a calibration for Century can be presumed.

For option **(ii)**, a summary of literature with calibration and validation for the Century model is described in § 4.1.2.

3.4 Initializations

The initialization run itself was based on a 'natural' environment, with no influence of human management or land use. This run is not to be compared to reality in The Netherlands, but is only necessary for the starting values of C pools and to make sure a steady state can be established within these pools. Century is adequate for simulating medium to long term (100 to >1000 years) changes in SOC and other ecosystem parameters in response to changes in climate, land use, and management. To establish initial pool sizes the models output of C in the active, slow and passive organic pools were used as starting values of C simulation [Bandaranayake *et al.*, 2003]. These initial values were then filled into the simulation runs where arable land is simulated with agronomic management. In order to see the actual changes over a longer period of time, the simulations were run for a longer time period then would be applied in reality. Table 3 gives an overview of the initializations made.

Table 3 Initializations made with Century 4.0

soil type	Initialization
Sand*	Temperate grassland with permanent grass (6000 years) (annex 2A)
Clay**	Temperate grassland with permanent grass (6000 years) annex 2B)

**sand with texture fractions: of 0.75 sand, 0.20 silt and 0.05 clay.*
***Clay with texture fractions of 0.40 sand, 0.40 silt and 0.20 clay.*

Since the initial C pools had to be estimated as Century parameters input, the two initializations with temperate grass for 6000 years were made. This is consistent with [Parton *et al.*, 1993] who ran Century for 5000 years, so steady state levels of SOM of the long term runs were used as initial conditions for the validation study. The end time was chosen by trial and error to make sure a steady state would be established which could be incorporated as the starting levels of the different SOM pools for the simulations. It was necessary to run Century for such a long period of time to make sure all parameters were adapted to the changed environment and all slow reaction pools (e.g. passive C pool) could establish a steady state.

3.5 Simulations

After this initialization, simulations were made with agronomic additions. The crop rotations used in the model runs were chosen from available literature [Schröder *et al.*, 2004, LEI, 2006, van Beek, 2006, Zwart, 2006]. The most common agricultural crop rotations were selected in combination with the soils most commonly used for these specific rotations. The two rotations used were picked from several possible Dutch rotations, because they are a commonly used combination in the Netherlands and represent an elaborate area of arable land and grassland in the Netherlands. The used reference year for this information was 2004. Table 4 gives an overview of the simulation runs made.

Table 4 Simulations made with Century 4.0

soil type	Simulation
Sand*	Agricultural crops, rotation of grass and maize in a 12 year rotation. (total of 5000 years initialization and ±1200 years rotations, annex 2C)
Clay**	Agricultural crops, rotation of 4 years with winter wheat, potato, grass/clover, sugar beet and potato (total of 5000 years initialization and ±1200 years with rotations, annex 2D)

**sand with texture fractions: of 0.75 sand, 0.20 silt and 0.05 clay.*
***Clay with texture fractions of 0.40 sand, 0.40 silt and 0.20 clay.*

The simulations started with the initial 5000 years with temperate grassland and the accompanied soil texture, after which the simulation period with the rotations would follow. The first rotation was a **grass-maize** (abbreviation: **GM**) rotation on a sandy soil. The first 5000 years were also run under permanent temperate grassland (initial), after which the rotation started. For this rotation, 6 years of grass, followed by 6 years of maize were programmed to simulate actual rotations in Dutch agriculture.

The second rotation involved a **wheat-potato-grass/clover-sugar beet-potato** (abbreviation: **WPSP**) rotation on a clayey soil. The rotation itself was a four year turnover of the different crops. Grass /clover is added during the winter months after the potato rotation year (second year) and is fully incorporated in the soil during ploughing in the following spring.

3.5.1 Adaptation Century model

In this report only arable crops under Dutch circumstances have been examined, which means that forest or savannah specific files, such as *tree.100* and *trem.100* were not used in the initializations or simulations. Also, the event *Fire.100* was not considered a recurring event, likely to alter soil organic matter dramatically in The Netherlands for long-term initializations and was not incorporated into the model for both the initializations and simulations. The different data files with altered values or parameters, necessary to run Century for Dutch agricultural rotations, are mentioned in the following sections.

3.5.2 Schedule.100 file

The schedule file is a pre-processor that allows the user to schedule management events and crop growth controls at specific times during the simulation. It produces an ASCII output file which is read by Century's list100 program [Metherell *et al.*, 1993]. The original schedule file used was c3grs.sch, which is meant for northern hemisphere c3 dominated vegetation. This file calls different data files for the parameters input. After the data files were checked and corrected for Dutch conditions, the schedule file was used for the initialization of the different SOM pools, required as a starting point for the actual simulation of the Dutch crop rotations. These adjusted data files can be found in annex 3.

For simulations the rotations were run for more or less 1200 years. Although this time period is considered to be very long for a repeated rotation with the same crops and does not resemble actual agricultural practices, it does give a good insight in the long term reaction of the different SOM pools. The four schedule files, used for determining the initialisations and the simulations can be found in Annex 4 (A till D).

3.5.3 The biome specific fix files

For the initialization and simulation one biome specific file gfix.100 was used, which adjusts the relative impact of a PET (monthly potential evapotranspiration) equation which was originally developed for the tropics. According to Keough (2006), gfix.100 is usually used for cropping simulations. These parameters are incorporated into the fix.100 file. This file with fixed parameters primarily relates to organic matter decomposition and is not normally adjusted between runs.

3.5.4 Data files

When running Century for a specific site, not all parameters are equally important to be altered for specific site parameters. Sometimes parameters had to be added to fit Dutch soils better. For example, an extra fertilization parameter has been added so that the amount of N given in one field application was raised from 5 g N/m2 to 10 g N/m2, which is more realistic for fertilization of Dutch grass-maize rotations.

It was also necessary to change some of the values of the parameters so this could approach Dutch conditions better. For example, the potential aboveground monthly production for potatoes was lowered from 150 g C/m2 to 120 g C/m2 after personal communication with [Zwart, 2006].

The altered values of the different data files are given in annex 3, and the data files that were not altered at all are the files cult.100, fix.100, graz.100, and irri.100. This implies that although they were examined for adjustments in the parameter values, the runs made with alterations did not improve or alter the outcome of the simulations or initializations, and the parameter values were kept at the initial values. Ministerie van landbouw- natuurbeheer en visserij (1993) has been used to verify parameter values, especially for grass and maize, but also for the management used for these crops.

The crop.100 data file has two crops (potato and sugar beet) with all parameters and their values (changed or unchanged) given. This has been done because the potato crop and the sugar beet crop parameters are not given with the standard Century 4.0 program. These files were provided by Keough (2006).

Crops in Century are defined by potential production, a temperature curve, C:N ratios and lignin contents of biomass pools [Kelly *et al.*, 1997]. The crops used in the different runs were temperate grass and maize in the GM run, and wheat (high yield), corn (high yield), clover/grass, temperate grass, potato and sugar beet in the WPSP run.

The omad.100 data file is used to add organic matter to the system. The different options are added animal manure or wheat straw. In the runs two more parameter values have been inserted to make a distinction between organic matter additions for initial runs (no intensive agriculture) and simulation runs in crop rotations. In annex 3 these added parameters and alterations to existing parameters can be found.

3.5.5 Climate Data

Century uses a monthly input of average minimum and maximum temperatures and a mean monthly input of precipitation. For the climate input in The Netherlands, data were used from the KNMI (Royal Netherlands Meteorological Institute). To run the initialization and the actual simulation of Century weather data were taken from 1901 till 2005 and the location used was *De Bilt*, a central located weather station in the Netherlands. Century was run with the stochastic generator, which generates weather from average and standard deviations of the monthly weather over at least 10 years [Metherell *et al.*, 1993].

3.5.6 Soils

The WPSP-rotation was simulated on a clayey soil, with sand-silt-clay fractions of 0.40, 0.40 and 0.20 respectively. The grass-maize rotation was simulated on a sandy soil, with sand-silt-clay fractions of 0.75, 0.20, and 0.05 respectively. These values were taken from data of several clayey and sandy soils found in BIS * (Bodemkundig Informatie Systeem).

4. Results

4.1 Validation Netherlands

4.1.1 Long term experiments in The Netherlands

Literature and several databases have been checked to find results from previous experiments in the Netherlands that could be used to calibrate Century for Dutch soils. Among these options were the following databases, literature and information systems: LEI (Landelijk Economisch Instituut), LNG (landelijk grondgebruik Nederland), BIS (Bodemkundig Informatie Systeem), Blgg (leading laboratory in the Dutch agricultural and horticultural sector), Kortleven (1963) and TAGA (extensive archive for technical information and soil samples from Alterra).

For several weeks these options were reviewed to find a long term experiment that could be used for calibrating Century. The search criteria as described in § 3.3 limited the experiments found suitable for calibrating Century. In many cases, long-term experiments were found with little or no good record of soil organic matter data or data not easily accessible as direct input in Century. LNG and LEI did not contain the soil data needed for Century input. BIS had soil data from point data and maps starting from 1960, but management knowledge as far as fertilization, cultivation and irrigation were absent, which makes it difficult to define Century parameter values. The combination of the unknown history and the crop data, which could not be read easily, made this option not suitable.

The laboratory for soil and crop analyses Blgg [Internet link 4, 2007] has over 2 million analysed soil samples taken at farmers' request. These samples date back as far as 1984 and are archived anonymously in an electronic database [Reijneveld *et al.*, 2007]. The major disadvantages of Blgg data were that soil samples are not taken from fixed depths, positions, fields and farms over time. For privacy reasons, the exact location is not documented in the database. Also, the samples are taken on the request of farmers each year, and whether this reflects a representative sample of a region (selected for land use and soil type homogeneity) has not been tested. Furthermore, the historic land use of the fields where samples are taken, are not clear; leaving an uncertainty about the state of SOC levels in the soil.

Kortleven (1963) had two possible experiments which could be used. The first experiment used crops in a rotation scheme so numerous, it would take extensive time to calibrate Century for the rare and irregular rotations used. The other experiment involved a fallow experiment for several years. However, this experiment did not involve plant or crop rotations, and had absent data for several years in which time crops were allowed to grow. Besides this, Century has already been tested extensively for fallow field decomposition experiments [Metherell *et al.*, 1993].

TAGA is a registry that consists of crop, soil and fertilization data from at least 2000 experiments. Though beforehand it was assumed that this archive would be the best option to find long term experiments, and that it would match the search profile for long-term experiments used in model calibration, the comprehensive time necessary to find and edit the soil and plant data for model use were considered too extended for the time span of this study.

4.1.2 Calibration and Validation Century by other authors

Several articles have been published as to how Century simulates data from long-term experiments. Amongst these experiments are European long-term experiments in Denmark (*Askov*) [Foereid and Hogh-Jensen, 2004], Eastern Germany (*Bad Lauchstadt*: [Smith *et al.*, 1997a], *Baden-Württemberg* [Werth *et al.*, 2005]), Czech republic (*Prague- Ruzyně*), the United Kingdom (*Rothamsted, park grass, Geescroft, Waite, Calhoun, Tamworth*) [Smith *et al.*, 1997a], Sweden (*Ultuna*) and Hungary (*Nagyhorksok, Martonvasar*) [Falloon and Smith, 2002].

Parton *et al.* (1993) tested Century for 11 temperate and tropical grasslands around the world. They found that the number of times the difference between Century model prediction and observed data differed by less than a threshold proportion (25%) of the observed data. In general, the observed versus simulated r^2 for the Century model and the empirical regression models are fairly similar (see figure 2).

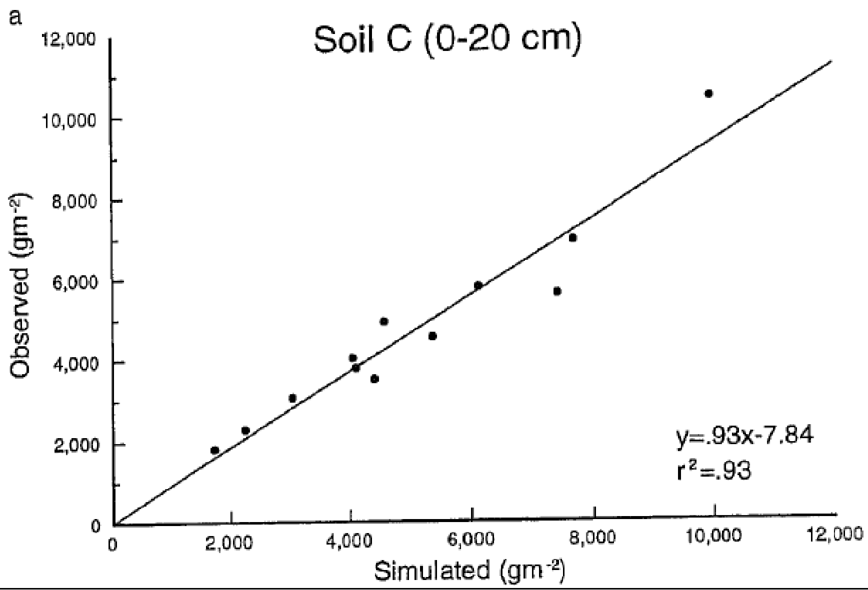

Figure 2, Comparison of simulated and observed steady state soil C for 9 of the 11 sites using Century [Parton et al., 1993].

Steady state soil C and N levels were simulated by the model (r^2 = 0.93 and 0.89 respectively) for a set of sites with differing climate and soil textures. The model was able to predict soil C (100%) and N levels (75%) errors less than ±25% of the observed values. The advantage of the Century model is said to be that it can predict total system behaviour (e.g. nutrient cycling, N gas fluxes, water fluxes, leaching inorganic and organic compounds) and responses to manipulations such as fertilization, irrigation, and land use changes, while regression models, like annual precipitation versus plant production, can only predict what will happen for the particular observed data set used to generate the regression models coefficients. The assumptions used to control soil C stability and decomposition (clay impact on passive SOM and silt plus clay on slow SOM) seem to work across a diverse set of soil textures and soil mineralogies.

Smith *et al.* (1997a) compared the performance of 9 models, including Century, using data sets from 7 long-term experiments. The methods for evaluating the accuracy of a simulation and determining the acceptable error are discussed in detail in Addiscott *et al.* (1995).

Smith *et al.* (1997a) did not try to show that measured and simulated values are significantly related (since they are not completely independent i.e. measured data have been used to render the measured and simulated values more similar) but instead showed the significant difference between measured and simulated values, despite attempts to render a more close correspondence with the measured data. Century showed the overall lowest bias and stayed on all occasions within the 95% confidence interval of the data.

Foereid and Hogh-Jensen (2004) tested and adapted Century for Northern European agricultural conditions using long-term datasets from the Askov experimental farm in southern Denmark. The part of the model dealing with decomposition was tested in isolation using a bare fallow experiment and it could predict soil organic matter levels with high accuracy. In the cropping experiments predictions were less accurate. The crop production was not accurately predicted, though predictions were more accurate on loamy than on sandy soils. They found that the decomposition model in Century was valid for most conditions and mild winters characterizing coastal areas in northern Europe.

Bandaranayake (2003) found that model predictions of organic C accumulation in turf grass systems compared reasonably well with compiled historical SOC data (figure 3), suggesting that the Century model was able to simulate and predict SOC changes and C sequestration in managed turf grass scenarios. The Century model was considered sensitive to both location and soil texture and is thought to be used effectively as a tool to predict SOC dynamics in turf grass systems.

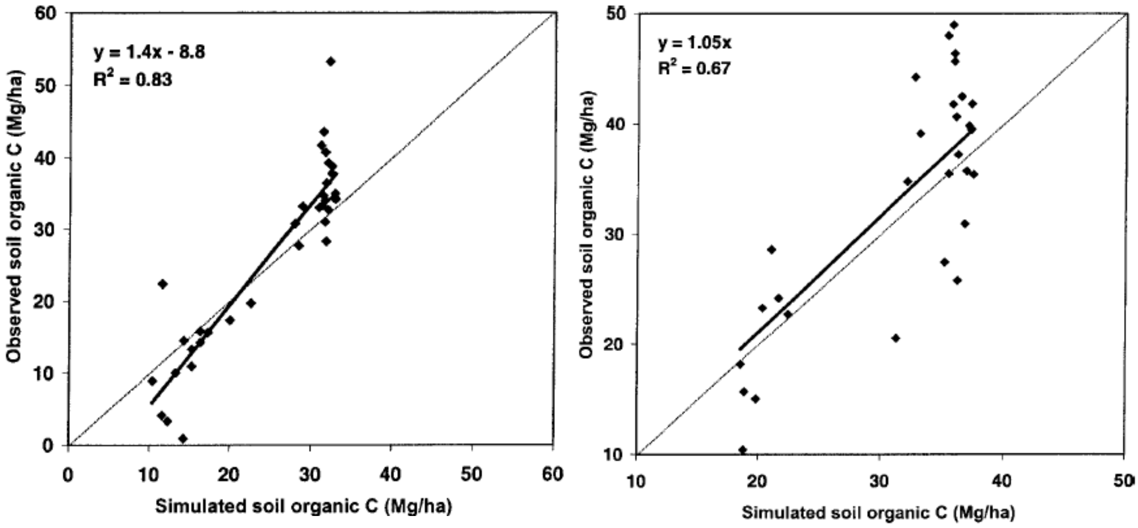

Figure 3, The graph on the left shows the comparison of observed and simulated soil organic C on putting greens in golf courses and the graph on the right shows the comparison of observed and simulated soil organic C in fairways in golf courses. Both located near Denver and Fort Collins [Bandaranayake et al., 2003].

Parton (1994) used Century (version 2.1) to model long-term management practices for wheat (*Triticum aestivum* L.) fallow agriculture. The comparison of the observed and simulated soil C levels gave a r^2=0.77, and model errors were less than ±5% of the observed data 57% of the time. The model results were within the 95% confidence interval of the observed data for 80% of the observations, and the major differences between the treatments were represented by the model.

Falloon and Smith, (2002) tested the SOM models Century and RothC by using datasets from 6 long-term experiments. Both models were tested for grassland, forest and arable management with different soil types. Century showed to work well under Hungarian arable conditions and estimated lower carbon inputs than RothC, but tended to turnover SOC much more rapidly. They found that for some sites, using default values for initialising SOM pool sizes in SOM models, may not give the most satisfactory results. However, the lack of detailed land use history information for many sites, or measurable analogues to SOM pools means that there may be little scientific basis for changing initial SOM pool values away from default values.

Werth *et al.* (2005) used 5 long-term experimental sites in South-West Germany under three different management practices; mowing, mulching (mowing twice a year without removal of the phytomass) and natural succession. They found that the organic carbon was in a steady state (mulched) or slightly decreasing for the succession plots and the mowed plots. Linear regressions between observed and simulated C stocks were given significant relations (R^2=0.8, figure 4) for mulched plots. The short term dynamics of C stocks were not reproduced.

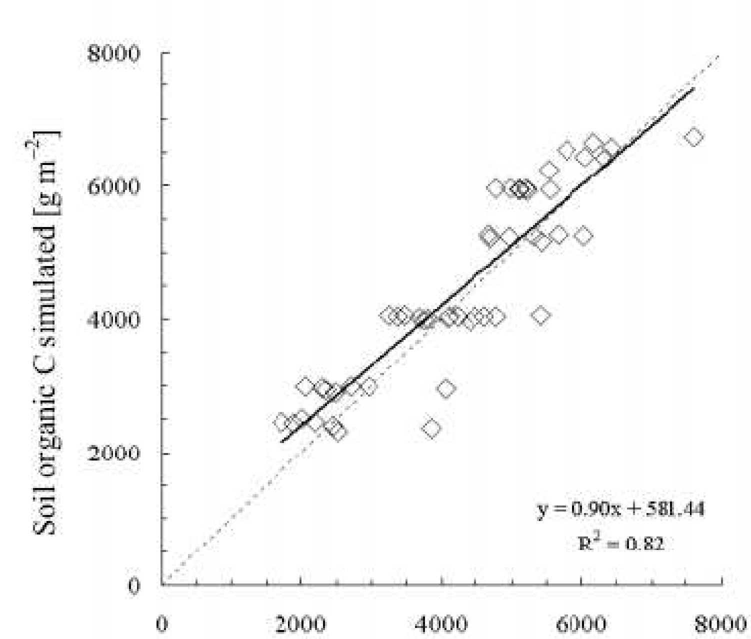

Figure 4, Comparison of measured and simulated soil organic carbon stocks during the experiment (1978-2002) for the "mulching twice a year" (n=49). The dashed lines show y=x line [Werth et al., 2005].

According to Price *et al.* (1999), who simulated the influence of climate change on boreal ecosystem carbon pools, Century 4.0 was able to reproduce spatial variation in soil and litter C densities satisfactorily but tended to overestimate biomass productivity.

Carvalho Leite *et al.* (2003) found that the Century model simulated changes in the total organic carbon content and obtained an excellent fit to measured data (only 5% contrast). This showed the high potential of the model to simulate soil organic matter dynamics in the tropics [Carvalho Leite *et al.*, 2003]. In 2004, Carvalho Leite *et al.* simulated SOM dynamics on an Acrisol under no-tillage and different ploughed systems using Century. TOC (total organic carbon) from tropical soil under different management systems could be simulated with Century, yet only the passive C pool correlated significantly. Both active and slow C pools were more sensitive to soil management systems than TOC and passive C pool. Century underestimated stocks of slow and active C pool and important chemical process in acid tropical soils have to be improved in this model.

In Canada, Monreal *et al.* (1997) tested Century with data obtained from long-term research plots cropped to wheat (*Triticum aestivum* L.) monoculture and cereal-hay. Century simulated changes in SOC within 10% of actual measurements taken over decades. SOC stock was slightly underestimated. It was suggested that the absence that C exudation by roots and its microbial metabolism and stabilization into soil humus are not explicitly defined in the model may contribute to the underpredictions. After considerate discussions and reviewing the literature, the conclusion was that calibration for Century has been done with long-term experiments in different locations of Western and Northern Europe and that Century can be used for the Netherlands: option **(ii)** from § 3.3 was used.

4.2 Initializations

In the two initializations of total soil organic carbon (SOC) no distinction was made in the management of the time schedule. This means that the two runs were identical, with the only exception of a difference in crop.100 parameter values (texture and start parameters). Figure 5 shows the total C found in Dutch soils when the initialization was made with adapted parameters.

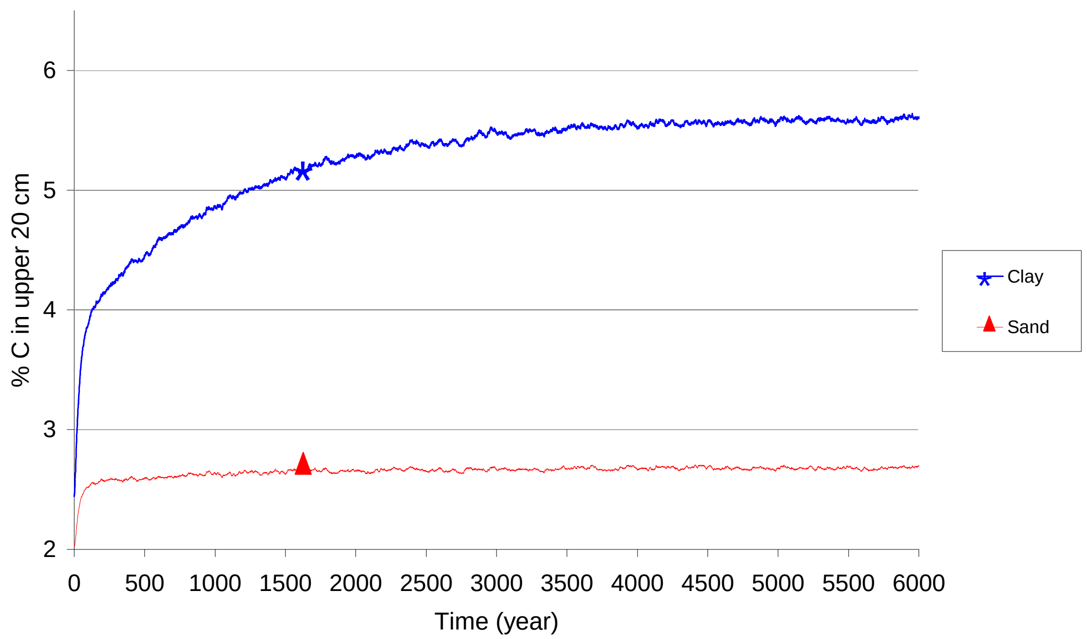

Figure 5, Total soil C under 6000 years of permanent grassland under clay and sand texture soil conditions. The x-axis shows the time after the run has started (in years).

The runs were made in such a time period that the total C is levelled to a steady state for both runs. This steady state is found at different years after the initialization started. The initialization for clay soils shows a higher total C build up in the upper 20 centimetres than for sand soils (5.6% and 2.7% for respectively clay and sand). Although a steady state is reached earlier than the end run time of 6000 years, the total run is used for testing the initialization so it can be verified that a steady state is reached within the run time. The starting values for both initial runs were 162 g C/m2 for the fast turnover pool, 3886 g C/m2 for the slow turnover pool and 2300 g C/m2 for the passive turnover pool. It was concluded that for both soil types after 5000 years a steady state was reached, so this period was used further.

4.3 Simulations

For the final simulations the runs were first programmed with temperate grass for 5000 years under the soil texture that was combined with the rotation needed. After this initialization, the actual rotation was programmed. The rotations lasted 1200 years so the model could adapt to the new conditions and a possible steady state could be reached. Figure 6 shows the total C under the GM and the WPSP rotation.

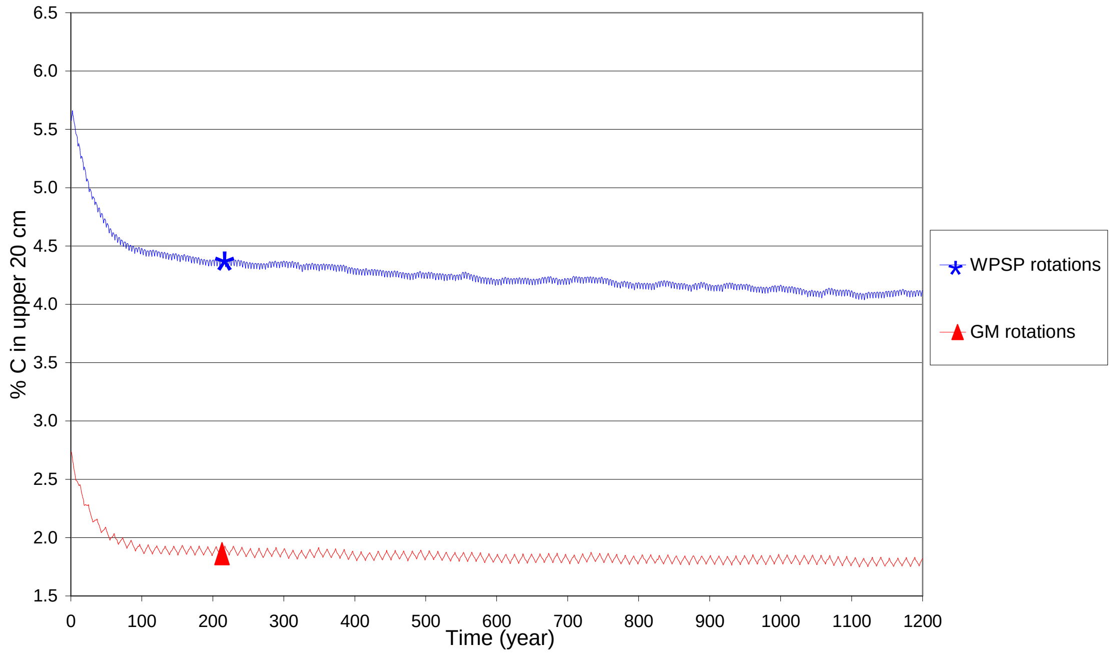

Figure 6, total soil C under common agricultural rotations of grass-maize (GM) on sandy soil and winter wheat-potato-clover-sugar beet and potato (WPSP) on clay soil. The x-axis shows the time after the rotation has started (in years).

The run with the GM-rotation shows a combination of a relatively rapidly decreasing %C line after which it declines more evenly. Overall, the run with the WPSP-rotation decreases rapidly at first (0-100 years), but advances into a slower decreasing graph. The final values for the GM and WPSP rotations are respectively 4.1 and 1.7 % C in the top 20 centimetres. The total C under the WPSP rotations has declined with 28% of the starting value, and under the GM rotation with 37 % of the starting value. The initialization of 5000 years is not shown in this figure, only the actual time of the simulation run itself. The absolute decrease in the gm-rotation between the beginning and the end of the simulation period is much smaller (± 1.0 % C in the upper 20 cm of the soil) than the decrease in the WPSP-simulation (± 1.6 % C in the top 20 centimetres of the soil). Figure 7 shows a more detailed part of figure 6.

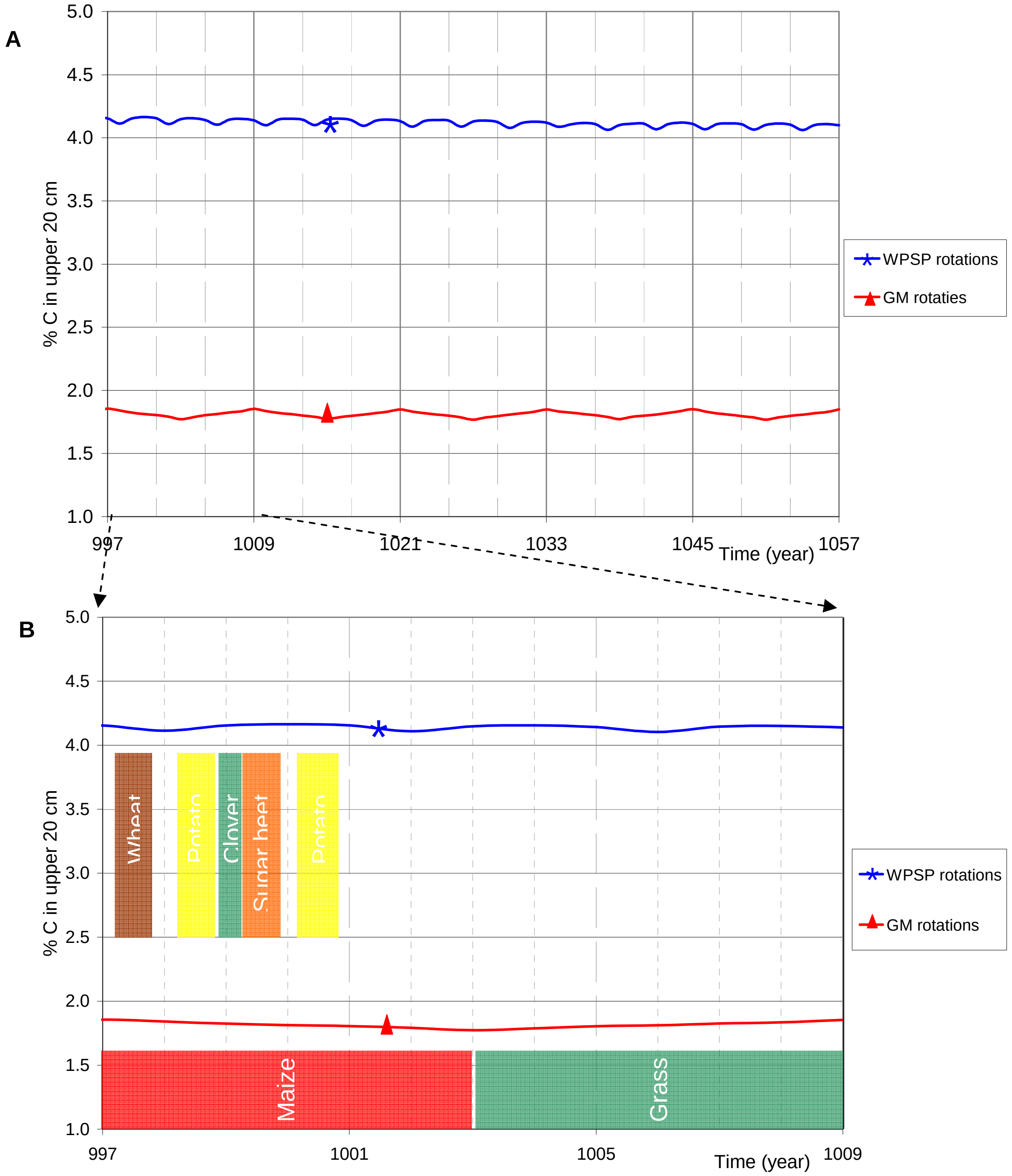

Figure 7, (A) Total soil C under common agricultural rotations of grass-maize (red) and winter wheat-potato-clover-sugar beet and potato (blue). The second graph (B) shows an enlargement of the first graph. The units in the second graph are identical to the ones used in the first graph. The x-axis shows the time after the simulation has started (in years).

In the upper graph (A) the simulation is shown at year 997 and ends for both rotations in the year 1056. The gm-simulation (red) has 5 rotations. Starting this period; these rotations are indicated by the 4 vertical, straight lines in the figure. The WPSP-simulation has 15 rotations (blue), and these divisions can be seen by the 4 vertical lines and the 10 vertical, dotted lines, which indicate 1 repeating cycle between each 2 lines. In the lower graph (B) a more detailed part of the upper graph is presented; the years 997 till 1009 are shown. 1 gm-rotation and 3 WPSP-rotations can be seen.

The percentage of SOC alters depending on the time in the rotation. As for the gm-simulation (Annex 4C) a distinction can be made between the period where maize grows (slow decrease of SOC between year 997 and 1003) and the period where grass grows (slow increase of SOC between 1003 and 1009). The difference between the lowest and the highest amount of SOC is 0.08 % C which corresponds with 4.7% or 0.05 g C/ Kg. The lowest amounts of SOC can be seen at the end of the maize period after which the grass period shows an evenly increase in SOC. The end total of soil organic C for the GM rotation is 1.82 % C.

The WPSP-simulation (Annex 4D) also shows variation within the rotation itself. It is possible to see a slight decrease in the first year of rotation, the year where winter wheat is planted. After wheat, potato is growing and it seems there is a slight increase in SOC (both wheat and potato are harvested in August). During the winter after potato, a grass/clover combination is grown and this vegetation is fully incorporated in the soil in spring through ploughing: the SOC level stabilizes slightly during this year and after sugar beet is planted this keeps continuing. Potato in the following year, gives a minimum decrease in SOC. At the end of the simulation a total amount of 4.12 % C is found for the WPSP rotation.

4.4 Comparison outcome original parameters and changed parameters

In order to determine whether the original Century parameters and the adjusted parameters differ very much a combination of the original runs with the adjusted runs can be seen in figure 8. The parameters which were added or changed can be found in annex 3 (A through C). The dark blue (diamond) line represents the adjusted WPSP run, the light blue (circle) line the original WPSP run, the red (triangle) line the adjusted GM run, and the purple (hexagon) line the original GM run. The main differences between the four runs can be found in the differences within the WPSP runs. The original run is much lower than the adjusted crop run. For the GM run, this difference is not so clear.

A steady state is not reached within the first 5000 years for the original runs, but % C is slowly increasing, whereas the adjusted initializations do reach a steady state within these 5000 years. The difference between the clay soil texture and sand soil texture is also more distinct in the adjusted runs. Within the original run with sand (GM), values are between 0.66 and 2.84 % C in the top 20 centimetres, in the adjusted run; these values are between 1.75 and 2.73 % C in the top 20 centimetres. For clay these values differ from 0.66 to 3.37 % C (original) to 2.44 and 5.66 % C (adjusted) in the top 20 centimetres.

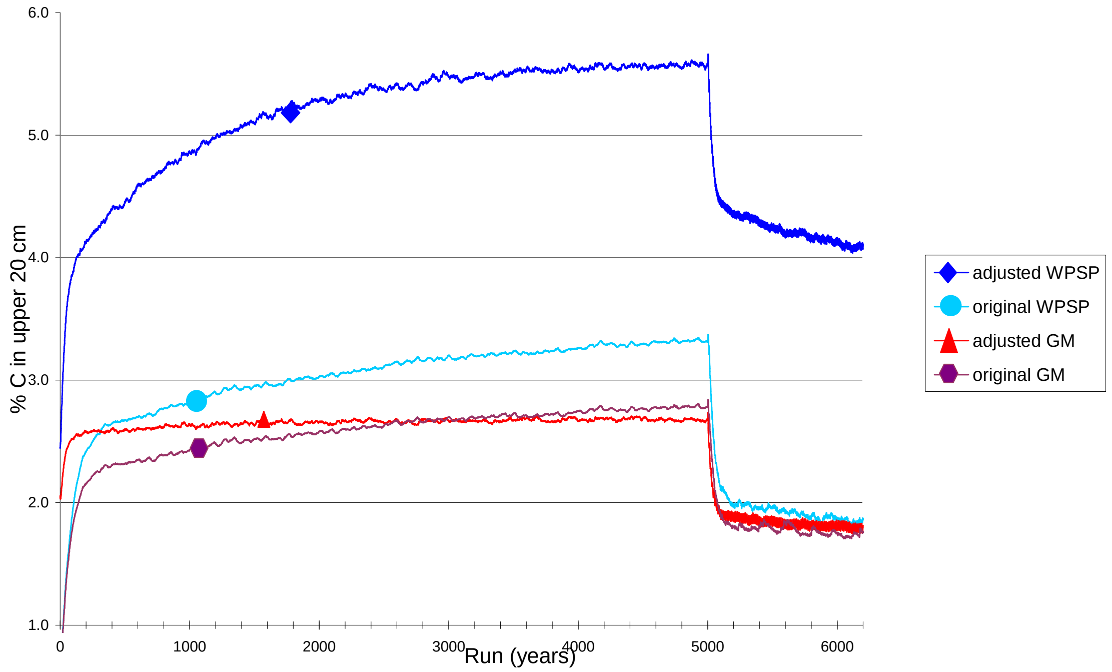

Figure 8, Initializations and simulations of GM and WPSP with original parameter values and of GM and WPSP with adjusted parameter values for Dutch conditions.

In the simulation (after 5000 years), the adjusted GM run shows a more evenly decreasing line than the original run. Overall, the original GM run is decreasing, but it shows an unbalanced increase and decrease of % C over the years. When comparing the WPSP runs, this simulation difference is not so varied.

5. Discussion

5.1 Model's performance

When working with Century, it became clear Century 4.0 had several model difficulties [amongst others[Internet link 5, 2000, Keough, 2006]:

The automatic fertilization function, the function where you can add fertiliser so that crop growth is at a maximum, does not function properly. Since Dutch agricultural soils have no N limitations when it comes to crop growth [Chardon, 2006], this would have been an interesting option to use while modelling under Dutch conditions. Instead of the automatic function the option of adding 5 g N/ m2 per fertilization is used in combination with adding specific grams per square meter through manure depending on the management used for different crops.

Century gave some problems with output data when adjusting parameters in specific blocks (multiple years where one kind of management is added). Planting two crops in one year was not given as an example or option in the manual of Century, though this practice is very common in the Netherlands and would be preferred in the model. The output data gave indistinct values when trying to implement several crops in multiple years and the decision was made to change the crop rotations to a minimum of runs where overlap occurred.

In the try-out of the runs a transition period between the initialization and the simulation years was used. This gave high unexplained temporary peaks in the SOC and at times no outputs from the model itself. Since this could only be solved by decreasing the number of transitions in the model run, the decision was made the transition years were not included in the simulation runs.

Werth *et.al*. (2005) stated that non fitting results of simulations and measurements between single years could be due to an underestimated turnover rate of the passive pool in the Century model compared to observed data. This was also found by Kelly *et al.* (1996).

Century can overestimate the C losses due to reduced plant inputs [Werth *et al.*, 2005]: this can be of importance for possible harvesting and mowing activities for grass and crops.

The irrigation file, irri.100, can be set to give fixed water quantities or can be set to give water amounts according to soil moisture. This last option is known to not work correctly in Century [Internet link 5, 2000], and considering that the only other option was to give a fixed amount of water during the whole year; the file was not used in any of the runs. This could cause a limit in water availability for the crops, especially for maize on sand in the summer, but this was considered a minor underestimation compared to the overestimation when applying too much water every year.

The Century manual states it is possible to look at output data more closely for given years; this is done by adjusting the time interval in the list file to the specific time span. However, it was not possible to obtain data output when a specific part of the run was entered for monthly output (no data was written to the output file). This meant the output SOC data from the WPSP simulation could not be observed per month, so no clarification can be given of the response from particular crops with regard to SOC levels.

Many current SOM models do not explicitly account for changes in pH. Smith *et.al*. (1997a) found that Century performance was best for grass and crop systems, but that it had difficulty in capturing the continuing rise in soil organic matter in one experiment where no fertilization took place. This was probably due to the lack of model to account for an effect of declining pH leading to a decreasing rate in decomposition. Century did not accounted for the effect of declining pH on decomposition rate despite some studies showing that pH affects only short-term decomposition. In this report only C and N were observed and therefore the pH was not accounted for; in Century 4.0 only P is affected by the pH.

Since Century uses a monthly time-step each action only affects SOM dynamics for that specific month although some studies have shown that ploughing affects decomposition for several months [Metherell et al., 1995], cited by Carvalho Leite et.al. (2004). The ploughing management in the Dutch runs also showed a strong reaction through decomposition rates of organic matter in the soil. Manies *et. al*. (2000) added an option ''Additional ploughing effect'' which was used in the months following ploughing in order to keep the decomposition rates at higher levels [Carvalho Leite *et al.*, 2003]. This was not done for the Dutch runs since decomposition rates were already high.

The output C levels for each year are given for month 8 of that specific year. Since these outputs can be made in any given month of the year, the values found for SOM levels can differ slightly, especially for the fast turnover pool of SOC. The slow and passive SOC change much slower; the output month will have smaller effects on the size of those SOC pools. Month 8 was chosen as the month for output, because the effect from the crop vegetation on the soil was considered extra strong in the months after harvesting.

These difficulties are not tested for their contribution to the results of the model. It is however important to mention the problems that can occur in order to understand the outputs from Century. Considering that an updated version of Century has been made in order to deal with these irregularities states that the model needs programme improvements in order to become more accurate at predicting the amount of C in the soil.

5.2 Initialization

The initialization period was set to 6000 years to reach a steady state in the C pools. This time span has been used after reading through literature where several long time spans were used to equilibrate the C pools [Parton *et al.*, 1993, Bandaranayake *et al.*, 2003, Carvalho Leite *et al.*, 2004] before any simulations were made in the model. This time span is not meant to approximate true C pools under a simulated long lasting Dutch environment with temperate grass, but it does equalize the different nutrient pools in the system to a level from which the rotation can start. The standard given C pools distribution could also be maintained for the Dutch runs, but considering these pools were based on estimated C pools in grassland in the USA, this decision was not made. The reason for the long initialization and not for a couple of years is that when looking at long-term responses from all C pools in the soil, a few years would be inaccurate to see slow C pools shifts.

The outcome of the soil C in the initialization (2.7% for sandy conditions and 5.6% for clayey conditions) signifies a value of ± 4.6% SOM for sandy and ± 9.6% SOM (when applying the rule of SSSA-part 5 (1996) of 1.72 as a conversion of total C to SOM) for clayey conditions. These values are relatively high for a permanent grassland situation, and can have two causes: (1) No Dutch environment has been under grassland conditions for the time used in the initialization and therefore no SOM values of that level can be reached in reality , and (2) it is known that Century can have difficulty with simulating certain grassland conditions [Bandaranayake *et al.*, 2003] since especially grass can create a relatively think layer of decomposing organic matter which is located on top of the surface layer and which is not taken into account by Century. This last reason is also important for the high and unrealistic SOM pools in forests: the highly decomposed litter that remains on the soil surface is automatically transferred to a slow SOM pool [Kelly *et al.*, 1997].

Century showed very high increases in some of the first initializations made. It was not clear what caused these increases and in order to look for the reason a test was done. This test implied that the last SOM pool results found in Century were given as the start SOM pools in a new, but identical run in Century. The runs still increased in the first couple of years.

Other runs, with changing time blocks in the run (changing of land use and land management) also gave an increase of soil C. This increase could not be traced back to a given adaptation. After re-entering the values of the 3 SOC pools in an otherwise identical initialization run, it can be suggested that the increase in SOC has something to do with an internal shift of C and N pools in Century itself. Figure 8 showed a larger difference between the original initialization run and the adjusted initialization run of the WPSP rotation. This distinct difference cannot only be explained by the parameter changes, and since the same site file has been used for all 4 runs (and one site file has only one weather file as an input) the weather data cannot explain the differences either. It is possible that the internal process graphs within the model, used to link different parameters to one another, are a cause for the large differences between the changed parameters and the output, but this has not been tested. The fact that the GM simulation does not respond as strong to these weather files is probably because of the crops used.

In the article of [Smith *et al.*, 1997a] models were forced to run for only 1 dataset without allowing model calibration. Model calibration for other datasets was permitted because many of the models were to be used in situations (land-uses, treatments and climatic conditions) which they had not previously encountered. For use at larger scales, however, and for predicting future changes, such calibration data will not exist, and although [Smith *et al.*, 1997a] want models to be used in a truly predictive manner so that their ability to predict SOC dynamics without site specific calibration, it is exactly the calibration which makes it possible to use a model for given circumstances in a specific area. However, Century is a very elaborate model when it comes to the model's influence on input and output parameters. It is difficult to understand why outputs change in relation to different inputs, and this cannot be explained easily when considering the model as a black box.

5.3 Simulation

Century responded well to calibration with fallow experiments [Metherell *et al.*, 1993, Parton, 1994, Foereid and Hogh-Jensen, 2004]. As described by Foereid and Hogh-Jensen (2004), who tested Century for long-term experiments, Century had somewhat difficulty to obtain accurate predictions in cropping experiments. The model was ultimately not calibrated and validated for Dutch long-term experiments.

For the Dutch simulations an outcome was found where a sand texture has a lower total soil organic carbon content in combination with grass maize rotation than a clay texture with mixed agricultural crops. Within these runs both soil texture types end in steady state conditions (clay: y = 0.0002x + 3.8495, and sand: y = 1E-05x + 1.7785 for the final 100 years). This trend line is not expected when looking at the trend of the clay simulation; it shows a more decreasing line than the sand simulation. The sand simulation trend is more evenly. The differences between SOM levels in grassland and in agricultural field's has already been described [Jenkinson and Rayner, 1977, Kelly *et al.*, 1997, Smith *et al.*, 1997b, Freibauer, 2004], and the relation that organic matter increases with the increase of clay in the soil as well [Sorensen, 1981, Parton, 1987]. For example; Falloon and Smith (2002) found that Century simulations of the arable-hay and grazed-fallow treatments in the UK both showed a SOC increase during the years when the treatments were under grass, due to the greater quantity, and lower decomposability of C input under grassland compared to arable management. This was also observed in the runs with grass-maize combinations. Under grass an increase in SOC was registered, but when changing to maize land, a decrease was observed in those years.

During the simulation, the amount of N-fertilizer applied to the soil was kept at high levels to ensure no lack of N-uptake for the crops (§ 5.1), but during the last 200 years of the simulation run of WPSP, N showed to be the limiting factor to crop growth. This limitation was not solved by adding even more N to the soil. Kelly *et al.* (1997) already mentioned that Century is heavily N constrained.

Carter *et al.* (2003) illustrated the importance of C inputs in the Century model to maintain SOM levels. Potato crop productivity and SOC were generally maintained in rotations that contained Italian ryegrass, but declined under rotations with red clover and barley. Janssens *et al.* (2003) concluded that despite the difference in size, both model estimate and observations suggest a net loss of C from arable soils. This net loss occurs because in arable soils harvest reduces C returns to the soil, whereas C losses may be enhanced because of agricultural practices such as tillage. Thus, land conversion from other land uses to cropland is likely to lead to a decline in soil C.

Even though the major land-use changes occurred much longer than 20 to 30 years ago, current loss of C from cropland soils may be the legacy of conversion of land to cropland in the past. Two hypotheses why arable lands lose organic matter are: (i) changes in management practice, such as a decrease in the application of organic manure to cropland and (ii) rotations of crops. If the conversion from cropland to grassland equals the conversion from grassland to cropland, national statistics will indicate no land-use change where in reality there is. Under such conditions, arable soils can continue to lose C, and grasslands to gain C, because national statistics only report net land use changes.

The lack of data and the simplifications assumed in aggregating fluxes from the mosaic of vegetation types, land-use histories, soil types, climates, and management regimes is offsetting the current best estimate of C changes in European agricultural soils. These indicators indicate that croplands are losing 300 Tg C/y to the atmosphere where the C balance of grassland ecosystems was estimated (by following exactly the same methodology as for arable soils) to constitute a net C sink (101 Tg C/ y). When a normal probability distribution is assumed, the probability that the land-based sink estimate is positive (i.e., a net C sink) only amounts to 0.66 Tg C/ y [Janssens *et al.*, 2003].

5.4 Sensitivity tests

When testing the sensitivity of some of the parameters of the model, clear distinctions have to be made between the most important parameters that have to be tested, and secondly; in which order the chosen parameters have to be altered, since the use and the order of parameters can change the outcome of the sensitivity dramatically. Sensitivity tests were not executed for Dutch soils. Foereid and Hogh-Jensen (2004) performed sensitivity tests for Century using a Danish long term experiment, and looked for the effect of soil organic carbon on maximum crop production and the effect of changing the starting conditions of size and C:N ratio for each pool of SOM by ± 10%. The decomposition model in Century turned out to be valid for most moist conditions and mild winters characterising coastal areas in Northern Europe, but variations among years could not be reproduced when it came to crop production. Their sensitivity analysis showed that the predicted carbon level was relatively insensitive to maximum crop production levels, except for grass-clover and spring cereals. Less than 1% change in the soil carbon was found in response to a 10% change in starting conditions of the active and slow organic pools. [Foereid and Hogh-Jensen, 2004] state that the crop model appears too simple to simulate crop growth outside the area and climate for which it was developed. Yet Smith *et.al.* (1997a) concluded that the coupling of simpler plant growth sub models to several SOM models, including Century (grasslands, arable crops, forest and savannah) did not result in poor model performance: there appeared to be some benefit in simplified approaches.

5.5 SOM levels in a Dutch map with Century as a tool

Century gives output which can be made valid for different scale variability (annex 2). The parameter requirements for rotations on the plot, field, etc. level, have to be identical for each separate run made. Century uses the data files which are located in the same directory as where the Century executable is located, so different schedule files for different circumstances are always linked to the same data files, for example ‘crop.100’. This means that all data Century needs for one run, has to be located in the files within the folder where the executable programme of Century is located. Several land uses in combination with different land management lead to more than 1 Century schedule file, which has to be specified and programmed for the specific rotation.

In summary: it is possible to create *several* schedule files, each with a unique land use, soil texture, and land management combination, yet *all possible* parameters for these schedule files have to be located in the 12 data files used.

In order to use Century as a tool to map The Netherlands with its combined land use and land management, it is best to divide The Netherlands in several main classes, e.g. nature classes (grassland and forests), and agricultural classes. The agricultural classes can then be divided into more broad land covering parts. For example grassland, maize, and 4 or 5 rotation schemes known to represent bulk areas of The Netherlands.

The time spans used for these rotations have to be similar for each run, in order to be able to combine the output data for each run. The level of carbon percentages in the last output year can then be used as the possible percentage of carbon levels in the top 20 centimeters of the soil. These carbon percentages can be combined with a geographic information system which gives a map of the Netherlands and the division of the areas used for the Century runs with the appropriate carbon percentages.

6. Conclusions & Recommendations

6.1. Conclusions

Century is a complex model which can be used to determine several changes in the soil. In this report only the soil organic model has been taken into account. During the review of literature it became clear that Century cannot be used in The Netherlands without the calibration of the model for Dutch conditions. It is essential that a model is tested for the location it is going to be used for in order to establish some kind of verification of the model. No usable long term experiments were found for the calibration and validation of Century. Therefore, the hypothesis given in § 1.1 could not be tested in this report. The continuation in case of the possibility where Century cannot be used in The Netherlands without additional changes to the model described (§ 1.1) and examples for possible options are given:

No usable long term experiments were found for the calibration and validation of the model. This does not mean there are no possibilities to find Dutch long term experiments. In this report a decision was made beforehand to evaluate the most representative land uses in The Netherlands concerning grassland and cropland. For the calibration and validation of Century a different approach should be considered, where in advance, the best long term experiments are chosen, after which the model is calibrated with these chosen experiments. Most likely these experiments can be found in the TAGA database (§ 4.1.1), where experiments which satisfy the Century basic input requirements, can be found. This step includes the search for (preferably two) long term experiments to calibrate and validate Century as a model. Specific attention has to be given to the accuracy of the crops rotation and land management carried out within these experiments. In order to understand the reactions and output of Century, the model itself should not be considered as a black box, but the internal pathways from the model should be evaluated as well.

Century showed a trend of decreasing soil organic matter decline when simulating Dutch agricultural management for both grass–maize rotation (with a sand texture) and a wheat-potato-clover-sugar beet and potato rotation (with a clay texture). The model responded strongly to the management of ploughing (increasing decomposition) and fertilizers (increasing SOM levels) added to the soil. No clear distinctions could be made about the different crops used while simulating rotations, since Century did not give output data when specifying for specific months during the rotations. The model itself has limitations as far as its possibilities (§ 5.1).

6.2 Recommendations

6.2.1 Long term experiments

In this report Century has been tested without calibration to verify the adaptations that were made to the model. It was mentioned already that a long term experiment is needed to model similar circumstances and influences to predict a good model's outcome. For a following experiment to test the ability of using Century in the Netherlands, a combination of at least two Dutch long term experiment should be given. One experiment to calibrate the model, and another experiment to validate the model.

6.2.2 Model runs

Two considerations can be given when using Century for future usage:

- In order to fully understand the reasons why Century reacts so strongly to certain changes in the model (sensitivity to fertilization) and runs (adding extra and overlapping rotations in one run), both described in § 5.1, it is recommended that when finding similar strong reactions to inputs, the source code should be evaluated as well. This can give a better inside in the model's performance and what inputs link to parameter outputs in the model.
- Since changes in pH may well occur in some ecosystems under global environmental change, further research and an explicit description linking pH and decomposition rate may be required in future model runs [Smith *et al.*, 1997a].

6.2.3 Climate

The Century model has not been tested to its full extent in this report. For example: the combination of the response of soil carbon storage to temperature is an aspect that can be tested while using Century. An increase in soil micro organisms and the soil respiration that comes with this increase can also be taken into account. The combinations of these extra tools make Century an interesting model to be used in climatic change studies.

6.2.4 Century 5.0

Century 5 is an improved version of Century 4.0. It has several advantages over Century 4.0. Century 4.0 integrates the effects of climate and soil driving variables and agricultural management to simulate carbon, nitrogen, and water dynamics in the soil-plant system, but version 5 includes a layered soil physical structure and represents a major change in the technical aspects of the model implementation, and includes new algorithms and structures for the physical soil, erosion, deposition, and depth distribution of organic C.

A Century 4.0 upgrade also added an option to simulate soil surface temperature warming experiments where the soil surface temperature is warmed without an increase in the minimum and maximum air temperature values if desired [internet link 5]. Century 5.0 also includes the current cumulative set of bug fixes to Century's algorithms, easier and quicker access to simulation results, and a graphical user interface with which to configure and run your simulations. SOC is distributed over depth in the physical soil according to an exponential density distribution of organic C which decreases with depth. New output variables include total profile C and total C below the simulation layer [Internet link 6, 2007].

Annex

Annex 1, Data files Century	name file
crop options	crop.100
cultivation options	cult.100
fertilization options	fert.100
fire options	fire.100
grazing options	graz.100
harvest options	harv.100
irrigation options	irri.100
organic matter additions options	omad.100
tree options	tree.100
tree removal options	trem.100

Annex 2, Characteristics of multi-compartment model Century, after [Shibu, 2006].

C Pools [-]	C/N Ratio [-]	Residence Time Pool (years)
Structural	150	1-5
Metabolic	10-30	0.1-1
Active SOM	3-14	1-5
Slow SOM	12-20	20-40
Passive SOM	11-12	400-2000

In this table the different C pools, the time C is situated in these pools and the C/N ratios used for the decomposition rate of the C in the pools are listed. This can be done on a plot, field, regional, national or globalscale and the scope can be natural vegetation, grazed ecosystem, arable ecosystem or forest ecosystem.

Annex **3 (A),** crop.100 parameters which have been changed or added

Parameter	**original**	**adjusted**	**Parameter**	**original**	**adapted**
Wheat		**W3**	**Potato**	**POT**	
HIWSF	0.5	0	PRBMN(3,2)	0	
Temperate Grassland		**TG**	PRBMX(1,1)	25	
PPDF(1)	22	23	PRBMX(2,1)	420	
PLTMRF	0.5	1	PRBMX(3,1)	420	
PRAMN(1,1)	30	20	PRBMX(1,2)	0	
PRAMN(1,2)	90	40	PRBMX(2,2)	0	
HIMON(1)	2	0	PRBMX(3,2)	0	
HIMON(2)	1	0	FLIGNI(1,1)	0.15	
SNFXMX(1)	0	10	FLIGNI(2,1)	0	
Potato		**POT**	FLIGNI(1,2)	0.06	
PRDX(1)	150	120	FLIGNI(2,2)	0	
PPDF(1)	17		HIMAX	0.42	
PPDF(2)	35		HIWSF	0	
PPDF(3)	1.2		HIMON(1)	1	
PPDF(4)	5		HIMON(2)	1	
BIOFLG	0		EFRGRN(1)	0.65	
BIOK5	1800		EFRGRN(2)	0.6	
PLTMRF	0.4		EFRGRN(3)	0.6	
FULCAN	150		VLOSSP	0.04	
FRTC(1)	0.6	0.7	FSDETH(1)	0	
FRTC(2)	0.75	0.85	FSDETH(2)	0	
FRTC(3)	2		FSDETH(3)	0	
BIOMAX	600		FSDETH(4)	200	
PRAMN(1,1)	12		FALLRT	0.12	
PRAMN(2,1)	100		RDR	0.03	
PRAMN(3,1)	100		RTDTMP	2	
PRAMN(1,2)	57		CRPRTF(1)	0	
PRAMN(2,2)	160		CRPRTF(2)	0	
PRAMN(3,2)	200		CRPRTF(3)	0	
PRAMX(1,1)	25		SNFXMX(1)	0	
PRAMX(2,1)	200		DEL13C	-27	
PRAMX(3,1)	230		CO2IPR(1)	1.3	
PRAMX(1,2)	125		CO2ITR(1)	0.77	
PRAMX(2,2)	260		CO2ICE(1,1,1)	1	
PRAMX(3,2)	270		CO2ICE(1,1,2)	1	
PRBMN(1,1)	20		CO2ICE(1,1,3)	1	
PRBMN(2,1)	390		CO2ICE(1,2,1)	1.3	
PRBMN(3,1)	340		CO2ICE(1,2,2)	1	
PRBMN(1,2)	0		CO2ICE(1,2,3)	1	
PRBMN(2,2)	0		CO2IRS(1)	1	

Annex **3 (A),** crop.100 parameters which have been changed or added

Parameter	original	adjusted	Parameter	original	adapted
Sugar Beet	**SUGB**		PRBMX(1,2)	0	
PRDX(1)	175	96	PRBMX(2,2)	0	
PPDF(1)	17		PRBMX(3,2)	0	
PPDF(2)	35		FLIGNI(1,1)	0.15	
PPDF(3)	1.2		FLIGNI(2,1)	0	
PPDF(4)	5		FLIGNI(1,2)	0.06	
BIOFLG	0		FLIGNI(2,2)	0	
BIOK5	1800		HIMAX	0.42	
PLTMRF	0.4		HIWSF	0	
FULCAN	150		HIMON(1)	1	
FRTC(1)	0.6	0.7	HIMON(2)	1	
FRTC(2)	0.75	0.9	EFRGRN(1)	0.65	
FRTC(3)	2		EFRGRN(2)	0.6	
BIOMAX	600		EFRGRN(3)	0.6	
PRAMN(1,1)	12		VLOSSP	0.04	
PRAMN(2,1)	100		FSDETH(1)	0	
PRAMN(3,1)	100		FSDETH(2)	0	
PRAMN(1,2)	57		FSDETH(3)	0	
PRAMN(2,2)	160		FSDETH(4)	200	
PRAMN(3,2)	200		FALLRT	0.12	
PRAMX(1,1)	25		RDR	0.03	
PRAMX(2,1)	200		RTDTMP	2	
PRAMX(3,1)	230		CRPRTF(1)	0	
PRAMX(1,2)	125		CRPRTF(2)	0	
PRAMX(2,2)	260		CRPRTF(3)	0	
PRAMX(3,2)	270		SNFXMX(1)	0	
PRBMN(1,1)	15		DEL13C	-27	
PRBMN(2,1)	390		CO2IPR(1)	1.3	
PRBMN(3,1)	340		CO2ITR(1)	0.77	
PRBMN(1,2)	0		CO2ICE(1,1,1)	1	
PRBMN(2,2)	0		CO2ICE(1,1,2)	1	
PRBMN(3,2)	0		CO2ICE(1,1,3)	1	
PRBMX(1,1)	35		CO2ICE(1,2,1)	1.3	
PRBMX(2,1)	420		CO2ICE(1,2,2)	1	
PRBMX(3,1)	420		CO2ICE(1,2,3)	1	
			CO2IRS(1)	1	

Annex **3 (B),** omad.100 parameters which have been changed or added.

	original	GM	WPSP
STRAW_MANURE	**M**	**M**	**M**
'ASTGC'	100	43.6	123.64
'ASTLBL'	0	0	0
'ASTLIG'	0.25	0.25	0.25
'ASTREC(1)'	30	7.3	7.3
'ASTREC(2)'	300	300	300
'ASTREC(3)'	300	300	300
MAIZE	**M**	**MM**	
'ASTGC'	123.6	123.6	-
'ASTLBL'	0	0	-
'ASTLIG'	0.25	0.25	-
'ASTREC(1)'	7.3	7.3	-
'ASTREC(2)'	300	300	-
'ASTREC(3)'	300	300	-
WHEAT_STRAW	**W**	**W**	**W**
'ASTGC'	100	162	162
'ASTLBL'	0	0	0
'ASTLIG'	0.15	0.06	0.06
'ASTREC(1)'	80	20	7.3
'ASTREC(2)'	300	300	300
'ASTREC(3)'	300	300	300
GRASS_STRAW	**G**	**G**	**G**
'ASTGC'	162	162	162
'ASTLBL'	0	0	0
'ASTLIG'	0.06	0.06	0.06
'ASTREC(1)'	20	20	20
'ASTREC(2)'	300	300	300
'ASTREC(3)'	300	300	300

Annex 3 (C), fert.100 parameters which have been changed or added

Parameter	original	adapted	Parameter	original	adapted
Nitrogen__10_gN/m2		N10			
'FERAMT(1)'		10.00000	'FERAMT(1)'		10.00000
'FERAMT(2)'		0.00000	'FERAMT(2)'		0.00000
'FERAMT(3)'		0.00000	'FERAMT(3)'		0.00000
'AUFERT'		1.90000	'AUFERT'		1.90000

Annex 4 (A) Schedule file initialization

grass-maize, with temperate grassland

0		Starting year
6000		Last year
GMINI.100		Site file name
0		Labelling type
TG		Initial crop
Year	Month	Option
6000		Last year
1		Repeats # years
0		Output starting year
8		Output month
1		Output interval
S		Weather choice
1	1	CROP
TG		
1	1	GRAZ
W		
1	2	GRAZ
W		
1	3	GRAZ
W		
1	4	FRST
1	4	GRAZ
GL		
1	5	GRAZ
GL		
1	6	GRAZ
GL		
1	7	GRAZ
GL		
1	8	OMAD
G		
1	8	GRAZ
GL		
1	9	GRAZ
GL		
1	10	LAST
1	10	OMAD
G		
1	10	GRAZ
W		
1	11	GRAZ
W		
1	12	GRAZ
W		

Clarifications abbreviations can be found in [Metherell, 1993]

Annex 4 (B) Schedule file initialization

Wheat-potato-grass-clover-sugar beet-potato initialization with temperate grassland

0		Starting year
6000		Last year
GPSPINI.100		Site file name
0		Labelling type
TG		Initial crop
Year	Month	Option
6000		Last year
1		Repeats # years
0		Output starting year
8		Output month
1		Output interval
S		Weather choice
1	1	CROP
TG		
1	1	GRAZ
W		
1	2	GRAZ
W		
1	3	GRAZ
W		
1	4	FRST
1	4	GRAZ
GL		
1	5	GRAZ
GL		
1	6	GRAZ
GL		
1	7	GRAZ
GL		
1	8	OMAD
G		
1	8	GRAZ
GL		
1	9	GRAZ
GL		
1	10	LAST
1	10	OMAD
G		
1	10	GRAZ
W		
1	11	GRAZ
W		
1	12	GRAZ
W		

Clarifications abbreviations can be found in [Metherell, 1993]

Annex 4 (C), Schedule file, simulation grass-maize rotation

Grass-maize simulation

0		Starting year									
6200		Last year									
GM1412.100		Site file name									
TG		Initial crop									
Year	month	Option									
6200		Last year									
12		Repeats # years									
5001		Output starting year									
8		Output month									
1		Output interval									
S		Weather choice									
1	1	CROP	3	10	HARV	6	4	OMAD	9	10	HARV
C-HI			GS			MM			H		
1	4	PLTM	3	10	LAST	6	6	FERT	9	10	LAST
1	4	CULT	3	10	SENM	N5			10	1	CROP
P			4	1	CROP	6	10	HARV	TG		
1	4	OMAD	C-HI			GS			10	4	FRST
MM			4	4	PLTM	6	10	LAST	10	4	CULT
1	6	FERT	4	4	CULT	6	10	SENM	P		
N5			P			7	1	CROP	10	4	OMAD
1	10	HARV	4	4	OMAD	TG			M		
GS			MM			7	4	PLTM	10	10	HARV
1	10	LAST	4	6	FERT	7	4	CULT	H		
1	10	SENM	N5			P			10	10	LAST
2	1	CROP	4	10	HARV	7	4	OMAD	11	1	CROP
C-HI			GS			M			TG		
2	4	PLTM	4	10	LAST	7	10	HARV	11	4	FRST
2	4	CULT	4	10	SENM	H			11	4	CULT
P			5	1	CROP	7	10	LAST	P		
2	4	OMAD	C-HI			8	1	CROP	11	4	OMAD
MM			5	4	PLTM	TG			M		
2	6	FERT	5	4	CULT	8	4	FRST	11	10	HARV
N5			P			8	4	CULT	H		
2	10	HARV	5	4	OMAD	P			11	10	LAST
GS			MM			8	4	OMAD	12	1	CROP
2	10	LAST	5	6	FERT	M			TG		
2	10	SENM	N5			8	10	HARV	12	4	FRST
3	1	CROP	5	10	HARV	H			12	4	CULT
C-HI			GS			8	10	LAST	P		
3	4	PLTM	5	10	LAST	9	1	CROP	12	4	OMAD
3	4	CULT	5	10	SENM	TG			M		
P			6	1	CROP	9	4	FRST	12	10	HARV
3	4	OMAD	C-HI			9	4	CULT	H		
MM			6	4	PLTM	P			12	10	LAST
3	6	FERT	6	4	CULT	9	4	OMAD	##	99	X
N5			P			M					

Clarifications abbreviations can be found in [Metherell, 1993]

Annex 4 (D), Schedule file, simulation wheat-potato-grass-clover-sugar beet-potato simulation

Wheat-potato-grass-clover-sugar beet-potato simulation

0			Starting year											
6205			Last year											
GPSP1412.100			Site file name											
TG		Initial crop												
Year	Month	Option												
5005		Last year												
5		Repeats # years												
5001		Output starting year												
8		Output month												
1		Output interval												
S		Weather choice												
1	1	CROP	3	3	CULT	5	4	PLTM	2	4	FERT	4	4	PLTM
TG			P			5	4	OMAD	N5			4	4	FERT
1	1	GRAZ	3	4	CROP	M			2	4	OMAD	N10		
W			POT			5	6	FERT	M			4	4	CULT
1	2	GRAZ	3	4	PLTM	N3			2	5	FERT	P		
W			3	4	OMAD	5	8	HARV	N10			4	4	OMAD
1	3	GRAZ	M			R			2	6	FERT	M		
W			3	6	FERT	5	8	LAST	N5			4	5	FERT
1	4	FRST	N3			5	10	CROP	2	8	HARV	N5		
1	4	GRAZ	3	8	HARV	W3			R			4	8	HARV
GL			R			5	10	PLTM	2	8	LAST	R		
1	5	GRAZ	3	8	LAST	5	10	CULT	2	9	CROP	4	8	LAST
GL			3	9	CROP	P			GCP					
1	6	GRAZ	GCP			5	10	OMAD	2	9	PLTM			
GL			3	9	PLTM	M			2	11	LAST			
1	7	GRAZ	3	11	LAST	5	11	LAST	3	1	CROP			
GL			4	1	CROP				GCP					
1	8	GRAZ	GCP			#	Last year		3	4	CROP			
GL			4	2	FRST	4	Repeats # years		SUGB					
1	10	CROP	4	3	CULT	#	Output starting year		3	4	PLTM			
W3			P			8	Output month		3	4	FERT			
1	10	PLTM	4	4	CROP	1	Output interval		N10					
1	10	CULT	SUGB			S	Weather choice		3	4	CULT			
P			4	4	PLTM	1	1	CROP	P					
1	10	OMAD	4	4	OMAD	W3			3	4	OMAD			
M			M			1	3	FRST	M					
1	11	LAST	4	6	FERT	1	3	FERT	3	5	FERT			
2	1	CROP	N5			N10			N10					
W3			4	9	HARV	1	5	FERT	3	6	FERT			
2	3	FRST	R			N5			N5					
2	3	OMAD	4	9	LAST	1	8	HARV	3	9	HARV			
M			4	10	OMAD	GS			R					
2	5	FERT	W			1	8	LAST	3	9	LAST			
N3			5	3	CULT	2	4	CROP	3	10	OMAD			
2	8	HARV	P			POT			W					
GS			5	4	CROP	2	4	PLTM	4	4	CROP			
2	8	LAST	POT						POT					

Clarifications abbreviations can be found in [Metherell, 1993]

Annex 4

Crop parameters (crop.100)

Crop options file "crop.100" will contain these values:

prdx(1)	potential aboveground monthly production for crops (gC/m2)
ppdf(1)	optimum temperature for production for parameterization of a Poisson Density Function curve to simulate temperature effect on growth
ppdf(2)	maximum temperature for production for parameterization of a Poisson Density Function curve to simulate temperature effect on growth
ppdf(3)	left curve shape for parameterization of a Poisson Density Function curve to simulate temperature effect on growth
ppdf(4)	right curve shape for parameterization of a Poisson Density Function curve to simulate temperature effect on growth
bioflg	flag indicating whether production should be reduced by physical obstruction = 0 production should not be reduced = 1 production should be reduced
biok5	level of aboveground standing dead + 10% strucc(1) C at which production is reduced to half maximum due to physical obstruction by dead material (g/m2)
pltmrf	planting month reduction factor to limit seedling growth; set to 1.0 for grass
fulcan	value of aglivc at full canopy cover, above which potential production is not reduced
frtc(1)	initial fraction of C allocated to roots; for Great Plains equation based on precipitation, set to 0
frtc(2)	final fraction of C allocated to roots
frtc(3)	time after planting (months with soil temperature greater than rtdtmp) at which the final value is reached
biomax	biomass level (g biomass/m2) above which the minimum and maximum C/E ratios of new shoot increments equal pramn(*,2) and pramx(*,2) respectively
pramn(3,1)	minimum C/E ratio with zero biomass (1,1) = N (2,1) = P (3,1) = S
pramn(3,2)	minimum C/E ratio with biomass greater than or equal to biomax (1,2) = N (2,2) = P (3,2) = S
pramx(3,1)	maximum C/E ratio with zero biomass (1,1) = N (2,1) = P (3,1) = S
pramx(3,2)	maximum C/E ratio with biomass greater than or equal to biomax (1,2) = N (2,2) = P (3,2) = S
prbmn(3,2)	parameters for computing minimum C/N ratio for belowground matter as a linear function of annual precipitation (1,1) = N, intercept (2,1) = P, intercept (3,1) = S, intercept (1,2) = N, slope (2,2) = P, slope (3,2) = S, slope
prbmx(3,2)	parameters for computing maximum C/N ratio for belowground matter as a linear function of annual precipitation (1,1) = N, intercept (2,1) = P, intercept (3,1) = S, intercept (1,2) = N, slope (2,2) = P, slope (3,2) = S, slope
fligni(1,1)	intercept for equation to predict lignin content fraction based on annual rainfall for aboveground material
fligni(2,1)	slope for equation to predict lignin content fraction based on annual rainfall for aboveground material. For crops, set to 0.
fligni(1,2)	intercept for equation to predict lignin content fraction based on annual rainfall for belowground material
fligni(2,2)	slope for equation to predict lignin content fraction based on annual rainfall for belowground material. For crops, set to 0.
himax	harvest index maximum (fraction of aboveground live C in grain)
hiwsf	harvest index water stress factor = 0 no effect of water stress = 1 no grain yield with maximum water stress
himon(1)	number of months prior to harvest in which to begin accumulating water stress effect on harvest index
himon(2)	number of months prior to harvest in which to stop accumulating water stress effect on harvest index
efrgrn(3)	fraction of the aboveground E which goes to grain (1) = N (2) = P (3) = S
vlossp	fraction of aboveground plant N which is volatilized (occurs only at harvest)

fsdeth(1)	maximum shoot death rate at very dry soil conditions (fraction/month); for getting the monthly shoot death rate, this fraction is multiplied times a reduction factor depending on the soil water status
fsdeth(2)	fraction of shoots which die during senescence month; must be greater than or equal to 0.4
fsdeth(3)	additional fraction of shoots which die when aboveground live C is greater than fsdeth(4)
fsdeth(4)	the level of aboveground C above which shading occurs and shoot senescence increases
fallrt	fall rate (fraction of standing dead which falls each month)
rdr	maximum root death rate at very dry soil conditions (fraction/month); for getting the monthly root death rate, this fraction is multiplied times a reduction factor depending on the soil water status
rtdtmp	physiological shutdown temperature for root death and change in shoot/root ratio
crprtf(3)	fraction of E retranslocated from grass/crop leaves at death (1) = N (2) = P (3) = S
snfxmx(1)	symbiotic N fixation maximum for grass/crop (Gn fixed/Gc new growth)
del13c	delta 13C value for stable isotope labeling
co2ipr(1)	in a grass/crop system, the effect on plant production ratio of doubling the atmospheric CO2 concentration from 350 ppm to 700 ppm
co2itr(1)	in a grass/crop system, the effect on transpiration rate of doubling the atmospheric CO2 concentration from 350 ppm to 700 ppm
co2ice(1,2,3)	in a grass/crop system, the effect on C/E ratios of doubling the atmospheric CO2 concentration from 350 ppm to 700 ppm (1,1,1) = minimum C/N (1,2,1) = maximum C/N (1,1,2) = minimum C/P (1,2,2) = maximum C/P (1,1,3) = minimum C/S (1,2,3) = maximum C/S
co2irs(1)	in a grass/crop system, the effect on root-shoot ratio of doubling the atmospheric CO2 concentration from 350 ppm to 700 ppm

Cultivation parameters (cult.100)

The cult.100 file will contain these parameters for each option:

cultra(1)	fraction of aboveground live transferred to standing dead
cultra(2)	fraction of aboveground live transferred to surface litter
cultra(3)	fraction of aboveground live transferred to the top soil layer
cultra(4)	fraction of standing dead transferred to surface litter
cultra(5)	fraction of standing dead transferred to top soil layer
cultra(6)	fraction of surface litter transferred to top soil layer
cultra(7)	fraction of roots transferred to top soil layer
clteff(1)	cultivation factor for som1 decomposition; functions as a multiplier for increased decomposition in the month of cultivation
clteff(2)	cultivation factor for som2 decomposition; functions as a multiplier for increased decomposition in the month of cultivation
clteff(3)	cultivation factor for som3 decomposition; functions as a multiplier for increased decomposition in the month of cultivation
clteff(4)	cultivation factor for soil structural material decomposition; functions as a multiplier for increased decomposition in the month of cultivation

Fertilization parameters (fert.100)

The fert.100 file will contain these parameters for each option:

feramt(3)	amount of E to be added (gE/m2) (1) = N (2) = P (3) = S
aufert	key for automatic fertilization aufert = 0: no automatic fertilization aufert < 1.0: automatic fertilizer may be applied to remove some nutrient stress without increasing nutrient concentration above the minimum level; the value of aufert is the fraction of potential C production (temperature and moisture limited) which will be maintained aufert > 1.0: automatic fertilizer may be applied to remove nutrient stress and increase nutrient concentrations above the minimum level; a value of aufert between 1.0 and 2.0 determines the extent to which nutrient concentration is maintained between the minimum and maximum levels

aufert = 2.0	automatic fertilizer may be applied to remove nutrient stress and increase nutrient concentrations to the maximum level

Fixed parameters (fix.100)

There can be only one option within this file.

adep(10)	depth of soil layer X, where X = 1-10 (only nlayer+1 values used) (cm)
agppa	intercept parameter in the equation estimating potential aboveground biomass production for calculation of root/shoot ratio (used only if frtc(1) = 0) (g/m2/y)
agppb	slope parameter in the equation estimating potential aboveground biomass production for calculation of root/shoot ratio (used only if frtc(1) = 0) (g/m2/y/cm) NOTE - agppb is multiplied by annual precipitation (cm)
aneref(1)	ratio of rain/potential evapotranspiration below which there is no negative impact of soil anaerobic conditions on decomposition
aneref(2)	ratio of rain/potential evapotranspiration below which there is maximum negative impact of soil anaerobic conditions on decomposition
aneref(3)	minimum value of the impact of soil anaerobic conditions on decomposition; functions as a multiplier for the maximum decomposition rate
animpt	slope term used to vary the impact of soil anaerobic conditions on decomposition flows to the passive soil organic matter pool
awtl(10)	weighing factor for transpiration loss for layer X, where X = 1-10 (only nlayer+1 values used); indicates which fraction of the available water can be extracted by the roots
bgppa	intercept parameter in the equation estimating potential belowground biomass production for calculation of root/shoot ratio (used only if frtc(1) = 0) (g/m2/y)
bgppb	slope parameter in the equation estimating potential belowground biomass production for calculation of root/shoot ratio (used only if frtc(1) = 0) (g/m2/y) NOTE - bgppb is multiplied by annual precipitation (cm)
co2ppm(1)	initial parts per million for CO2 effect
co2ppm(2)	final parts per million for CO2 effect
co2rmp	flag indicating whether CO2 effect should be: = 0 step function = 1 ramp function
damr(1,3)	fraction of surface E absorbed by residue (1,1) = N (1,2) = P (1,3) = S
damr(2,3)	fraction of soil E absorbed by residue (2,1) = N (2,2) = P (2,3) = S
damrmn(3,3)	minimum C/E ratio allowed in residue after direct absorption (1) = N (2) = P (3) = S
dec1(1)	maximum surface structural decomposition rate
dec1(2)	maximum soil structural decomposition rate
dec2(1)	maximum surface metabolic decomposition rate
dec2(2)	maximum soil metabolic decomposition rate
dec3(1)	maximum decomposition rate of surface organic matter with active turnover
dec3(2)	maximum decomposition rate of soil organic matter with active turnover
dec4	maximum decomposition rate of soil organic matter with slow turnover
dec5	maximum decomposition rate of soil organic matter with intermediate turnover
deck5	available soil water content at which shoot and root death rates are half maximum (cm)
edepth	depth of the single soil layer where C, N, P, and S dynamics are calculated (only affects C, N, P, S loss by erosion)
elitst	effect of litter on soil temperature relative to live and standing dead biomass
enrich	the enrichment factor for SOM losses
favail(1)	fraction of N available per month to plants
favail(6)	mineral N in surface layer corresponding to maximum fraction of P available (gN/m2)
fleach(1)	intercept value for a normal month to compute the fraction of mineral N, P, and S which will leach to the next layer when there is a saturated water flow; normal leaching is a function of sand content
fleach(2)	slope value for a normal month to compute the fraction of mineral N, P, and S which will leach to the next layer when there is a saturated water flow; normal leaching is a function of sand content
fleach(3)	leaching fraction multiplier for N to compute the fraction of mineral N which leaches to the next layer when there is a saturated water flow; normal leaching is a function of sand content

fwloss(1) scaling factor for interception and evaporation of precipitation by live and standing dead biomass
fwloss(2) scaling factor for bare soil evaporation of precipitation (h2olos)
fwloss(3) scaling factor for transpiration water loss (h2olos)
fwloss(4) scaling factor for potential evapotranspiration (pevap)
fxmca intercept for effect of biomass on non-symbiotic soil N fixation; used only when nsnfix = 1
fxmcb slope control for effect of biomass on non-symbiotic soil N fixation; used only when nsnfix = 1
fxmxs maximum monthly non-symbiotic soil N-fixation rate (reduced by effect of N:P ratio, used when nsnfix = 1)

fxnpb N/P control for N-fixation based on availability of top soil layer (used when nsnfix = 1)

gremb grazing effect multiplier for grzeff types 4, 5, 6

idef flag for method of computing water effect on decomposition
= 1 option using the relative water content of soil (0-15 cm)
= 2 ratio option (rainfall/potential evaporation rate)
lhzf(1) lower horizon factor for active pool; = fraction of active pool (SOM1CI(2,*)) used in computation of lower horizon pool sizes for soil erosion routines
lhzf(2) lower horizon factor for slow pool; = fraction of slow pool (SOM2CI(*) used in computation of lower horizon pool sizes for soil erosion routines
lhzf(3) lower horizon factor for passive pool; = fraction of passive pool (SOM3CI(*) used in computation of lower horizon pool sizes for soil erosion routines
minlch critical water flow for leaching of minerals (cm of h2o leached below 30 cm soil depth)
nsnfix equals 1 if non-symbiotic N fixation should be based on N:P ratio in mineral pool, otherwise non-symbiotic N fixation is based on annual precipitation
ntspm number of time steps per month for the decomposition submodel
omlech(1) intercept for the effect of sand on leaching of organic compounds
omlech(2) slope for the effect of sand on leaching of organic compounds
omlech(3) the amount of water (cm) that needs to flow out of water layer 2 to produce leaching of organics
p1co2a(1) intercept parameter which controls flow from surface organic matter with fast turnover to CO2 (fraction of C lost to CO2 when there is no sand in the soil)
p1co2a(2) intercept parameter which controls flow from soil organic matter with fast turnover to CO2 (fraction of C lost to CO2 when there is no sand in the soil)
p1co2b(1) slope parameter which controls flow from surface organic matter with fast turnover to CO2 (slope is multiplied by the fraction sand content of the soil)
p1co2b(2) slope parameter which controls flow from soil organic matter with fast turnover to CO2 (slope is multiplied by the fraction sand content of the soil)
p2co2 controls flow from soil organic matter with intermediate turnover to CO2 (fraction of C lost as CO2 during decomposition)
p3co2 controls flow from soil organic matter with slow turnover rate to CO2 (fraction of C lost as CO2 during decomposition)
pabres amount of residue which will give maximum direct absorption of N (Gc/m2)
pcemic(1,3) maximum C/E ratio for surface microbial pool
(1,1) = N (1,2) = P (1,3) = S
pcemic(2,3) minimum C/E ratio for surface microbial pool
(2,1) = N (2,2) = P (2,3) = S
pcemic(3,3) minimum E content of decomposing aboveground material above which the C/E ratio of the surface microbes equals pcemic(2,*)
(3,1) = N (3,2) = P (3,3) = S
peftxa intercept parameter for regression equation to compute the effect of soil texture on the microbe decomposition rate (the effect of texture when there is no sand in the soil)
peftxb slope parameter for regression equation to compute the effect of soil texture on microbe decomposition rate; the slope is multiplied by the sand content fraction
pligst(2) effect of lignin on soil structural or coarse root decomposition
pmco2(2) controls flow from metabolic to CO2 (fraction of C lost as CO2 during decomposition)
(1) = surface (2) = soil
pmnsec(3) slope for E; controls the flow from mineral to secondary N (/yr)
(1) = N (2) = P (3) = S
pmntmp effect of biomass on minimum surface temperature

pmxbio	maximum dead biomass (standing dead + 10% litter) level for soil temperature calculation and for calculation of the potential negative effect on plant growth of physical obstruction by standing dead and surface litter
pmxtmp	effect of biomass on maximum surface temperature
pparmn(3)	controls the flow from parent material to mineral compartment (fraction of parent material that flows to mineral E) (1) = N (2) = P (3) = S
pprpts(1)	the minimum ratio of available water to PET which would completely limit production assuming WC = 0
pprpts(2)	the effect of WC on the intercept
pprpts(3)	the lowest ratio of available water to PET at which there is no restriction on production
ps1co2(2)	controls amount of CO_2 loss when structural decomposes to som1, subscripted for surface and soil layer (1) = surface (2) = soil
ps1s3(1)	intercept for effect of clay on the control for the flow from soil organic matter with fast turnover to som with slow turnover (fraction of C from som1c to som3c)
ps1s3(2)	slope for the effect of clay on the control for the flow from soil organic matter with fast turnover to som with slow turnover (fraction of C from som1c to som3c)
ps2s3(1)	slope value which controls flow from soil organic matter with intermediate turnover to soil organic matter with slow turnover (fraction of C from som2c to som3c)
ps2s3(2)	intercept value which controls flow from soil organic matter with intermediate turnover to soil organic matter with slow turnover (fraction of C from som2c to som3c)
psecmn(3)	controls the flow from secondary to mineral E (1) = N (2) = P (3) = S
rad1p(1,3)	intercept used to calculate addition term for C/E ratio of slow SOM formed from surface active pool (1,1) = N (1,2) = P (1,3) = S
rad1p(2,3)	slope used to calculate addition term for C/E ratio of slow SOM formed from surface active pool (2,1) = N (2,2) = P (2,3) = S
rad1p(3,3)	minimum allowable C/E used to calculate addition term for C/E ratio of slow SOM formed from surface active pool (3,1) = N (3,2) = P (3,3) = S
rcestr(3)	C/E ratio for structural material (1) = N (2) = P (3) = S
rictrl	root impact control term used by rtimp; used for calculating the impact of root biomass on nutrient availability
riint	root impact intercept used by rtimp; used for calculating the impact of root biomass on nutrient availability
rsplig	fraction of lignin flow (in structural decomposition) lost as CO2
seed	random number generator seed value
spl(1)	intercept parameter for metabolic (vs. structural) split
spl(2)	slope parameter for metabolic split (fraction metabolic is a function of lignin to N ratio)
strmax(1)	maximum amount of structural material in surface layer that will decompose (gC/m2)
strmax(2)	maximum amount of structural material belowground that will decompose (gC/m2)
tmax	maximum temperature for decomposition (deg. C)
tmelt(1)	minimum temperature above which at least some snow will melt
tmelt(2)	ratio between degrees above the minimum and cm of snow that will melt
topt	optimum temperature for decomposition (deg. C)
tshl	shape parameter to left of the optimum temperature (for decomposition)
tshr	shape parameter to right of the optimum temperature
varat1(1,3)	maximum C/E ratio for material entering som1 (1,1) = N (1,2) = P (1,3) = S
varat1(2,3)	minimum C/E ratio for material entering som1 (2,1) = N (2,2) = P (2,3) = S
varat1(3,3)	amount of E present when minimum ratio applies (3,1) = N (3,2) = P (3,3) = S
varat2(1,3)	maximum C/E ratio for material entering som2 (1,1) = N (1,2) = P (1,3) = S
varat2(2,3)	minimum C/E ratio for material entering som2 (2,1) = N (2,2) = P (2,3) = S
varat2(3,3)	amount of E present when minimum ratio applies

(3,1) = N (3,2) = P (3,3) = S

varat3(1,3)	maximum C/E ratio for material entering som3 (1,1) = N (1,2) = P (1,3) = S
varat3(2,3)	minimum C/E ratio for material entering som3 (2,1) = N (2,2) = P (2,3) = S
varat3(3,3)	amount of E present when minimum ratio applies (3,1) = N (3,2) = P (3,3) = S
vlosse	fraction per month of excess N (i.e. N left in the soil after nutrient uptake by the plant) which is volatilized
vlossg	fraction per month of gross mineralization which is volatilized

Grazing parameters (graz.100)

The graz.100 file will contain these parameters for each option:

flgrem	fraction of live shoots removed by a grazing event
fdgrem	fraction of standing dead removed by a grazing event
gfcret	fraction of consumed C which is excreted in faeces and urine
gret(3)	fraction of consumed E which is excreted in faeces and urine (should take into account E losses due to leaching or volatilization from the manure) (1) = N (2) = P (3) = S
grzeff	effect of grazing on production = 0 no direct effect = 1 moderate effect (linear decrease in production) = 2 intensively grazed production effect (quadratic effect on production)
fecf(3)	fraction of excreted E which goes into faeces (rest goes into urine) (1) = N (2) = P (3) = S
feclig	lignin content of feces

Harvest parameters (harv.100)

The harv.100 file will contain these parameters for each option:

aglrem	fraction of aboveground live which will not be affected by harvest operations
bglrem	fraction of belowground live which will not be affected by harvest operations
flghrv	flag indicating if grain is to be harvested = 0 if grain is not to be harvested = 1 if the grain is to be harvested
rmvstr	fraction of the aboveground residue that will be removed
remwsd	fraction of the remaining residue that will be left standing
hibg	fraction of roots that will be harvested

Organic matter addition parameters (omad.100)

The omad.100 file will contain these parameters for each option:

astgc	grams of C added with the addition of organic matter (g/m2)
astlbl	fraction of added C which is labeled, when C is added as a result of the addition of organic matter
astlig	lignin fraction content of organic matter
astrec(3)	C/E ratio of added organic matter (1) = N (2) = P (3) = S

Site specific parameters (<site>.100)

There can be only one option within this file. This file is named by the user to some "filename".100.

*** Climate parameters

precip(12)	precipitation for January through December (cm/month)
prcstd(12)	standard deviations for January through December precipitation value (cm/month)
prcskw(12)	skewness value for January through December precipitation
tmn2m(12)	minimum temperature at 2 meters for January through December (deg C)
tmx2m(12)	maximum temperature at 2 meters for January through December (deg C)

** Site and control parameters

ivauto	use Burke's equations to initialize soil C pools = 0 the user has supplied the initial values = 1 initialize using the grass soil parameters = 2 initialize using the crop soil parameters
nelem	number of elements (besides C) to be simulated = 1 simulate N = 2 simulate N and P = 3 simulate N, P, and S
sitlat	latitude of model site (deg) (for reference only)
sitlng	longitude of model site (deg) (for reference only)
sand	fraction of sand in soil
silt	fraction of silt in soil
clay	fraction of clay in soil
bulkd	bulk density of soil used to compute soil loss by erosion, wilting point, and field capacity (kg/liter)
nlayer	number of soil layers in water model (maximum of 9); used only to calculated the amount of water available for survival of the plant
nlaypg	number of soil layers in the top level of the water model; determines avh2o(1), used for plant growth and root death
drain	the fraction of excess water lost by drainage; indicates whether a soil is sensitive for anaerobiosis (drain=0) or not (drain=1)
basef	the fraction of the soil water content of layer NLAYER + 1 which is lost via base flow
stormf	the fraction of flow from NLAYER to NLAYER + 1 which goes into storm flow
swflag	flag indicating the source of the values for awilt and afiel, either from actual data from the site.100 file or from equations from Gupta and Larson (1979) or Rawls et al. (1982). swflag = 0 use actual data from the site.100 file swflag = 1 use G & L for both awilt (-15 bar) and afiel (-0.33 bar) swflag = 2 use G & L for both awilt (-15 bar) and afiel (-0.10 bar) swflag = 3 use Rawls for both awilt (-15 bar) and afiel (-0.33 bar) swflag = 4 use Rawls for both awilt (-15 bar) and afiel (-0.10 bar) swflag = 5 use Rawls for afiel (-0.33 bar) with actual data for awilt swflag = 6 use Rawls for afiel (-0.10 bar) with actual data for awilt
awilt(10)	the wilting point of soil layer X, where X = 1-10 (fraction); used only if swflag = 0, 5, or 6
afiel(10)	the field capacity of soil layer X, where X = 1-10 (fraction); used only if swflag = 0
ph	soil pH used to calculate the solubility of secondary P within the boundaries specified by phesp(1) and phesp(3)
pslsrb	slope term which controls the fraction of mineral P that is labile
sorpmx	maximum P sorption potential for a soil

*** External nutrient input parameters

epnfa(2)	values for determining the effect of annual precipitation on atmospheric N fixation (wet and dry deposition) (g/m2/y) (1) = intercept (2) = slope
epnfs(2)	values for determining the effect of annual precipitation on non-symbiotic soil N fixation; not used if nsnfix = 1 (g/m2/y) (1) = intercept (2) = slope

*** Organic matter initial parameters

som1ci(1,1)	initial value for unlabeled C in surface organic matter with fast turnover; used only if ivauto = 0 (gC/m2)
som1ci(1,2)	initial value for labeled C in surface organic matter with fast turnover; used only if ivauto = 0 (gC/m2)
som1ci(2,1)	initial value for unlabeled C in soil organic matter with fast turnover; used only if ivauto = 0 (gC/m2)
som1ci(2,2)	initial value for labeled C in soil organic matter with fast turnover; used only if ivauto = 0 (gC/m2)
som2ci(1)	initial value for unlabeled C in soil organic matter with intermediate turnover; used only if ivauto = 0 (gC/m2)
som2ci(2)	initial value for labeled C in soil organic matter with intermediate turnover; used only if ivauto = 0 (gC/m2)
som3ci(1)	initial value for unlabeled C in soil organic matter with slow turnover; used only if ivauto = 0 (gC/m2)
som3ci(2)	initial value for labeled C in soil organic matter with slow turnover; used only if ivauto = 0 (gC/m2)
rces1(1,3)	initial C/E ratio in surface organic matter with fast turnover (active som) (1,1) = N (1,2) = P (1,3) = S
rces1(2,3)	initial C/E ratio in soil organic matter with fast turnover (active som) (2,1) = N (2,2) = P (2,3) = S
rces2(3)	initial C/E ratio in soil organic matter with intermediate turnover (slow SOM) (1) = N (2) = P (3) = S
rces3(3)	initial C/E ratio in soil organic matter with slow turnover (passive SOM) (1) = N (2) = P (3) = S
clittr(2,2)	initial value for plant residue; used only if ivauto = 0 (g/m2) (1,1) = surface, unlabeled (2,1) = soil, unlabeled (1,2) = surface, labeled (2,2) = soil, labeled
rcelit(1,3)	initial C/E ratio for surface litter (1,1) = N (1,2) = P (1,3) = S
rcelit(2,3)	initial C/E ratio for soil litter (2,1) = N (2,2) = P (2,3) = S
aglcis(2)	initial value for aboveground live C isotope; used only if ivauto = 0 or 2 (gC/m2) (1) = unlabeled (2) = labeled
aglive(3)	aboveground E initial value (gE/m2); used only if ivauto = 0 or 2 (1) = N (2) = P (3) = S
bglcis(2)	initial value for belowground live C; used only if ivauto = 0 or 2 (gC/m2) (1) = unlabeled (2) = labeled
bglive(3)	initial value for belowground live E; used only if ivauto = 0 or 2 (gE/m2) (1) = N (2) = P (3) = S
stdcis(2)	initial value for standing dead C; used only if ivauto = 0 (gC/m2) (1) = unlabeled (2) = labeled
stdede(3)	initial value for E in standing dead; used only if ivauto = 0 (gE/m2) (1) = N (2) = P (3) = S

*** Mineral initial parameters

minerl(10,1)	initial value for mineral N for layer X, X = 1-10 (gN/m2)
minerl(10,2)	initial value for mineral P for layer X, X = 1-10 (gP/m2)
minerl(10,3)	initial value for mineral S for layer X, X = 1-10 (gS/m2)
parent(3)	initial E value for parent material (gE/m2) (1) = N (2) = P (3) = S
secndy(3)	initial E value for secondary E (gE/m2) (1) = N (2) = P (3) = S

*** Water initial parameters

rwcf(10)	initial relative water content for layer X, X = 1-10

Terminology

Soil Organic Matter

Soil organic matter - non-living components which are a heterogeneous mixture composed largely of products resulting from microbial and chemical transformations of organic debris. Soil organic matter can exist in different morphological patterns, which are the bases of the classification of so called forms and types of humus [Internet link 3, -].

Calibration

The procedure that changes model parameters, so that it produces acceptable (realistic) results [Internet link 7, -].

Validation

The process of checking if something satisfies a certain criterion [Internet link 8, 2007].

BIS

Systematically collected information on Dutch soil data. The profiles have been described until a depth of 1.20 m. This data is stored and can be divided into point data and map data.

Sequestration

Carbon sequestration refers to the provision of long-term storage of carbon in the terrestrial biosphere, underground, or the oceans so that the build up of carbon dioxide (the principal greenhouse gas) concentration in the atmosphere will reduce (…) [Internet link 9, 2007].

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