User's Guide for Biome-BGCMuSo 4.0

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1. Introduction

Biome-BGC is a widely used, popular biogeochemical model that simulates the storage and flux of water, carbon, and nitrogen between the ecosystem and the atmosphere, and within the components of the terrestrial ecosystems (Thornton, 2000). Biome-BGC was developed by the Numerical Terradynamic Simulation Group (NTSG), University of Montana (http://www.ntsg.umt.edu/project/biome-bgc). The currently available, official model version (published by NTSG) is 4.2.

Several researchers used and modified the original Biome-BGC model in the past. Most recently our research group developed an updated version of Biome-BGC (called Biome-BGCMuSo – where the abbreviation refers to **Mu**ltilayer **So**il Module – or briefly BBGCMuSo) to improve the ability of the model to simulate carbon and water cycle in managed ecosystems, with options for managed croplands, grasslands and forests. The modifications included structural improvements of the model (e.g., the simple, outdated, one-layer soil module was replaced by a multilayer soil module; drought related plant senescence was implemented; model phenology was improved) and also management modules were developed (e.g. to simulate mowing, grazing, fertilization, ploughing, sowing, harvesting, forest thinning and clearcut). Some of the modifications (primarily those that are related with grasslands) are published in Hidy et al. (2012).

Since the publication of the Hidy et al. (2012) study additional modules were developed to simulate cropland management (e.g., planting, harvest, ploughing, application of fertilizers). Forest thinning was also implemented as a possible human intervention, and dynamic (annually varying) whole plant mortality was implemented in the model to enable more realistic simulation of forest stand development. Annually varying management options were also introduced. In the most recent model version separate pools have been defined for fruit following the method of Ma et al. (2011) to support cropland related simulations. Detailed description of the modifications will be presented in a forthcoming publication (Hidy et al., 2016; in preparation).

This User's Guide was created to provide practical information for the use of the improved model. The Hidy et al. (2012) study used Biome-BGC v4.1.1 with previous modifications made by Max Planck Institute, Germany (we refer this code as Biome-BGC v4.1.1 MPI version; see Trusilova et al., 2009) as the starting point for model developments. BBGCMuSo has many version (MuSo v1.0, v1.1 v1.2, v1.3, v2.0, v2.1, v2.2, v2.3, v3.0, v4.0), but hereinafter only 4.0 is referred.

Note that NTSG continues to develop the original model with the inclusion of management using a new disturbance handler module. In their implementation disturbance (or management) is described by a separate disturbance descriptor file. Our implementation of disturbance is different from the NTSG approach, as we included management settings in the INI file of the model (note that in MuSo there is an option to use additional management rules provided in separate text files; see below).

2. Model description

Prior to using the model, the User might want to get information on the basic model logic. This section provides a brief overview on the model logic, and on the simulation phases that are essential for the preparation of the needed input data.

2.1 Overview, general model logic

BBGCMuSo was developed from the Biome-BGC family of models (Thornton, 2000) and in this sense it is an extension and generalization of the Forest-BGC model for the description of different vegetation types including C3 and C4 grasslands (Running and Coughlan, 1988; Running and Gower, 1991; Running and Hunt, 1993; Thornton, 1998, 2000; White et al., 2000; Thornton and Rosenbloom, 2005; Trusilova et al., 2009).

The model uses daily time step, and is driven by daily values of maximum and minimum temperatures, precipitation amount, solar radiation, and vapor pressure deficit. If the user only has basic meteorological data (daily maximum and minimum temperature, and precipitation amount), the other input meteorological data can be easily estimated by the MT-CLIM model that can be considered as a preprocessor to BBGC (http://www.ntsg.umt.edu/project/mtclim).

BBGCMuSo uses meteorological data, site-specific data, ecophysiological data, carbon-dioxide concentration (CO_2) and N-deposition (N-dep) data to simulate the biogeochemical processes of the given biome. The main processes assessed are photosynthesis, allocation, litterfall, carbon (C), nitrogen (N) and water dynamics in the plant, litter and soil.

The most important blocks of the model are the carbon flux block, the phenological block and the soil flux block. In the carbon flux block gross primary production (GPP) of the biome is calculated using Farquhar's photosynthesis routine (Farquhar et al., 1980). Autotrophic respiration is separated into maintenance and growth respirations. Maintenance respiration is the function of the nitrogen content of living material, while growth respiration is calculated proportionally to the carbon allocated to the different plant compartments. The phenological block calculates foliage development; therefore it affects the accumulation of carbon and nitrogen in leaf, stem, root and litter. The soil block describes the decomposition of dead plant material and soil carbon pools (Running and Gower, 1991).

In BBGCMuSo the main parts of the ecosystem are defined as plant, soil and litter. Since the model simulates water, carbon and nitrogen cycles of ecosystems, the following main pools are defined (some of them are not present in specific ecosystems): leaf (carbon, nitrogen and water), fine root (carbon, nitrogen), fruit (carbon, nitrogen), soft stem (carbon, nitrogen), live wood (carbon, nitrogen), dead wood (carbon, nitrogen), coarse root (carbon, nitrogen), soil (carbon, nitrogen and water) and litter (carbon, nitrogen). Carbon and nitrogen pools have sub-pools, i.e. actual pools, storage pools and transfer pools. Actual sub-pools contain the amount of carbon or nitrogen available on the actual simulation day. Storage sub-pools store the amount that will appear next year (like a core or bud, or unstructured carbohydrate), while the transfer sub-pools store the whole content of the storage pool after the end of the actual transfer period (defined by model parameters) until the next one, and that will be transferred gradually into the leaf carbon pool (like a germ) in the next transfer period, in the beginning of the growing season.

One major difference between the earlier versions of Biome-BGC and BBGCMuSo is the representation of soil processes. In BBGCMuSo a seven-layer soil submodel was implemented. The thicknesses of the active layers (layers 1-6) from the surface to the bottom are 10, 20, 30, 40, 100 and 100 cm again. It means that the first layer is located at depth of 0-

10 cm; the second is at 10-30 cm, the third is at 30-60 cm, the fourth is at 60-100 cm, the fifth is at 100-200 cm, and the sixth is at 200-300 cm. The thickness of bottom (7th, inactive) layer is defined to be 7 m in depth (it is located at depth 300-1000 cm). The thickness of the lowest boundary layer is only important for technical reasons (water movement calculations use finite differences method, so for calculating the gradients we need to specify the distance of layers). The depth of each soil layer is represented by the middle level of the given layer (e.g. the thicknesses of the top soil layer is 0.1 m, therefore it is represented at 0.05 m).

We assume that below 3 meters the soil properties are constant. Therefore the bottom layer is special: it is assumed that its temperature is equal to the annual average air temperature of the site; its soil water content (SWC) is equal to the field capacity (constant value); its soil mineral nitrogen content is constant (1 kg N ha^{-1}). The percolated water (and soluble nitrogen) from the 6th soil layer is a net loss, while the upward diffused water (and soluble nitrogen) from the bottom layer to the active layers is a net gain for the soil system.

Soil texture is defined by the User in initialization file layer by layer. If the maximum depth of rooting zone (defined by the User) is greater than 3 m, the roots can reach the static boundary soil layer, so the plants can take up water even during severe drought.

2.2   Simulation phases including the novel transient run option and the implemented support for land use change related simulations

The model simulation has basically two phases. The first is the spinup simulation (in other words self-initialization, or equilibrium run), which starts with very low initial level of soil carbon and nitrogen, and runs until a steady state is reached with the climate in order to estimate the initial values of the state variables (mostly soil carbon and nitrogen pools including recalcitrant soil organic matter, the latter is being the primary source of nitrogen mineralization in the model; Thornton, 2000). The second phase, the normal simulation uses the results of the spinup simulation as initial values for the carbon and nitrogen pools. This simulation is performed for a given, predetermined time period.

The usual strategy for CO_2 and N-dep control is to use constant (preindustrial) values during the spinup phase, then use annually varying CO_2 and N-dep for the entire normal simulation (representative to present day conditions). However, this logic can lead to undesired transient behavior during the first few simulation years of the normal run as the user may introduce a sharp change for the CO_2 and/or N-dep data (both are important drivers of plant growth).

In order to avoid this undesired sharp change in the environmental conditions between spinup and normal phase a third simulation phase, a so-called transient simulation was implemented in BBGCMuSo. According to the modifications, now it is possible to make an automatic transient simulation after the spinup phase simply using the spinup INI file settings (and some ancillary files; see later). In other words, now it is possible to initiate 3 consecutive simulations instead of the usual two phases (triggered by the spinup and normal INI file).

As management might play an important role in site history and consequently in the biogeochemical cycles, in BBGCMuSo the new transient simulation can include management, in an annually varying fashion. The settings of management optionally defined within the initialization file of the spinup are only used during the transient run, but not during the regular spinup phase.

Another new feature was added to BBGCMuSo that is also related with the proper simulation of site history. As the spinup phase is usually associated with preindustrial conditions, the normal phase might represent a plant functional type that is different from the one present in the spinup phase. For example, present-day croplands occupy land that was originally forest or grassland, so in this case spinup will simulate forest in equilibrium, and the normal phase

will simulate croplands. Another example is the simulation of afforestation that might require spinup for grasslands, and normal phase for woody vegetation. We may refer to these scenarios as land use change (LUC) related simulations. One problem that is associated with LUC is the frequent crash of the model with the error 'negative nitrogen pool' during the beginning of the normal phase. This error is typical if the spinup and normal EPC files differ in terms of plant C:N ratios. The explanation of the error is not simple (and elimination of the error is indeed a hard task) due to the model logic: in BBGC changes within the defined pools due to e.g. allocation, litterfall, litter and soil organic matter decomposition etc. are calculated at the end of each simulation day. Due to this day-end calculations inconsistency might arise between available mineralized N and N demand by the plant, and this might cause negative nitrogen pool.

In order to avoid this error, we have implemented an automatism that solves this problem. According to the changes only the equilibrium carbon pools are passed to the normal phase from the endpoint (restart) file. The endpoint nitrogen pools are calculated by the model code so that the resulting carbon to nitrogen ratios are harmonized with the C:N ratio of the different plant compartments presented in the EPC file of the normal phase. This modification means that equilibrium nitrogen pools are not passed to the normal phase at all, but in our interpretation this issue is compensated with the fact that LUC and site history can be simulated properly.

3. Input files

3.1 Overview

BBGCMuSo uses at least three input files each time it is executed. A brief description of all files is given first, followed by detailed discussions of each file.

The first required input file is called the *initialization* file (INI file in BBGC terminology). It provides general information about the simulation, including a description of the physical and climatic characteristics of the simulation site, a description of the time-frame for the simulation, the names of all the other required input files including optional management files, the names for output files that will be generated, and lists of variables to store in the output files.

The second required input file is the *meteorological data* file. It contains daily values for temperature, precipitation, humidity (in terms of daylight vapor pressure deficit), radiation, and daylength at the simulation site. It can contain any number of years of data. Important note: BBGCMuSo code assumes that all years have 365 days, so meteorological data files should be edited to remove one day from leap years (we propose to drop 31 December in the Northern hemisphere).

The third required input file is the *ecophysiological constants* file (EPC file). It contains an ecophysiological description of the vegetation at a site, including parameters such as leaf C:N ratio, maximum stomatal conductance, fire and non-fire mortality frequencies, and allocation ratios.

There are also seven optional input files: *carbon-dioxide* file, *nitrogen-deposition* file, *mortality* file, *conductance* file, *groundwater* file, *onday* and *offday* file (see below).

The last input file is the special *restart* file, which is the output of spinup and input for normal simulation. Detailed description of the files can be found below.

3.2 Initialization file (INI file)

Below we introduce the structure of the INI file of the model which was substantially extended in comparison with the Biome-BGC v4.1.1. MPI version. The initialization file is broken into sections with a keyword starting each new section and a special keyword at the end of the file. This organization helps to ensure that the proper format for the initialization file is maintained while editing for new simulations. The order of the sections and the order of the lines within each section is critical, and changes in order will result in failed or flawed executions. It is highly recommended that the example INI files be copied to a safe directory for future reference on proper formatting. There is a fair amount of errorchecking on the INI file format, but it is still possible to scramble the order of lines in a way that the program does not detect. In this case the model will run, but the results will be garbage. Copying the template is the easiest way to make a new INI file with assurance of the correct format, but remember to replace ALL of the parameters with those for the new site. It is not necessary to have blank lines between the end of one section and the keyword for the next section, but keeping them in makes the INI file more readable.

Each line can contain up to 100 characters of comment information, after a keyword or after an input parameter (or after more than one input parameter; see below e.g. the soil texture definition in the SITE block). This information is for your reference in keeping the correct format in the INI file, and is ignored by the program. Every line is required, even if flags are

set that mean the information on a line will be ignored. The first line of the file is for header information that helps you keep track of which INI file is for which simulation when you are doing a sequence of simulations. This line can contain up to 100 characters of information. There is no keyword for this header line.

Below we provide examples for the specific sections using `Courier New Font`. A complete example INI file is given in Appendix B.

Section MET_INPUT

The first section begins with the keyword MET_INPUT. It has the following two lines:
1) name (including relative path if appropriate [relative path to the model executable file]) of input meteorological data file
2) number of header lines in meteorological data file

```
MET_INPUT
metdata/bugac_2009-2011.mtc43          (filename) met file name
4                                      (int) number of header lines in met file
```

Section RESTART

The next section begins with the keyword RESTART. It has the following five lines:
1) flag (1 or 0) for reading (1) or not reading (0) a restart file from the end of a previous simulation
2) flag (1 or 0) for writing (1) or not writing (0) a restart file at the end of this simulation
3) flag (1 or 0) for met year from restart file (1) or met year reset to beginning of record (0). Met year means the current year from the meteorology input file. We suggest to set this flag to 0.
4) input restart filename (including path if appropriate)
5) output restart filename (including path if appropriate)
Lines 3) and 4) are only relevant when flag in line 1) is set to 1. Line 5) is only relevant when flag in line 2) is set to 1. In most cases the flag in line 3) should be set to 0.

```
RESTART
1                                      (flag) 1: read restart 0: don't read restart
0                                      (flag) 1: write restart 0: don't write restart
0                                      (flag) 1: use restart metyear 0: reset metyear
restart/bugacI.endpoint                (filename) name of the input restart file
restart/bugacO.endpoint                (filename) name of the output restart file
```

Section TIME_DEFINE

The next section begins with the keyword TIME_DEFINE. It has the following five lines:
1) number of years of data in meteorological input data file
2) number of years to run for this simulation.
3) first simulation year (e.g. 1998)
4) flag (1 or 0) for spinup simulation (1) or normal simulation (0)
5) maximum number of years to run in spinup mode
If line 2) is greater than line 1), then the meteorological data file is "recycled" enough times to satisfy the requested number of simulation years. Line 3) defines the starting point for the simulation output, and is mainly used in the simple text output file (described below). Line 4) sets the simulation mode for either a spinup run or a normal run.
If spinup mode is selected, the meteorological data file will be recycled enough times to establish steady-state conditions in the soil carbon and nitrogen pools. The number of years of simulation for a spinup run will depend on the climate and vegetation characteristics, but will not exceed the number of years specified on line 5). Line 2) has no effect for a spinup run. If a spinup run reaches the maximum number of years specified in line 5), it is likely that the

resulting final soil carbon and nitrogen pools are not equilibrated with the climate, usually indicating a long-term net sink of carbon. This is observed, for example, in some boreal climates, where the model predicts long-term accumulation of organic matter (peat formation).

```
TIME_DEFINE
3                                      (int) number of meteorological data years
3                                      (int) number of simulation years
2009                                   (int) first simulation year
0                                      (flag) 1: spinup run 0: normal run
6000                                   (int) maximum number of spinup years
```

Section CLIM_CHANGE

The next section begins with the keyword CLIM_CHANGE. It has the following five lines:
1) temperature offset for maximum temperature
2) temperature offset for minimum temperature
3) scaling factor for precipitation
4) scaling factor for vapor pressure deficit
5) scaling factor for incoming shortwave radiation

This section is included to facilitate simulation of simple climate change effects on ecosystem processes. The default values are shown in the example below (also see Appendix B), which result in no changes to the input meteorological data. Increases or decreases in temperature (Tmax and/or Tmin) can be introduced with lines 1) and 2). The values indicated are simply added to the daily values from the meteorological data file. For precipitation, VPD, and radiation, the daily values from the input file are multiplied by the values on lines 3), 4), and 5) to get new daily values. This mechanism does not allow for the simulation of seasonal differences in climate change.

```
CLIM_CHANGE
0.0                                    (degC) offset for Tmax
0.0                                    (degC) offset for Tmin
1.0                                    (degC) multiplier for PRCP
1.0                                    (degC) multiplier for VPD
1.0                                    (degC) multiplier for RAD
```

Section CO2_CONTROL

The next section begins with the keyword CO2_CONTROL. It has the following 3 lines:
1) flag (0,1) controlling CO_2 concentration: 0=constant, 1=varying using values from an external file
2) the value to use for constant CO_2 concentration (ppm)
3) the filename for annual CO_2 levels (see notes below for format information)
When line 1) is set to 0, then the value on line 2) sets the constant CO_2 level for the entire simulation. When line 1) is set to 1, then the file named on line 3) is used to define the annual timeseries of CO_2 concentration.

```
CO2_CONTROL
1                                      (flag) 0=constant 1=vary with file
290.0                                  (ppm) constant atmospheric CO2 concentration
co2/CO2_2009-2011.txt                  (filename) name of the CO2 file
```

This external text file must have one line for each simulation year (the number given on line 2 of the TIME_DEFINE section), and the format of each line should be like this:

```
1895   294.8
```

where the first value on the line is the year, and the second value is the CO_2 mole fraction (ppm). It is important to note that although the text files contain the year of the actual data, the model neglects the date and uses data from the text files sequentially (first line for the first simulation year, second line for the second etc.).

Section NDEP_CONTROL
The next section begins with the keyword NDEP_CONTROL. It has the following 3 lines:
1) flag (1 or 0) for variable nitrogen deposition (1) or constant nitrogen depostition (0)
2) the value to use for constant atmospheric N deposition (kgN m^{-2} yr^{-1})
3) the filename for annual N-deposition levels (see notes below for format information)
When line 1) is set to 0, then the value set on line 2) is used as constant N-deposition for the entire simulation. When line 1) is set to 1, then the file named on line 3) is used to define the annual timeseries of N-deposition.

```
NDEP_CONTROL
1                                       (flag) 0=constant 1=vary with file
0.001100                                (kgN/m2/yr) wet+dry atmospheric Ndep
nitrogen/Ndep_1901-2000.txt             (filename) name of the N-dep file
```

Similarly to the CO_2 external file, this file also must have one line for each simulation year (the number given on line 2 of the TIME_DEFINE section), and the format of each line should be like this:

```
1895   294.8
```

where the first value is the year, and the second value is the N-deposition (kgN m^{-2} yr^{-1}). It is important to note that although the text files contain the year of the actual data, the model neglects the date and uses data from the text files sequentially (first line for the first simulation year, second line for the second etc.).

A NOTE ON THE CO2_CONTROL AND NDEP_CONTROL SECTIONS

An important feature of the BBGCMuSo model is the possibility to control annually varying CO_2 concentration and N deposition independently, driven by separate text files (this feature was introduced in Biome-BGC v4.1.1 MPI version; Trusilova et al., 2009).
A new feature of BBGCMuSo 4.0 is the possibility to trigger a so-called transient simulation as an extension of the spinup phase (controlled solely by the spinup INI file). This feature was introduced to enable smooth transition from constant CO_2 and N deposition used in the spinup phase (representing preindustrial conditions, up to ~1850) to the higher CO_2 and N deposition values representative to present day (or past ~10-100 years) conditions.
If the User wants to initiate the transient run, he/she can set it in the spinup INI file by simply setting the CO2_CONTROL and/or NDEP_CONTROL flag to 1. It means that first a regular spinup will be performed with constant CO_2 and/or N deposition values set in the INI file, then a second run will be performed using the same meteorological data file defined by the spinup INI file.
The input for the transient run is the endpoint of the regular spinup, and the output of the transient simulation is the input for the normal phase with the same name.
As an example, spinup INI file might contain the following lines:

```
CO2_CONTROL
1                                (flag) 0=constant; 1=vary with file
280                              (ppm) constant atmospheric CO2 concentration
co2/CO2_1901-2000.txt            (filename) name of the CO2 file
```

```
NDEP_CONTROL
1                                 (flag) 0=constant; 1=vary with file
0.001100                          (kgN/m2/yr) wet+dry atmospheric N-dep
nitrogen/Ndep_1901-2000.txt       (filename) name of the N-dep file
```

With these settings first a spinup simulation will be performed re-using the meteorological data (in this example spinup meteorology covers the time period of 1901-2000; not shown here), keeping both CO_2 (280 ppm) and N deposition constant (0.0011 kgN/m^2/yr). Then, as the flags are set to 1, transient simulation will be performed, using the 100-years-long meteorology, and the `CO2_1901-2000.txt` CO_2 data file, and the 100-years long `Ndep_1901-2000.txt` files. Note that the user has to make sure to construct the proper CO_2 and/or N deposition files used for the transient run.

If the CO2_CONTROL and NDEP_CONTROL flags are set to 0, no transient simulation will be performed. CO2_CONTROL can be also set to 1 while NDEP_CONTROL flag is 0 (and vica versa). If this happens, then only CO_2 (or only N deposition) will vary during the transient run.

Section SITE

The next section begins with the keyword SITE. It has the following lines:

1) soil texture: percent sand (by volume in rock-free soil) for the 7 soil layers separately
2) soil texture: percent silt (by volume in rock-free soil) for the 7 soil layers separately
3) site elevation in meters above mean sea level
4) site latitude in decimal degrees (negative values for southern hemisphere)
5) site shortwave albedo for bare soil (albedo is LAI-dependent in BBGCMuSo)
6) mean annual air temperature (Celsius) (representative long term mean)
7) mean annual air temperature range (Celsius) based on monthly mean temperatures
8) * user-defined SCS runoff curve number (no data: -9999)
9) * user-defined bulk density of the 7 soil layers (no data: -9999)
10) * user-defined soil water content at saturation of the 7 soil layers (no data: -9999)
11) * user-defined soil water content at field capacity of the 7 soil layers (no data: -9999)
12) * user-defined soil water content at wilting point of the 7 soil layers (no data: -9999)
13) * user-defined hygroscopic soil water content of the 7 soil layers (no data: -9999)

Note that if no data are available regarding to variables marked with asterisks (*), it should be set to -9999, so the model will estimate them based on empirical functions. It is important to note that *all or none* of the user-defined critical SWC and bulk density data should be set by the user in order to avoid discrepancy in soil data (runoff curve number data is independent from the rest).

```
SITE (keyword - do not remove)
78.5 84.7 92.7 92.7 92.7 92.7 92.7      (%) sand percentage by volume
8.6 6.0 2.9 2.9 2.9 2.9 2.9             (%) silt percentage by volume
111.4                                   (m) site elevation
46.69                                   (degrees) site latitude (- for S.Hem.)
0.20                                    (DIM) bare soil shortwave albedo
11.00                                   (Celsius) mean annual air temperature
20.00                                   (Celsius) mean annual air temperature range
-9999                                       (DIM) user-defined RCN (no data: -9999)
-9999 -9999 -9999 -9999 -9999 -9999 -9999   (g/cm3) user-defined bulk density
-9999 -9999 -9999 -9999 -9999 -9999 -9999   (m3/m3) user-defined SWC at SAT
-9999 -9999 -9999 -9999 -9999 -9999 -9999   (m3/m3) user-defined SWC at FC
-9999 -9999 -9999 -9999 -9999 -9999 -9999   (m3/m3) user-defined SWC at WP
-9999 -9999 -9999 -9999 -9999 -9999 -9999   (m3/m3) user-defined SWC at HW
```

Section EPC_FILE
The next section begins with the keyword EPC_FILE. It has a single line:
1) the name of the input ecophysiological constants file

```
EPC_FILE (keyword - do not remove)
epc/enf.epc                          (file) evergreen needleleaf forest
```

Details on the format and interpretation of these files are given in a later section.

Section W_STATE
The next section begins with the keyword W_STATE. It has the following two lines:
1) initial snowpack water content (start of simulation)
2) initial soil water content as a proportion of saturation

```
W_STATE (keyword) start of water state variable initialization block
0.0                     (kg/m2) water stored in snowpack
0.5                     (DIM) initial soil water as a proportion of saturation
```

When using a restart file (which is the result of the spinup/transient phase) these values are ignored. Otherwise, they set the initial conditions for the water state variables (storage components) on the first day of simulation. Line 1) sets the snowpack, and is in water equivalent units, where kg water/m^2 is equivalent to mm of water. The second line controls the initial soil water content. This is set as a proportion of saturation so that the user is not required to know the saturation water content of the site (depends on texture and depth). For a spinup run, these values are used as the initial conditions.

Section C_STATE
The next section begins with the keyword C_STATE. It has the following eleven lines:
1) peak leaf carbon to be attained during the first simulation year
2) peak stem carbon to be attained during the first year
3) initial coarse woody debris carbon (dead trees, standing or fallen)
4) initial litter carbon, labile pool
5) initial litter carbon, unshielded cellulose pool
6) initial litter carbon, shielded cellulose pool
7) initial litter carbon, lignin pool
8) soil carbon, fast pool
9) soil carbon, medium pool
10) soil carbon, slow pool
11) soil carbon, slowest pool

```
C_STATE (keyword) start of carbon state variable initialization block
0.001   (kgC/m2) first-year maximum leaf carbon
0.0     (kgC/m2) first-year maximum stem carbon
0.0     (kgC/m2) coarse woody debris carbon
0.0     (kgC/m2) litter carbon, labile pool
0.0     (kgC/m2) litter carbon, unshielded cellulose pool
0.0     (kgC/m2) litter carbon, shielded cellulose pool
0.0     (kgC/m2) litter carbon, lignin pool
0.0     (kgC/m2) soil carbon, fast microbial recycling pool
0.0     (kgC/m2) soil carbon, medium microbial recycling pool
0.0     (kgC/m2) soil carbon, slow microbial recycling pool
0.0     (kgC/m2) soil carbon, recalcitrant SOM (slowest)
```

As with the W_STATE section, these values are ignored when using an input restart file, since all the initial conditions are defined by the endpoint from the previous simulation

(usually a spinup run and the optional transient run). In starting a spinup run these values have to be supplied. The above example shows the best approach to these initial conditions for a spinup run: start with very low initial leaf area, and no carbon in any of the other pools. This is essentially a primary succession simulation, starting with no organic matter and a very meager colonizing plant cover. The development of soil organic matter depends on the site's climate and external fluxes of nitrogen (deposition, fixation, leaching, volatilization), as well as on the vegetation type. The end result is that soil and litter pools are in equilibrium with climate and N deposition/loss rates. If these values are assigned without performing a spinup/transient run, then the initial model dynamics are likely to represent a transient response to disequilibrium conditions between the specified initial conditions and the specified climate and N deposition/loss. This can produce very misleading signals in net ecosystem exchange of carbon that can persist for many hundreds of years. For this reason it is recommended that new simulations be started with a spinup run, then a restart from the spinup conditions.

Section N_STATE
The next section begins with the keyword N_STATE. It has the following two lines:
1) litter nitrogen associated with labile litter carbon pool
2) soil mineral nitrogen pool

```
N_STATE (keyword) start of nitrogen state variable initialization block
0.0 (kgN/m2)                    litter nitrogen, labile pool
0.0 (kgN/m2)                    soil nitrogen, mineral pool
```

As with W_STATE and C_STATE, the N_STATE values are ignored when using an input restart file. For the reasons outlined above, it is recommended that new simulations be started with a spinup run and an optional transient run, and then continued from the end with a restart file. In the case of a spinup run, it is recommended that the N_STATE values both be set to 0.0, as in the example shown here.

Section GROWING_SEASON
The next section is defined to control optional growing season estimation within the model code based on the HSGSI method (Hidy et al., 2012). It is only applicable if the MODEL PHENOLOGY flag is set to 1 in the EPC file (in this sense it can be considered as an alternative model phenology routine). It has the following 14 lines:
1) critical amount of snowpack that limits photosynthesis through shading
2) flag (0,1) controlling the use of the HSGSI method to calculate growing season (1) or not (0)
3) lower limit of heatsum controlling the growing season
4) upper limit of heatsum controlling the growing season
5) lower limit of minimum temperature controlling the growing season
6) upper limit of minimum temperature controlling the growing season
7) upper limit of vapor pressure deficit controlling the growing season
8) lower limit of vapor pressure deficit controlling the growing season
9) upper limit length of the day controlling the growing season
10) lower limit of length of the day controlling the growing season
11) length of time window (in days) used for boxcar averaging of the HSGSI index
12) lower limit of growing season index; if the HSGSI index exceeds this threshold, then growing season will start
13) upper limit of growing season index; if the HSGSI index reaches this value after the onset, then the growing period will terminate

14) name of output GSI file (containing the estimated start and end of the growing season and index values; this text file can be used to check the internal calculations)

When the flag in line 2) is set to 1, then the beginning and end of the growing season will be calculated based on the data provided in the other lines (using HSGSI index). If the flag in line 2) is 0, then the method will not be used (in this case the original model phenology will be used). For details on the theoretical background see Hidy et al. (2012). Note that the HSGSI calculations use the base temperature for growth defined in the EPC file (see below).

```
GROWING_SEASON    (keyword) on/off flag for HSGSI and HSGSI related settings
5.00                  (kg/m2) crit. amount of snow limited photosynthesis
1                     (flag) use GSI index to calculate growing season
1.00                  (Celsius) limit1 (under: fully constrained) of HEATSUM index
10.00                 (Celsius) limit2 (above: unconstrained) of HEATSUM index
-2.00                 (Celsius) limit1 (under: fully constrained) of TMIN index
5.00                  (Celsius) limit2 (above: unconstrained) of TMIN index
4000                  (Pa) limit1 (above: fully constrained) of VPD index
1000                  (Pa) limit2 (under: unconstrained) of VPD index
0                     (s) limit1 (under: fully constrained) of DAYLENGTH index
0                     (s) limit2 (above: unconstrained) of DAYLENGTH index
10                    (day) time window used for moving average calculation
0.10                  (DIM) GSI limit1 (GSI>limit: start of vegetation period)
0.01                  (DIM) GSI limit2 (GSI<limit2: end of vegetation period)
intvar/GSI_bugac.txt  file of the estimated start and end of the growing season
```

If any of the heatsum, tmin, VPD or daylength indices is set to -9999 it means that the variable has no effect on the growing season beginning/cessation calculations. We propose to use HSGSI for grasslands, and use the original model logic for woody vegetation unless the HSGSI method is studied further for non-herbaceous vegetation.

Section OUTPUT_CONTROL
The next section begins with the keyword OUTPUT_CONTROL. It has the following 7 lines:
1) text string giving the prefix for all output files, including path if appropriate
2) filename for output file containing internal control variables (this is independent of the prefix defined in line 1)
3) flag (1 or 0) to write (1) or not write (0) a binary output file with daily values
4) flag (1 or 0) to write (1) or not write (0) a binary output file with monthly averages of the daily variables
5) flag (1 or 0) to write (1) or not write (0) a binary output file with annual averages of the daily variables
6) flag (1 or 0) to write (1) or not write (0) a binary output file with year-end values
7) flag (1 or 0) to send (1) or not send (0) simulation progress information to the screen

```
OUTPUT_CONTROL (keyword - do not remove)
outputs/test           (text) prefix for output files
intvar/ctrl_bugac.txt  (file path) file for internal BBGC variables (control)
1                      (flag) 1: write daily output 0: no daily output
0                      (flag) 1: monthly avg of daily variables 0: no file
0                      (flag) 1: annual avg of daily variables 0: no file
0                      (flag) 1: write annual output 0: no annual output
1                      (flag) for on-screen progress indicator
```

The user can select two different groups of variables for output; one group that will be used for daily output and the monthly and annual averages of daily values, and a second group that is used for writing year-end (day 365) values for each simulation year. The flag for daily output on line 3) does not need to be set to 1 in order to get monthly and/or annual averages of

the daily output variables. Setting any of the output flags to 1 (lines 3-6) will result in the creation of an output file, having the specified path and filename prefix (from line 2) and the following suffix depending on which type of output was requested:

daily output suffix: ".dayout"

monthly average output suffix: ".monavgout"

annual average output suffix: ".annavgout"

year-end output suffix: ".annout

The internal control variables file aims to support debugging of the model code, and it can be neglected by the User.

Section DAILY_OUTPUT

The next section begins with the keyword DAILY_OUTPUT. The number of lines can vary depending on the number of output variables requested, as follows:

1) the number of daily output variables requested. This value can be 0.

2) the index number for the first requested daily output variable

3) etc.

```
DAILY_OUTPUT (keyword)
5                  number of daily output variables
623                GPP (kgC/m2/day)
649                total ecosystem respiration (kgC/m2/day)
34                 Latent heat flux (evapotranspiration) (kgH2O/m2/day)
509                LAI (m2/m2)
638                total soil carbon (kgC/m2)
```

The number of lines after line 1) must equal the number of daily output variables specified on line 1). There are more than 500 possible output variables, and the use of an index is the simplest way to allow the User access to all of them without introducing complicated parsing routines that would tend to clutter the code. The index value for each variable is listed in Appendix D (they are also available within the output_map_init.c and the bgc_struct.h source file).

This indexing system is admittedly awkward for new users, since it requires first knowing which data structure element to reference and then getting the index value for that element. On the other hand, it has the advantages of being unambiguous and providing a direct user interface to the logical organization of the data structures used in the code.

As in all INI file lines with one defined value, all text after the first value on each output specification line is ignored by the program. It is recommended that as you add or delete output variable index values, you also add a descriptive comment reminding you what variable is being requested. The variables requested in this section are available for daily output, for monthly average output, and for annual average output, specified by the flags in the OUTPUT_CONTROL section.

Section ANNUAL_OUTPUT

The next section begins with the keyword ANNUAL_OUTPUT. It has exactly the same format as just described for the DAILY_OUTPUT section.

```
ANNUAL_OUTPUT (keyword)
6                  number of annual output variables
545                annual maximum projected LAI (m2/m2)
630                cumumative NEE (kgC/m2)
631                cumulative GPP (kgC/m2)
636                vegetation C (kgC/m2)
638                soil C (kgC/m2)
639                total C (kgC/m2)
```

The variables requested in this section are reported once each year (yearday 365, that is the last day of the year) and are stored in the *.annout file. This provides a once-in-a-year snapshot of the system state and activity, and so it is most appropriate for recording system states that are changing relatively slowly, such as soil carbon, vegetation carbon, etc. Remember that if annual averages of system behavior or system state are desired, then it is necessary to specify these variables in the DAILY_OUTPUT section, and set the annual averaging of daily output flag to 1 (line 5 in OUTPUT_CONTROL section).

Structure of the MANAGEMENT_SECTION block

The following blocks were defined to describe different management activities on the simulated ecosystem. This block was not present in previous versions of Biome-BGC. Each management type can be activated or deactivated for a given simulation independent of the other management types. Implemented management types are documented in Hidy et al. (2012) and in the forthcoming Hidy et al. (2016) study.

The management section starts with the following lines (this is mandatory):

```
------------------
MANAGEMENT_SECTION
------------------
```

Note that management settings can be optionally defined within the spinup INI file, but they are only used during the optional transient run, and not during the regular spinup phase. Note again that in case of transient run, the endpoint file created by the regular spinup will be overwritten by the endpoint of the transient run.

The management blocks must be present even if the user deactivates them (i.e. the structure of the INI file is fixed, similarly to previous versions of Biome-BGC).

A management type can be activated if the flag in the first line of the block is set to 1, or if there is a filename present in the first line of the block that refers to external management descriptor file (see below, and also Appendix E for examples). Note that the lines which are parts of this external management descriptor file are marked with asterisks (*).

If the flag is 0 it means that the management type is deactivated.

For each management type maximum 7 events can be defined for each year. In case of less than 7 events -9999 can be used to skip some of the events.

Section PLANTING

The first management section begins with the keyword PLANTING. Mainly cropland or grassland related simulations should use this type of management, but it is also applicable in case of forestry. This section has the following 5 lines:

1) flag (0, 1, or filename) to use PLANTING (1 or filename) or do not use planting (0)

2) *day(s) of planting, expressed as day of year (0: 1 January; 364: 31 December in regular years)

3) *the quantity of the seed expressed in kg seed per hectare (in forestry this refers to the weight of the seedlings)

4) *carbon content of seed (or seedling) in percent

5) *useful part of seed; this is the amount of seed that is germinating; the rest is lost to litter

```
PLANTING (keyword)
1    (flag) do PLANTING? 0=no 1=yes filename=external file is used
134 -9999 -9999 -9999 -9999 -9999 -9999  (yday) PLANTING day
5.  -9999 -9999 -9999 -9999 -9999 -9999  (kg seed/ha) quantity of seed
40. -9999 -9999 -9999 -9999 -9999 -9999  (%) C content of seed
90. -9999 -9999 -9999 -9999 -9999 -9999  (%) useful part of seed
```

Section THINNING
The next management section begins with the keyword THINNING. This management type is associated with forest related simulations. Clearcut can also be defined as it is the upper limit of fellings. This section has the following 5 lines:
1) flag (0, 1 or filename) to use THINNING (1 or filename) or not (0)
2) *day(s) of thinning
3) *rate of the thinning (proportion of removed biomass during felling); 0.5 means that 50% of the trees are removed via felling (note that roots are left at the site and they become part of the coarse woody debris and litter pool depending on root type)
4) *transported part of stem (percent); this is the percent of cut down stem that is removed from the site after intervention
5) *transported part of leaf (percent); this is the percent of leaf on cut down trees that is removed from the site during thinning

```
THINNING
0       (flag) do THINNING? 0=n 1=yes filname=external file is used
200  -9999 -9999 -9999 -9999 -9999 -9999  (yday) THINNING day
0.1  -9999 -9999 -9999 -9999 -9999 -9999  (prop) thinning rate
100. -9999 -9999 -9999 -9999 -9999 -9999  (%) transported part of stem
100. -9999 -9999 -9999 -9999 -9999 -9999  (%) transported part of leaf
```

Section MOWING
This management section begins with the keyword MOWING. Seven parameters are defined to simulate mowing:
1) flag (0, 1, or filename) to define MOWING (1 or filename) or not (0)
2) flag (0 or 1) for choosing the type of mowing simulation method (0: mowing on predefined day(s) of year; 1: mowing each time the LAI reaches a predefined threshold LAI-value)
3) predefined value of the LAI before mowing (in case of LAI threshold method, i.e. flag is 1 in line 2; note that this value should deviate from the measured value if LAI is overestimated by the model)
4) predefined value of LAI after mowing (in case of the LAI threshold method, i.e. flag is 1 in line 2; see note on LAI overestimation above)
5) *day(s) of the year of mowing (in case of predefined day method, i.e. flag is 0 in line 2)
6) *the value of LAI after mowing (in case of predefined day method; see note on LAI overestimation above)
7) *percent of removed part of mowed grass; this defines the lateral carbon flux caused by mowing which has a strong influence on Net Biome Production (NBP). In case of the predefined day method this data should be supplied for all mowing events. In case of the LAI threshold method this number should be supplied only once, as the number of yearly cuts is not known a priori. In this case the defined ratio will be applied to all events.

```
MOWING (keyword)
0                                       (flag) do MOWING? 0=no 1=yes or filename
0                                       (flag) mowing method? 0: fixday, 1: fixed LAI
6.0                                     (int) fixed value of the LAI before MOWING
1.0                                     (int) fixed value of the LAI after MOWING
150 234 -9999 -9999 -9999 -9999 -9999 (yday) MOWING day (day of year)
1.0 1.0 -9999 -9999 -9999 -9999 -9999 (int) value of the LAI after MOWING
95. 95. -9999 -9999 -9999 -9999 -9999 (%) transported part of plant material
```

Section GRAZING
The next management section begins with the keyword GRAZING. 16 parameters are defined to simulate GRAZING by livestock in pastures. Grazing is defined based on the 'livestock

unit' (LSU) terminology, where 1 LSU refers to an average animal (the animal-specific exact value can be set below). This section has the following lines:

1) flag (0, 1 or filename) to define GRAZING (1 or filename) or not (0)

2) *first day(s) of the grazing period(s) (day of year, 0-364); continuous grazing is assumed between the first and last grazig days defined here and by line 3). The first number defines the start of the first grazing period, and the second defines the start of the second grazing period. The grazing periods should not overlap. 7 grazing periods can be defined within one year. The other settings should be repeated according to the number of periods defined.

3) *last day(s) of the grazing period(s) (day of year, 0-364); see line 2)

4) *weight equivalent of an averaged animal in kilogramms; this is the average weight of the livestock

5) *animal stocking rate regarding a unit area (number of LSU per hectare)

6) *daily ingested dry matter regarding a unit LSU (kg dry biomass per LSU per day; carbon content of dry biomass is defined in line 10)

7) *trampling effect coefficient. It defines the increase of senescence coefficient (see theoretical basis document) due to animal movement. The proposed value is 1.5 which means that the senescence coefficient during the grazing period is 1.5 times higher than the senescence coefficient value set in EPC file.

8) *proportion of ingested dry matter which turns into excrement (percent of consumed grass)

9) *proportion of excrement returning to litter (percent of excrement)

10) *carbon content of dry matter (percent; 40-50% is a realistic estimate)

11) *N content of excrement (percent)

12) *carbon content of excrement (percent)

13) *manure emission factor for direct N_2O emissions from manure management (IPCC, 2006); we suggest to use the value defined below in the example

14) *fraction of nitrogen excretion left at the site (IPCC, 2006); we suggest to use the value defined below in the example

15) *manure emission factor for CH_4 emission (IPCC, 2006); we suggest to use the value defined below in the example

16) *fermentation emission factor for CH_4 emission (IPCC, 2006); we suggest to use the value defined below in the example

```
GRAZING (keyword)
0                                       (flag) do GRAZING? 0=no, 1=yes or file
156  262   -9999 -9999 -9999 -9999 -9999 (yday) first day of GRAZING
202  311   -9999 -9999 -9999 -9999 -9999 (yday) last day of GRAZING
650  650   -9999 -9999 -9999 -9999 -9999 (kg/animal) weight equivalent of LSU
0.69 1.15  -9999 -9999 -9999 -9999 -9999 (LSU/ha) animal stocking rate
13.0 13.0  -9999 -9999 -9999 -9999 -9999 (kg dry matter/LSU/day)daily ingested grass
1.50 1.50  -9999 -9999 -9999 -9999 -9999 (prop) trampling effect
25.0 25.0  -9999 -9999 -9999 -9999 -9999 (%) ratio of DM intake formed excrement
100. 100.  -9999 -9999 -9999 -9999 -9999 (%) ratio of excrement returning to litter
40.  40.   -9999 -9999 -9999 -9999 -9999 (%) carbon content of dry matter
2.0  2.0   -9999 -9999 -9999 -9999 -9999 (%) N content of manure
40.  40.   -9999 -9999 -9999 -9999 -9999 (%) C content of manure
0.02 0.02  -9999 -9999 -9999 -9999 -9999 (kgN2O-N:kgN) manure N2O emission factor
0.93 0.93  -9999 -9999 -9999 -9999 -9999 (dimless) fraction of nitrogen excretion left at site
33.0 33.0  -9999 -9999 -9999 -9999 -9999 (kgCH4/LSU/yr) manure CH4 emission factor
58.0 58.0  -9999 -9999 -9999 -9999 -9999 (kgCH4/LSU/yr) fermentation CH4 emission factor
```

Section HARVESTING

The next management section begins with the keyword HARVESTING. Harvest should be used in crop related simulations; for hay meadows the MOWING section should be used; for forest management the THINNING section is applicable. Four parameters are defined to simulate harvesting:

1) flag (0, 1 or filename) to define using harvesting (1 or file) or not (0)
2) *day(s) of harvesting (day of year)
3) *carbon content of soft stem after harvest (kgC/m^2; this is the weight of snag, which is the remaining aboveground soft stem; no living leaves remain at the site after harvest)
4) *percent of harvested leaves and soft stem that is removed from the field; it is assumed that fruit (yield) is always transported away from the field after harvest; fine roots are always left at the field; this parameter controls the lateral carbon flux caused by harvest which has significant implications on Net Biome Production (NBP)

```
HARVESTING (keyword)
1                                          (flag)do HARVESTING? 0=no,1=yes or file
200  -9999 -9999 -9999 -9999 -9999 -9999   (yday) HARVESTING day
0.01  -9999 -9999 -9999 -9999 -9999 -9999  (kgC/m2) remaining soft stem weight
90.0 -9999 -9999 -9999 -9999 -9999 -9999   (%) transported part of plant material
```

Section PLOUGHING
The next management section begins with the keyword PLOUGHING. This management type is applicable for croplands and grasslands, but it can also be used in other biome types. Four parameters are defined to simulate PLOUGHING:
1) flag (0, 1 or file) to define using ploughing (1 or file) or not (0)
2) *day of ploughing (day of year)
3) *parameter (1, 2 or 3) to define ploughing depth: 1: shallow (0 - 10 cm), 2: medium (0 - 30 cm), 3: deep (0 - 50 cm)
4) *dissolving coefficient of ploughed biome to litter (proportion); this parameter was introduced to avoid unrealistic sharp preaks in respiration that is caused by the transformation of ploughed dead plant material to the litter pool

```
PLOUGHING (keyword)
0                                          (flag) do PLOUGHING? 0=no,1=yes or file
201  -9999 -9999 -9999 -9999 -9999 -9999   (yday) PLOUGHING day
1    -9999 -9999 -9999 -9999 -9999 -9999   (type) PLOUGHING depth (1, 2 or 3)
0.10 -9999 -9999 -9999 -9999 -9999 -9999   (prop) dissolving coefficient
```

Ploughing has effect on the predefined soil texture, as it is supposed to homogenize the soil (in terms of texture, temperature and soil water content) for the depth of the ploughing at the ploughing day. In case of ploughing depth 2 the two upper soil layers are affected. In case of dept 3 the upper three layers are affected. This homogenization means that the model will use soil textures for the affected layers that might differ from those provided by the user within the SITE section.
Note that ploughing causes burial of litter that is usually supposed to reside on the soil surface. To handle this process, BBGCMuSo differentiates between aboveground and belowground litter pools.

Section FERTILIZING
The next management section begins with the keyword FERTILIZING. 13 parameters are defined to simulate fertilizing:
1) flag (0, 1 or file) to define using FERTILIZING (1 or file) or not (0)
2) *day(s) of fertilizing (day of year)
3) *amount of (organic or inorganic) fertilizer per hectare per day (kg fertilizer/ha/day)
4) *nitrate content of fertilizer in percent (%, considering weight of fertilizer)
5) *ammonium content of fertilizer (%)
6) *carbon content of fertilizer in case of organic manure (%)

7) *labile carbon fraction of fertilizer (%) (only applicable if carbon content of fertilizer is greater than zero)

8) *unshielded cellulose fraction of the carbon content within the fertilizer (%) (only applicable if carbon content of fertilizer is greater than zero)

9) *shielded cellulose fraction of the carbon content within the fertilizer (%) (only applicable if carbon content of fertilizer is greater than zero)

10) *lignin fraction of the carbon within the fertilizer (%) (only applicable if carbon content of fertilizer is greater than zero)

11) *dissolving coefficient of fertilizer; this parameters defines the speed at which the fertilizer will be available for plant uptake or nitrification (in case of ammonium); this parameter was introduced to simulate gradual effect of fertilizer input

12) *useful part of fertilizer (%); this defines the efficiency of fertilization which means that some part of the fertilizer is leached from the soil

13) *emission factor of N additions from mineral fertilizers [kg N_2O–N $(kgN)^{-1}$]

```
FERTILIZING (keyword)
0                                          (flag) do FERTILIZING?0=no,1=yes file
60   200  -9999 -9999 -9999 -9999 -9999    (yday) FERTILIZING day
30.0 30.0 -9999 -9999 -9999 -9999 -9999    (kg/ha/day) weight of fertilizer per day
17.0 17.0 -9999 -9999 -9999 -9999 -9999    (%) nitrate content of fertilizer
17.0 17.0 -9999 -9999 -9999 -9999 -9999    (%) ammonium content of fertilizer
5.0  5.0  -9999 -9999 -9999 -9999 -9999    (%) carbon content of fertilizer
70.0 70.0 -9999 -9999 -9999 -9999 -9999    (%) labile fraction of fertilizer
20.0 20.0 -9999 -9999 -9999 -9999 -9999    (%) unshielded cellulose fraction of fertilizer
0.0  0.0  -9999 -9999 -9999 -9999 -9999    (%) shielded cellulose fraction of fertilizer
10.0 10.0 -9999 -9999 -9999 -9999 -9999    (%) lignin  fraction of fertilizer
0.05 0.05 -9999 -9999 -9999 -9999 -9999    (prop) dissolving coefficient
90.0 90.0 -9999 -9999 -9999 -9999 -9999    (%) useful part
0.01 0.01 -9999 -9999 -9999 -9999 -9999    (kgN2O-N:kgN*) emission factor for N
```

Section IRRIGATION

The next management section begins with the keyword IRRIGATION. Three parameters are defined to simulate irrigation:

1) flag (0, 1 or file) to define using IRRIGATION (1 or file) or not (0)

2) *day(s) of irrigation (day of year)

3) *amount of water from irrigation in kg per m^2 per day (equivalent with mm of precipitation)

```
IRRIGATION (keyword)
0                                      (flag) do IRRIGATION? 0=no,1=yes file
150 250 -9999 -9999 -9999 -9999 -9999  (yday) IRRIGATION day
30. 30. -9999 -9999 -9999 -9999 -9999  (kgH2O/m2/day) amount of water
```

Section END_INIT

The last section of the INI file consists only of the keyword END_INIT, signaling the end of the file. This signal is used to make sure that the proper number of lines have been read from the INI file.

```
END_INIT (keyword) indicates the end of the initialization file
```

OPTION TO USE ANCILLARY MANAGEMENT FILES TO SIMULATE ANNUALLY VARYING HUMAN INTERVENTION

As we mentioned above, BBGCMuSo has a built-in option to define annually varying management settings for all implemented management types. This can be achieved by creating ancillary text files with a given structure. The name(s) of the ancillary management

file(s) can be set by the User, but for clarity we suggest to use names that are identical with the name of the management block defined within the INI file (e.g. mowing.txt, fertilizing.txt, grazing.txt, harvesting.txt, planting.txt, ploughing.txt, thinning.txt). These files are supposed to be present next to the model executable. The text files are only utilized if the first line of the given management block in the INI file contains reference to the file. For example, in case of mowing the MOWING section should look like this:

```
MOWING
mowing.txt   (flag or filename) do MOWING? 0=no 1=yes read file
0            (flag) mowing method? 0 - on fixday, 1 - fixLAI
…
```

In this example the mowing.txt file is supposed to be in the `management` directory relative to the directory of the model executable.

The ancillary management files only contain rows that define the 7 events for the specific management type (data marked with asterisk above). For example, in case of mowing (predefined day method), the mowing method (and the LAI before and after mowing, but this is not used in the present example) is always defined in the INI file, while the other settings (mowing days, LAI after mowing, transported part) are given in the ancillary file (if defined). As the management might vary from year to year, these settings must be repeated for each year during the normal simulation.

In other words, the 7-event-lines must be repeated for all years defined by the number given on line 2 of the TIME_DEFINE section. (Note that in case of the LAI threshold method the removed amount should be defined only once, as it will be applied to all cutting events.)

Similarly to the 7 management setting within the INI file, -9999 means that the given management event should not be considered (applicable if there are less then 7 management events per year; note that there can be years when there is no management at all).

Examples are given in Appendix E separately for each management type.

3.3   Meteorological input file

As described above, the MET_INPUT section of the INI file names a file containing the meteorological data used to drive a BBGCMuSo simulation. This file can contain any number of header lines, followed by numeric values for the meteorological data. The number of header lines must be specified after the filename in the MET_INPUT section of the INI file. Below is an example of the top of a meteorological data file having four header lines:

```
Bugac, 2009-2011: input for MTCLIM v4.3
MTCLIM v4.3 OUTPUT FILE
year yday    Tmax   Tmin  Tday  prcp     VPD    srad    daylen
              °C     °C    °C    cm       Pa     W/m2         s
2009  1      -4.70  -8.05 -6.52 0.00    25.88   40.68    30346
2009  2      -1.10  -5.90 -2.79 0.00   113.53  116.23    30400
2009  3      -2.03 -11.95 -5.54 0.00    56.67  177.67    30459
2009  4      -3.63 -17.26 -8.45 0.00    20.00   58.86    30522
2009  5      -2.76  -9.56 -4.68 0.00    83.68  105.26    30590
2009  6      -1.84  -9.34 -3.95 0.00    88.24  206.67    30662
2009  7      -4.52  -9.35 -5.35 0.00    42.50   29.07    30738
2009  8      -0.51 -10.99 -3.31 0.00   161.18  189.28    30819
```

In this case, the meteorological input file is generated by the MT-CLIM (version 4.3) program, as indicated in the header lines. Meteorological data files generated by MT-CLIM version 4.3 will always have four header lines, with the last two header lines describing the

variables and their units. This example also illustrates the required input variables, their units, and their order. BBGCMuSo requires these variables, using these units, and in this order, with no additional variables, for every simulation. The spacing between variables is not important, as long as there is some white space between each value on a line. Do not use commas or other non-white space separators.

The nine values required for each day are as follows:
1) year: the numerical year, repeated for each yearday
2) yday: the numerical day of the year, values must start with 1 and end with 365
3) Tmax: the daily maximum temperature (°C)
4) Tmin: the daily minimum temperature (°C)
5) Tday: the average *daytime* temperature (sunrise to sunset, °C)
6) prcp: the daily total precipitation (cm, *not millimeters!*)
7) VPD: the *daylight average* vapor pressure deficit (Pa)
8) srad: the *daylight average* shortwave radiant flux density (W/m^2)
9) daylen: the daylength (sunrise to sunset, seconds)

The meteorological input data file can contain any number of years of data, and each year must have exactly 365 days, with one line of data per day, and no separations between years. BBGCMuSo expects each year to have 365 days of data, so leap years will have to be truncated by eliminating one day. We suggest eliminating December 31 of a leap year, since then the yearday numbering doesn't have to be adjusted. We have found that this truncation has negligible effects on most simulations. The rationale for requiring 365-day years is that the met data files are commonly of shorter duration than the intended simulation, so they must be "recycled" enough times to match the number of requested simulation years. Recycling is also essential in the spinup runs. If the number of years in the met data file is not a multiple of four, then the handling of leap days in the code becomes very tedious, and introduces several layers of testing and manipulation between the input and the process algorithms. We have accepted the small errors introduced by eliminating one day from leap years in exchange for code that is clear and easier to maintain. Meteorological data files can be assembled from observations if all of the required parameters have been measured for the site of interest. They can also be generated using the MT-CLIM program using only observations of temperature and precipitation. The MT-CLIM code and documentation is available from the NTSG website: http://www.ntsg.umt.edu/project/mtclim.

A note on the bug related to the calculation of daylight average temperature

According to the Biome-BGC 4.2 User's Guide there was a bug in the source code of the model that is related to the calculation of daylight average temperature (Thornton and Running, 2002): *„An incorrect parameter was being used in the calculation of the daylight average air temperature in daymet.c. The parameter value in version 4.1.1 was 0.212, and the correct value, for consistency with the MT-CLIM and Daymet code, should be 0.45. The daylight average air temperature (tday) is used in the photosynthesis routine, and in the calculation of daytime leaf maintenance respiration. As an example of the net result of changing to the correct value, the example simulations described later in this guide show an increase in steady state leaf area index of about 10% and an increase in steady state net primary production of about 5%. Thanks to Michael Guzy at Oregon State University for finding this bug."*
We corrected this bug in BBGCMuSo, but not in terms of the parameter in daymet.c, but we modified the model in order to use the daylight average temperature value that is provided by

the meteorological input file (MT-CLIM output in many cases). We prefer this solution as the user of the model can use his/her own calculation method for daylight average temperature (e.g. based on hourly measurements), which would be meaningless if the model would re-calculate its value based on daily maximum and minimum temperature.

3.4   Ecophysiological input file (EPC file)

This input file defines the ecophysiological characteristics of the vegetation type being simulated. It is kept separate from the initialization file so that multiple initialization files can reference the same ecophysiology constants without cutting and pasting. Researchers at NTSG have spent considerable effort summarizing a large number of ecophysiological studies from the literature to come up with a set of default parameterizations for a small number of highly aggregated vegetation classes (plant functional types; see White et al., 2000). Model Users should also discover the features of the popular TRY database (Kattge et al., 2011) for parameters. If you have good measurements from your site(s) relating to any of these parameters, you should replace the defaults with your observations.

Users are cautioned that some of these parameters show strong covariance, and so replacing some but not others with local observations may reduce the quality of results. For example, canopy average specific leaf area, leaf C:N, and fraction of leaf N in Rubisco tend to covary, so if you replace any of these default values you should consider replacing all of them. Consult with your local ecophysiologist if you aren't sure about reparameterization of the default *.epc files. Note that all *.epc files must have the same parameter lines, in the same order, but that not all lines are relevant to all vegetation types.

The following section describes each line of an epc file, in the required order. The line number is followed by the units for the parameter in question and the short text description (some parameters are dimensionless, and these units are given as DIM). This is followed by a detailed description of the parameter(s) in question.

```
line 1
ECOPHYS (keyword) start of canopy ecophysiological constants block
```

This is a keyword used by the code to interpret the start of a block of ecophysiological data. The first line of each *.epc file *must* start with ECOPHYS.

```
line 2
(flag) 1: WOODY 0: NON-WOODY
```

An integer flag specifying the growth form (biome type), where 1 for woody includes both tree and shrub vegetation types, and 0 for non-woody includes grasses as well as other primarily herbaceous plants.

```
line 3
(flag) 1: EVERGREEN 0: DECIDUOUS
```

An integer flag specifying the leaf habit, where 1 for evergreen includes leaf habits that retain at least some of their foliage year-round, and 0 for deciduous includes leaf habits in which all foliage is absent at some point during a year. Either value for this flag can apply to both woody and non-woody growth forms.

```
line 4
(flag) 1: C3 PSN 0: C4 PSN
```

An integer flag specifying the photosynthetic pathway, where 1 indicates that the C3 photosynthesis model should be invoked, and 0 indicates that the C4 model should be invoked. Although this flag can be set to 0 for any combination of the other parameters, use of the C4 model should be restricted to grasses and herbaceous plants. Note that in BBGCMuSo v4.0 we implemented a new, enzyme-driven C4 photosynthesis routine in the photosynthesis module, based on the work of Di Vittorio et al. (2010).

```
line 5
(flag) 1: MODEL PHENOLOGY 0: USER-SPECIFIED PHENOLOGY
```

An integer flag specifying how the phenological control for a simulation will be exercised. A value of 1 invokes the internal phenology routine (including the optional HSGSI method), while a value of 0 indicates that the user will supply information on the yeardays for the start of new growth and the end of the litterfall period within the EPC file. See below for more details on how to set these parameters for the case of user-specified phenology. Note that there is an option to use an external file to define annually varying, user-specified values (see below).

Note that setting the parameter value to 1 will need a decision from the User. If the flag in the 2nd line of the GROWING_SEASON section within the INI file is set to 1, then the HSGSI method will be used to estimate start and end of the growing season (Hidy et al., 2012). If the flag in the INI file is zero, the original Biome-BGC v4.1.1 phenology will be used. We propose to use the HSGSI method for herbaceous vegetation, while we suggest to use the original logic for forests and shrublands.

```
line 6
(flag)  1: temperature dependent Q10 value 0: constant Q10 value
```

An integer flag that can be used to enable temperature dependent Q10 for autotrophic respiration (dynamic response of respiration to temperature). If the parameter is zero, then a constant Q10=2 will be used. In case of temperature dependent value (parameter is set to 1), Q10 is the function of the daily averaged air temperature: $Q10=3.22-0.046T_{day}$ where T_{day} is the mean (average of minimum and maximum) temperature for a given day (Smith and Dukes, 2010).

```
line 7
(flag)  0=no acclimation 1=phot acclim 2: resp acclim 3: phot+resp acclim
```

An integer flag specifying whether photosynthesis acclimation and/or maintenance respiration acclimation is enabled or not. A value of 0 means that acclimation is not simulated. If the flag is 1 it means that photosynthesis acclimation is simulated. A value 2 enables the respiration acclimation routine. If the flag is set to 3 it means that both photosynthesis acclimation and respiration acclimation are enabled.

Respiration acclimation is calculated after Tjoelker et al. (2001) and Smith and Dukes (2013). In this routine adjustment of respiration is calculated based on the mean temperature of the previous 10 days.

Photosynthesis acclimation is simulated in a very simple way, by modifying the relationship between V_{cmax} (maximum rate of carboxylation) and J_{max} (maximum electron transport rate). (Kattge and Knorr, 2007) that was temperature-independent in the original code. Temperature dependency is calculated based on average temperature for the previous 30 days. This simple

photosynthesis method is not a complete representation of the acclimation of the photosynthetic machinery (Smith and Dukes, 2013).

Note that we also modified the default (temperature independent) relationship between V_{cmax} and J_{max}, which is activated if the flag in line 7 is set to 0 or 2. The original code used the $J_{max}=2.1V_{cmax}$ relationship. According to Rogers et al. (2014) the $J_{max}=1.97V_{cmax}$ relationship is more realistic based on the dataset published by Wullschleger (1993).

```
line 8
(flag) maximum stomatal conductance modulation by CO2 (0=off  1=modulation)
```

An integer flag specifying whether stomatal conductance should be affected by changing atmospheric CO_2 concentration or not (Franks et al., 2013). For details see the notes for line 53. We recommend to set this flag to 1.

```
line 9
(flag) soil water balance calc method (0: R, 1: T (up+down), 2: T (down only))
```

An integer flag specifying the soil water balance calculation method. 0 means that soil water balance is simulated based on the Richards equation, while 1 means that the so-called tipping bucket method is used with both possible downward and upward water movement. 2 means that the tipping bucket method is used with downward water movement only. For details see Hidy et al. (2016) (in prep.). There is no recommended value for this flag; the User has the freedom to test all 3 methods and use the most appropriate based on comparison with measured data.

```
line 10
(int)  SWC calculation discretization (0: low, 1: medium, 2: high)
```

An integer flag specifying the discretization level of soil water balance calculation method. 0 means low, 1 means medium, while 2 means high accuracy of the finite difference method used for soil water balance. Level 0 is the fastest, level 2 is the slowest. We propose to use level 0 for everyday simulation. It is only applicable in case of the Richards-equation based water balance method (if flag is 0 in line 9).

```
line 11
(flag) soil temperature calculation method (0: Zheng, 1: DSSAT)
```

An integer flag specifying the soil temperature calculation method. 0 invokes the Zheng et al. (1993) based method with logarithmic downward dampening of temperature fluctuations within the soil. 1 means that the empirical method of DSSAT/4M (Sándor and Fodor, 2012) will be used. For details see Hidy et al. (2016) (in prep.). The preferred method should be selected based on comparison with measurements at the specific site (if available).

```
lines  12 and 13
(yday) yearday to start new growth (when phenology flag: 0)
(yday) yearday to end litterfall (when phenology flag: 0)
```

Two integers specifying the day of year for the start of new leaf growth, and the day of year for the end of the litterfall season, respectively. Relevant only when the phenology flag is 0 (see above line 5). There are several important notes about setting these values: to suppress new leaf growth entirely, for example in the case of a simulation concerned with bare soil processes, set both of these values to -1.

Yearday values for these parameters start at 0 and go to 364. Note that BBGCMuSo does not accept leap-years, i.e. all years are by definition 365 days long.

Northern and Southern hemisphere yeardays are treated differently for these parameters. In the northern hemisphere, yearday 0: Jan 1, while in the southern hemisphere yearday 0: July 2. This allows the same yearday values to be used to specify deciduous growth habit in the northern and southern temperate zones.

If the leaf habit flag is set to evergreen (1), and the phenology model flag is set to user-specified (0), these values do not have any effect.

```
lines 14 and 15
(prop.) transfer growth period as fraction of growing season
(prop.) litterfall as fraction of growing season
```

These two parameters determine the duration of the transfer growth and litterfall periods, and are defined as proportions of the period between the start of new growth and the end of litterfall. These parameters must be set by the user regardless of whether internal model phenology or user-specified phenology is specified in the phenology model flag. These parameters can take any values from 0.0 to 1.0, where a value of 0.0 indicates that all transfer growth or all litterfall occurs in a single day, and a value of 1.0 indicates that transfer growth or litterfall occur throughout the growing season. Transfer growth is the growth derived from carbon and nitrogen resources stored over the course of the previous growing season. It is the growth that produces the first flush of new leaves in the spring for deciduous plants. NOTE that when the leaf habit flag is set for evergreen (1), both transfer growth and litterfall are assumed to occur at constant rates throughout the year, and the specification of these two parameters has no effect.

```
line 16
(Celsius) base temperature
```

This parameter sets the base temperature for plant processes. (In general, base temperature is defined as the lowest temperature where metabolic processes may result in a net substance gain in aboveground biomass.) Base temperature is used to calculate a special growing season index (HSGSI; see the description of the INI file) to estimate the start and the end of the vegetation period (Hidy et al., 2012) and to calculate growing degree-day to estimate the start of fruit allocation or leaf phenological senescence (Hidy et al., 2016 (in prep.)). If the HSGSI method is not used, or if there is no fruit allocation or phenological senescence (see below), then this parameter has no effect.

```
lines 17 and 18
(Celsius) growing degree day for start of fruit allocation
(Celsius) growing degree day for maturity (start of leaf senescence)
```

These two parameters set specific thresholds to be reached by the internally calculated growing degree-day sum (GDD). GDD sum is a measure of heat accumulation to predict plant development rates such as the date when a flower will bloom, fruit allocation starts, or a crop will reach maturity (start of phenological senescence). GDD is calculated using the cumulative difference between mean daily temperature and base temperature (see line 16) similarly to the method used in crop models (negative differences are ignored and have no effect on the GDD values). In case of planting (crop related simulations) GDD is calculated from the day of planting. In other cases, GDD is calculated from the beginning of the year. These two specfic thresholds defined by lines 17 and 18 use GDD thresholds to be reached for *start of fruit allocation* (line 17) and for the start of *genetically programmed leaf senescence* (specific to some plant types - typical for maize and wheat) (line 18). This senescence process is related to the age of the plant tissue in leaves.

If there is no fruit allocation (see below) then the parameter in line 17 has no effect. If phenological senescence is not needed, the parameter in line 64 (mortality coefficient of phenological leaf senescence) should be set to 0 (it means that setting line 18 to zero does not switch off the genetically programmed senescence!).

```
line 19
(1/yr) annual leaf and fine root turnover fraction
```

Determines leaf and fine root turnover for evergreen plants. This is the fraction of the annual maximum leaf and fine root mass that will be dropped in the following year as litter. It is the reciprocal of the leaf longevity, so a plant that retains its leaves an average of two years would have a leaf/fine root turnover of 0.5. Note that leaf and fine root phenology are assumed to be entirely synchronized for all vegetation types. Also note that when the leaf habit is specified as deciduous (0), this parameter is always assumed to be 1.0, and will be reset inside the code if the user specifies any other value.

```
line 20
(1/yr) annual live wood turnover fraction
```

Determines livewood turnover to deadwood for all woody types (deciduous and evergreen). Important note about the definition of livewood and deadwood in BBGCMuSo: livewood is defined as the actively respiring woody tissue, that is, the lateral sheathing meristem of phloem tissue, plus any ray parenchyma extending radially into the xylem tissue. Deadwood consists of all the other woody material, including the heartwood, the xylem, and the bark. It has been common in many tree models, including previous versions of BBGCMuSo, to divide the woody tissue into two compartments called "sapwood" and "heartwood", where sapwood is usually defined as the sum of phloem and xylem, with heartwood defined as the non-conducting woody tissue. The current treatment ignores the distinction between water-conducting xylem and non-conducting heartwood.
For herbaceous vegetation the wood related parameters does not affect the simulation.

```
line 21
(1/yr) annual whole-plant mortality fraction
```

This parameter specifies the fraction of all plant pools that will be removed and sent to the litter compartments over the course of a year. In case of woodlands, this is one mechanism by which woody material (live and dead) leaves the plant pool and enters the litter pools to be made available for subsequent decomposition. It is the conceptual equivalent of wind-throw (but not exclusively, as diseases, competetive processes in early development phase or frost damage can also cause mortality of plants), and all plant pools, living and dead, are attenuated at the same rate. This annual proportion is converted internally to a daily rate, and whole-plant mortality is assumed to go on at a constant rate throughout the year. Note that BBGCMuSo has other mechanism for plant mortality, not present in previous versions of BBGC. For example, drought related leaf senescence acts together with annual whole-plant mortality, if applicable. Also, gentically programmed leaf senescence (which is another option in BBGCMuSo) can also cause leaf death besides this daily fixed plant mortality. In BBGCMuSo annually varying whole-plant mortality fraction can be set by providing an external file (see later in this manual). In this case the external data overrides the setting in the EPC file.

```
line 22
(1/yr) annual fire mortality fraction
```

This parameter specifies the fraction of plant pools subject to fire, on average, each year. The current treatment ignores the timing of individual fire events, taking a long-term view of the fire process, in which some fraction of the community is subject to fire each year, at a rate commensurate with the long-term fire frequency. For example, in a system with a stand-replacing fire return interval of 100 yrs, this parameter would be set to 0.01.

```
lines 23-25
(ratio) (ALLOCATION) new fine root C : new leaf C
(ratio) (ALLOCATION) new fruit C : new leaf C
(ratio) (ALLOCATION) new soft stem C : new leaf C
```

Sets the ratio of new fine root, fruit (e.g. crop yield) and soft stem growth to new leaf growth. These are constant values, and applies to both current year growth, and growth resources stored for the next year's transfer growth. Fruit and soft stem growth is optional: in the absence of fruit/soft stem the parameter value should be set to 0. Note that fruit and soft stem pools are novel features of BBGCMuSo, as they were unavailable in previous versions. Soft stem is applicable to grasslands and croplands, and it was introduced to handle the well known LAI overestimation problem (i.e. in the original logic, in case of herbaceous vegetation all aboveground carbon and nitrogen formed photosynthesizing leaves, which resulted in unrealistic high LAI values).

```
line 26
(ratio) (ALLOCATION) new stem C : new leaf C
```

Sets the ratio of new woody stem to new leaf growth. Stem growth includes both the live and dead woody components, as described above. This ratio is constant, and applies to both current year growth and growth resources stored for the next year's transfer growth. This is a woody biome related parameter only.

```
line 27
(ratio) (ALLOCATION) new live wood C : new total wood C
```

Sets the ratio of new live wood to new total wood. This ratio is constant, and applies to both current year growth and growth resources stored for the next year's transfer growth.

```
line 28
(ratio) (ALLOCATION) new croot C : new stem C
```

Sets the ratio of new coarse root growth to new stem growth. This ratio is constant, and applies to both current year growth and growth resources stored for the next year's transfer growth. Coarse roots are only present in woody biomes, but not in herbaceous vegetation.

```
line 29
(prop.) (ALLOCATION) current growth proportion
```

Sets the proportion of daily production that is displayed immediately as new growth, with the remainder stored for the next year's transfer growth. If the new growth in the next year is not possible due to e.g. crop harvest in autumn, this parameter can be set to zero. In this case all photosynthate will be allocated to new growth, and plant growth in the consecutive year will be suppressed until sowing.

```
line 30
(kgC/kgN) C:N of leaves
```

Mass ratio of carbon:nitrogen in live leaves.

```
line 31
(kgC/kgN) C:N of leaf litter, after retranslocation
```

Mass ratio of carbon:nitrogen in freshly fallen leaf litter. This can only be higher than or equal to the C:N for live leaves, i.e. retranslocation can only be positive or zero. Retranslocation is the removal of nitrogen from the leaves prior to litterfall. The model does not consider the possibility of retranslocation of carbon out of leaves prior to litterfall.

```
line 32
(kgC/kgN) C:N of fine roots
```

Mass ratio of carbon:nitrogen in fine roots. The model assumes that there is no retranslocation of nitrogen out of fine roots prior to litterfall, so this is the only C:N parameter for fine roots. This will typically be greater than the C:N for leaf.

```
line 33
(kgC/kgN) C:N of fruit
```

Mass ratio of carbon:nitrogen in fruit. The model assumes that there is no retranslocation of nitrogen out of fruit prior to litterfall. Fruit C:N ratio will typically be greater than the C:N for leaf.

```
line 34
(kgC/kgN) C:N of soft stem
```

Mass ratio of carbon:nitrogen in soft stem. The model assumes that there is no retranslocation of nitrogen out of soft stem prior to litterfall, so this is the only C:N parameter for soft stem. This will typically be greater than the C:N for leaf. Note that soft stem simulation is novel feature of BBGCMuSo. Soft stem is not present for woody vegetation.

```
line 35
(kgC/kgN) C:N of live wood
```

Mass ratio of carbon:nitrogen for live wood (phloem and ray parenchyma). This will typically be a much smaller value than the average C:N for all woody parts, and is typically found to be close to that for fine roots. As we noted, in case of herbaceous vegetation the wood related parameters does not affect the simulation.

```
line 36
(kgC/kgN) C:N of dead wood
```

Mass ratio of carbon:nitrogen for dead wood (bark, xylem, heartwood).

```
line 37
(DIM) leaf litter labile proportion
```

The proportion of leaf litter mass in the labile fraction, usually defined as that fraction soluble in hot water/alcohol.

```
line 38
(DIM) leaf litter cellulose proportion
```

The proportion of leaf litter mass in the cellulose fraction, usually defined as that fraction soluble in a mild acid solution, after extraction of the water/alcohol soluble fraction. As labile, cellulose, and lignin fractions for leaf litter must sum to 1.0, lignin proportion is calculated by the model as 1-labile-cellulose (defined in lines 37 and 38, respectively).

```
line 39
(DIM) fine root labile proportion
```

The proportion of fine root mass in the labile fraction, usually defined as that fraction soluble in hot water/alcohol.

```
line 40
(DIM) fine root cellulose proportion
```

The proportion of fine root mass in the cellulose fraction, usually defined as that fraction soluble in a mild acid solution, after extraction of the water/alcohol soluble fraction. As labile, cellulose, and lignin fractions for fine root must sum to 1.0, lignin proportion is calculated by the model as 1-labile-cellulose.

```
line 41
(DIM) fruit labile proportion
```

The proportion of fruit mass in the labile fraction, usually defined as that fraction soluble in hot water/alcohol.

```
line 42
(DIM) fruit cellulose proportion
```

The proportion of fruit mass in the cellulose fraction, usually defined as that fraction soluble in a mild acid solution, after extraction of the water/alcohol soluble fraction. As labile, cellulose, and lignin fractions for fruit must sum to 1.0, lignin proportion is calculated by the model as 1-labile-cellulose.

```
line 43
(DIM) soft stem labile proportion
```

The proportion of soft stem mass in the labile fraction, usually defined as that fraction soluble in hot water/alcohol.

```
line 44
(DIM) soft stem cellulose proportion
```

The proportion of soft stem mass in the cellulose fraction, usually defined as that fraction soluble in a mild acid solution, after extraction of the water/alcohol soluble fraction. As labile, cellulose, and lignin fractions for soft stem must sum to 1.0, lignin proportion is calculated by the model as 1-labile-cellulose.

```
line 45
(DIM) dead wood cellulose proportion
```

The proportion of dead wood mass in the cellulose fraction, usually defined as that fraction soluble in a mild acid solution, after extraction of the water/alcohol soluble fraction. As cellulose and lignin fractions for dead wood must sum to 1.0, lignin proportion is calculated by the model as 1-cellulose.

```
line 46
(1/LAI/d) canopy water interception coefficient
```

The proportion of daily rainfall that can be intercepted and retained on the canopy per unit of projected leaf area index.

```
line 47
(DIM) canopy light extinction coefficient
```

The Beer's law extinction coefficient for attenuation of radiation in the canopy, using a projected leaf area basis.

```
line 48
(DIM) all-sided to projected leaf area ratio
```

The ratio between the all-sided area and the projected area for leaves. Projected area for this and all other uses in BBGCMuSo is the projected area of the leaf laid flat with its two longest dimensions parallel to the measurement surface, while all-sided area is the total leaf surface area. For C3 and C4 grasslands and deciduous broadleaf forests this value is fixed to 2 within the model code, so setting line 48 to other value has no effect.

```
line 49
(m2/kgC) canopy average specific leaf area (projected area basis)
```

Projected area per unit of leaf carbon mass, averaged over the canopy.

```
line 50
(DIM) ratio of shaded SLA:sunlit SLA
```

Ratio between specific leaf area for leaves in the shaded canopy fraction and specific leaf area for leaves in the sunlit canopy fraction. White et al. (2000) suggest that this parameter should be set to 2.

```
line 51
(DIM) fraction of leaf N in Rubisco
```
The fraction of total live leaf nitrogen occurring in the RuBisCO enzyme. In the model V_{cmax} is calculated from this parameter also using SLA and C:N of leaves.

```
line 52
(DIM) fraction of leaf N PEP Carboxylase
```

The fraction of total live leaf nitrogen occurring in the PEP Carboxylase enzyme (Di Vittorio et al., 2010). This parameter is only applicable in case of C4 photosynthetic pathway (see line 4 in the EPC file).

```
line 53
(m/s) maximum stomatal conductance (projected area basis)
```

The maximum stomatal conductance to water vapor, expressed on a projected leaf area basis. This is the conductance under saturating light, low VPD, leaf water potential near 0.0, and moderate temperatures. Reciprocal of minimum stomatal resistance. Note that BBGCMuSo uses the Jarvis multiplicative stomatal regulation method (Jarvis, 1976). Also note that by setting the parameter in line 8 to 1 this value might be subject to change, and in that case this value refers to ~ end of the 20th cencury conditions (~present day). If this is the case, the maximum stomatal conductance to water vapor and also to CO_2 are varying according to ambient CO_2 concentration (Franks et al., 2013). In elevated CO_2 concentration this modification will cause down-regulation of maximum stomatal conductance thus it might improve water use efficiency of the biome.

```
line 54
(m/s) cuticular conductance (projected area basis)
```

The conductance of the leaf cuticle to water vapor, expressed on a projected area basis. Assumed constant under all environmental conditions.

```
line 55
(m/s) boundary layer conductance (projected area basis)
```

Leaf boundary layer conductance to water vapor, expressed on a projected area basis. This is also referred to as the aerodynamic conductance. It is defined as the conductance for water vapor entering the atmosphere from a free water surface on the leaf surface (a raindrop on the leaf). It is assumed constant under all environmental conditions, although it is in reality a strong function of wind speed. A constant wind speed of 1 m/s is assumed in defining values of this parameter for various leaf morphologies.

```
line 56
(DIM) relative soil water content (prop. to FC) to calculate soil moisture limit 1
```

This parameter defines the critical relative soil water content ($RSWC_{FC}$, i.e. actual soil water content divided by field capacity) where drought related soil moisture limitation starts to affect plant processes. If actual SWC is larger than critical SWC calculated from this parameter, then soil moisture does not affect stomatal conductance, evapotranspiration and root water uptake. Linear ramp function is defined between this critical value (where limitation starts) and wilting point (complete limitation). Note that saturation, field capacity and wilting point can be given within the INI file by the User, or alternatively they can be estimated from soil texture using empirical relationship (by setting their value to -9999 in the SITE section of the INI file). If there is no available data for this parameter, the User should set it to 1 (in this case moisture limitation starts at field capacity, which means that there is no water stress above field capacity; note that another stress is defined close to saturation which is controlled by line 57, so here we mean stress caused by soil moisture deficit). If soil water potential is used to calculate this limitation factor (see below), the User should set this parameter to -9999.
See Appendix A for details on drought related plant mortality which might use this parameter (or line 58).

```
line 57
(DIM) relative soil water content (prop. to SAT) to calculate soil moisture limit 2
```

Critical relative soil water content ($RSWC_{SAT}$; actual soil water content divided by saturation value) where elevated soil moisture content starts to affect stomatal conductance and decomposition, thus acts as limitation factor. The idea behind introducing this parameter is that presence of elevated groundwater or a wet, rainy period can negatively affect stomatal conductance and decomposition. If actual SWC is smaller than critical SWC calculated from this parameter then soil moisture does not affect stomatal conductance (at least due to elevated soil moisture), evapotranspiration, decomposition, and root water uptake. Linear ramp function is defined between this critical value (limitation starts) and saturation (complete limitation). If no available estimation is available, set this parameter to 1 (in this case the parameter will be saturation, which means that no stress will occur below saturation;

note that in this case drought related stress can still be active, as defined by line 56). If soil water potential is used to calculate this limitation factor, User should set this parameter to -9999.

```
line 58
(MPa) soil water potential to calculate soil moisture limit1
```

This parameter defines the critical soil water potential where drought related soil moisture limitation starts. The difference between lines 56 and 58 is only the calculation method: in case of line 58 the critical soil water content value is calculated from critical soil water potential instead of critical relative soil water content. If no estimation is available or if soil water content is used to calculate this limitation factor, the User should set this parameter to -9999. If both critical relative soil water content and soil water potential data are defined by the User (lines 56 and 58) the model will use the critical relative soil water content data.
See Appendix A for details on drought related plant mortality which might use this parameter.

```
line 59
(MPa) soil water potential to calculate soil moisture limit 2
```

Critical soil water potential where elevated soil moisture content starts to affect stomatal conductance and decomposition. The difference between lines 57 and 59 is only the calculation method: in case of line 59 critical soil water potential is used instead of critical relative soil water content. If no estimation is available or if soil water content is used to calculate this limitation factor, the User should set this parameter to -9999. If both critical relative soil water content and soil water potential data are defined by the User (lines 56 and 58) the model will use the critical relative soil water content data.

```
lines 60 and 61
(Pa) vapor pressure deficit: start of conductance reduction
(Pa) vapor pressure deficit: complete conductance reduction
```

These two parameters set the endpoints for a linear control on stomatal conductance due to the water vapor pressure difference (VPD) between the interior of the leaf and the air adjacent to the leaf. The first parameter sets the VPD at which conductance reduction begins, and the second parameter sets the VPD at which stomatal conductance is reduced to 0. In the range between these values, reduction of stomatal conductance is a linear function of VPD.

```
line 62
(DIM)  minimum  mortality  coefficient  of  non-woody  aboveground  plant  material
senescence
```

Soil moisture stress related mortality coefficient (causing plant senescence) on non-woody aboveground plant material (leaves; in case of herbaceous vegetation soft stem is also affected). The parameter controls the fraction of non-woody aboveground plant material (carbon and nitrogen) that dies during one day due to long lasting drought. The fraction of wilted biomass is calculated from this parameter, but this value is modified to take into account the length of the drought and the severity of the drought. Its proposed value is 0.05, which means that 5% of the actual carbon and nitrogen pool is lost during one day due to the drought stress. The User might want to change this parameter. The 0.05 value was set based on experiences on drought prone grassland in the Hungarian Great Plain. See Appendix A for details on drought related plant mortality simulation.

```
line 63
```

```
(DIM)  minimum  mortality  coefficient  of  non-woody  belowground  plant  material
senescence
```

Soil moisture stress related mortality coefficient (causing plant senescence) on non-woody belowground plant material (i.e. fine roots). Its proposed value is 0.05. The parameter is defined similarly to line 62. Note that this parameter is also used to deplete the storage pools (leaf and fine root storage, fruit storage) due to prolonged drought. Lines 62 and 63 might be important to simulate the carry-over effect of drought stress during the consecutive year as drought might also affect the storage/transfer pools. See Appendix A for details on drought related plant mortality simulation.

```
line 64
(DIM) mortality coefficient of phenological leaf senescence
```

Phenological stage related mortality coefficient (causing plant senescence) on leaf plant material. This senescence process is genetically programmed (it is related to the age of the plant tissue in leaves) in contrast to the drought related senescence that is handled by lines 62 and 63. The suggested value is 0.05, which means that 5% of the actual carbon and nitrogen pool is lost during one day due to the phenological state.

```
line 65
(DIM) turnover rate of wilted standing biomass to litter
```

Turnover rate of dead standing biomass (wilted leaves) to litter. The proposed value is 0.01 which means that 1% of the standing dead biomass turns into the litter pool during one day. This parameter is introduced to enable more realistic simulation of dead leaves behavior which can eventually stay intact for a longer time period before they touch the ground so that decomposition can start. The concept of standing dead biomass was introduced in BBGCMuSo, and it was not present in the predecessor Biome-BGC versions.

```
line 66
(DIM) turnover rate of cut-down biomass to litter
```

Turnover rate of cut-down (but not removed) non-woody biomass to litter. The proposed value is 0.05. This parameter controls the speed of transformation of harvested plant residues in croplands (or clipped grass leaves in case of mown grasslands) to litter. In case of forests this parameter controls the fate of (previously living) leaves on cut down trees (if thinning option is switched on), but it also controls the turnover of dead coarse root (stump) into coarse woody debris (cwd). Implementation of this turnover process was necessary to avoid C and N balance errors caused by large fluxes between specific pools.

```
line 67
(DIM) N denitrification proportion
```

Daily N denitrification proportion (amount of N mineralization that is available to volatilization each day). In the original model this parameter was constant, fixed within the source code. Its original value is 0.01. Our preliminary results suggest that the model is sensitive to the choice of this parameter.

```
lines 68-69
(DIM) bulk N denitrification WET proportion
(DIM) bulk N denitrification DRY proportion
```

These two parameters define the daily bulk denitrification proportion in case of wet soil (close to saturation) and dry soil (far from saturation). According to the model logic (Thornton and

Rosenbloom, 2005) if there is excess mineral nitrogen in the soil following microbial immobilization and plant N uptake, it is subject to volatilization and denitrification as a constant proportion of the excess mineral nitrogen pool for a given day. For the wet case this parameter was fixed as 0.068 in the original model code (Biome-BGC v4.2 logic), which means that 6.8% of the excess mineralized N pool is lost in one day. For the dry case it was fixed at 0.01 (1% loss). In BBGCMuSo these values can be adjusted as EPC parameters, if needed. We propose to use the original 0.068 and 0.01 values for lines 68-69 for initial tests. Further studies are needed to contrain these parameters.

```
line 70
(DIM) N mobile proportion
```

N mobile proportion is the proportion of mineralized N that is leached each day if there is deep percolation. In the original model this parameter was constant fixed within the source code. The original value is 0.1. Note that lines 67, 68, 69 and 70 control the total N loss from the ecosystem if there is no fire event.

```
line 71
(kgN/m2/yr) symbiotic+asymbiotic fixation of N
```

This parameter defines the annual rate of symbiotic + asymbiotic nitrogen fixation for the plant in kgN/m^2/yr. In previous Biome-BGC versions this parameter was defined within the SITE section of the INI file. Due to the complexity associated with the definition of this parameter we moved it to the EPC file so the User might want to adjust its value through model optimization (calibration). Total external N input to the ecosystem is the sum of symbiotic + asymbiotic nitrogen fixation and the reactive N deposition from the atmosphere where the latter is defined within the INI file (see above).

```
line 72
(DIM) ratio of the storage and the actual pool mortality due to management
```

Ratio of management related mortality of storage and actual pools. In order to understand the meaning of this parameter, some knowledge about the internal model logic is needed (Thornton, 1998). Briefly, in BBGCMuSo storage pools are defined that are responsible to control the initial plant growth at the beginning of the consecutive growing season (at the end of the actual year storage pools are turned into the transfer pools which are used in next year's initial growth; in this sense transfer pool is just another name for the storage pool). Our interpretation for the physical location of the storage/transfer pools is the following: aboveground material refers to the actual pools of leaf, soft stem, woody stem and fruit, while belowground material refers to the actual pools of root and storage/transfer pools of leaf, fruit, soft and woody stem and root (of course there can be exceptions). Using this logic the storage/transfer pools are supposed to be underground, which means that disturbance should have less (but non-zero) effect on these important pools as compared to the aboveground biomass (actual pools).

In BBGCMuSo specific management types (e.g. grazing, mowing and harvest) affects (decrease) the storage/transfer of leaf, fruit and soft stem. The parameter in line 72 defines the ratio of the storage/transfer and actual pool decline due to grazing, mowing and harvest. We propose to set this parameter to 0.1. This means that e.g. in case of removing 50% of actual pools of leaf due to cutting causes 5% decrease in both the leaf storage/transfer pools. If this parameter is set to zero, the storage/transfer pools will be unaffected by management.

```
line 73
(DIM)  critical value of soil moisture stress coefficient
```

This parameter sets the critical value of SMSI below which soil moisture stress related plant mortality begins. We suggest to set this parameter to 0.3, unless the User has other choice. 0.3 means that the soil moisture stress index within the entire root zone should fall below 0.3 to trigger plant senescence (caused by drought).

Note that, by definition, SMSI and $NSWC_{act}$ is zero below wilting point.

See Appendix A for details on drought related plant mortality simulation.

```
line 74
(days) critical number of stress days after which senescence mortality is complete
```

Critical number of drought related water stress days after which water stress is complete (it causes maximal plant death – set in lines 61 and 62 in the EPC file). We propose to use 30 days for grasslands based on experiences gained in drought-prone grasslands in Central Europe. For forests a higher value is more realistic. The User might revise this value in other, drought-prone ecosystems. See Appendix A for details on drought related plant mortality simulation.

```
line 75
(m) maximum depth of rooting zone
```

This parameter sets the maximum rooting depth for the biome. Timing of root growth is controlled by line 71 of the EPC file. The actual length of the root is simulated based on empirical function in case of non-woody biomes (Campbell and Diaz, 1988). In case of forests, fine root growth is assumed to occur in the entire root zone represented by coarse roots. In case of forest this depth does not change with time.

```
line 76
(DIM)  root distribution parameter
```

Empirical exponential root distribution parameter to calculate the distribution of roots within the soil layers (Jarvis, 1989). The proposed value is 3.67.

```
line 77
(DIM) root maturity coefficient
```

Rooting depth reaches its maximum value in the state of maturity. The maturity day is estimated using the maturity coefficient defined by line 77. This parameter defines the relative time (0...1) within the growing season when maximum rooting depth (set by line 75 of the EPC file) is reached. We propose to set this parameter to 0.5 which means the middle of the growing season (between onset and end of growing season). In case of woody biomas rooting depth is assumed to be constant, so this parameter has no effect (see line 75).

```
line 78
(DIM) growth respiration per unit of C gain
```

This parameter controls the growth respiration cost per unit of carbon growth (GPP). In the original model this parameter was fixed within the source code. The proposed value of the parameter is 0.3. Some studies suggest that this parameter might deviate from 0.3, and it is important to properly set the adequate value of this parameter.

```
line 79
(DIM) c parameter of DSSAT TSOIL estimation
```

Parameter that adjusts soil temperature in case of the DSSAT/CERES method (Sándor and Fodor (2012), see their eq. 5). The proposed value is 4. This parameters has only effect if the flag in line 11 is set to 1.

A NOTE ON THE REMAINING ECOPHYSIOLOGICAL PARAMETERS

The rest of the ecophysiological parameters should be left intact by the User in most of the cases. The predefined values of these parameters should only be changed in special cases and after careful consideration (e.g. if the model shows large sensitivity to the given parameter). We have included these parameters in the EPC file to allow easy modification if needed, without the need to re-compile the source code.

```
line 80
(kgC/kgN/d) maintenance respiration in kgC/day per kg of tissue N
```

This parameter defines the maintenance respiration in kgC per kg of tissue N per day. The proposed value is 0.218.

```
lines 81-86
(DIM) labile litter to fast microbial soil pool respiration fraction
(DIM) cellulose litter to medium microbial soil pool respiration fraction
(DIM) lignin litter to slow microbial soil pool respiration fraction
(DIM) fast microbial to medium microbial soil pool respiration fraction
(DIM) medium microbial to slow microbial soil pool respiration fraction
(DIM) slow microbial to recalcitrant SOM (humus) pool respiration fraction
```

Respiration fractions for allocation fluxes between litter and soil compartments. The default values are 0.39, 0.55, 0.29, 0.28, 0.46 and 0.55, respectively.

```
lines 87-94
(DIM) rate constant scalar of labile litter pool
(DIM) rate constant scalar of cellulose litter pool
(DIM) rate constant scalar of lignin litter pool
(DIM) rate constant scalar of fast microbial recycling pool
(DIM) rate constant scalar of medium microbial recycling pool
(DIM) rate constant scalar of slow microbial recycling pool
(DIM) rate constant scalar of recalcitrant SOM (humus) pool
(DIM) rate constant scalar of physical fragmentation of coarse woody debris
```

Base values of rate constants to calculate the non-nitrogen limited decomposition fluxes between litter and soil compartments. The default values are 0.7, 0.07, 0.014, 0.07, 0.014, 0.0014, 0.0001 and 0.001, respectively.

```
lines 95-96
(DIM) param1 for N2O calculations (empirical function of C:N)
(DIM) param2 for N2O calculations (empirical function of C:N)
```

Empirical parameters for N_2O flux estimation using the C:N ratio of the soil based on the method of Hashimoto et al. (2011). The default values are 41.18 and 0.249, respectively. The description of the calculation method can be found in Hidy et al. (2016) (in prep.).

```
line 97-100
(DIM) param1 for N2O calculations (empirical function of SWC)
(DIM) param2 for N2O calculations (empirical function of SWC)
(DIM) param3 for N2O calculations (empirical function of SWC)
(DIM) param4 for N2O calculations (empirical function of SWC)
```

Empirical parameters for N_2O flux estimation based on the soil water content following the method of Hashimoto et al. (2011). The default values are -0.224, 0.961, 1.898 and 7.461, respectively. The description of the calculation method can be found in Hidy et al. (2016) (in prep.).

```
line 101
(DIM) param1 for N2O calculations (empirical function of Tsoil)
```

Empirical parameter for N_2O flux estimation using the temperature of the soil based on the method of Hashimoto et al. (2011). The default value is 0.125. The description of the estimation can be found in Hidy et al. (2016) (in prep.).

```
lines 102-103
(DIM) param1 for CH4 calculations (empirical function of bulk density)
(DIM) param2 for CH4 calculations (empirical function of bulk density)
```

Empirical parameters for CH_4 flux estimation using bulk density of the soil based on the method of Hashimoto et al. (2011). The default values are 212.5 and 1.81, respectively. The description of the estimation can be found in Hidy et al. (2016) (in prep.).

```
lines 104-107
(DIM) param1 for CH4 calculations (empirical function of VWC)
(DIM) param2 for CH4 calculations (empirical function of VWC)
(DIM) param3 for CH4 calculations (empirical function of VWC)
(DIM) param4 for CH4 calculations (empirical function of VWC)
```

Empirical parameters for CH_4 flux estimation using soil water content following the method of Hashimoto et al. (2011). The default values are -1.353, 0.2, 1.781 and 6.786, respectively. The description of the estimation can be found in Hidy et al. (2016) (in prep.).

```
line 108
(DIM) param1 for CH4 calculations (empirical function of Tsoil)
```

Empirical parameter for CH_4 flux estimation using soil temperature based the method of Hashimoto et al. (2011). The default value is 0.01. The description of the estimation can be found in Hidy et al. (2016) (in prep.).

Note that in the original Biome-BGC model there were only 43 EPC parameters. BBGCMuSo has 107 EPC parameters, which means that the number of parameters increased. We are fully aware that high number of adjustable parameters might complicate calibration and application of the model. However, our intention was to extend the EPC file with some of the parameters that were „burned in" within the source code but might need adjustment. Implementation of the new, multilayer soil module and fruit also involved the definition of new EPC parameters, similarly to drought related processes. In the simplest case these extra parameters should be left intact by the user. In any case, sensitivity analysis is needed to check whether the new parameters have strong influence on the variability of the output or not. We are implementing a so-called workflow (using web services technology) within the frame of the BioVeL project to enable simple sensitivity analysis of BBGCMuSo. Please contact us for access to the workflow (virtual e-laboratory) environment.
A complete example EPC file is given in Appendix C.

3.5   Restart file

Restart file provides all the information required to start one simulation from the endpoint of a previous simulation. The results of the restarted simulation are exactly the same as if the original simulation had been carried out for additional years. This option is typically used in conjunction with the spinup mode (described above) to initialize the soil carbon and nitrogen components for a site without adequate measurements of these characteristics. Users need only know the names of input and output restart files, and need not be concerned with the file contents.

3.6   Optional input files

3.6.1   Carbon-dioxide concentration and nitrogen-deposition files

As we mentioned in the description of INI file, it is possible to use annual varying CO_2 concentration and/or N-deposition data for transient and normal simulation phase. These files must have one line for each simulation year: the first value on the line is the year, and the second value is the CO_2 concentration and/or N-deposition data. It is important to note that although the text files contain the year of the actual data, the model neglects the date and uses data from the text files sequentially (first line for the first simulation year, second line for the second etc.).

3.6.2   Mortality and conductance files

In order to enable more realistic simulation of forest stand development (or disturbance events for other biomes) we implemented an option for supplying annually varying whole plant mortality to BBGCMuSo. It is also possible to set maximum stomatal conductance in an annually varying fashion (note that this can also be done automatically using line 8 in the EPC file). During the transient and the normal phase of the simulation the model can either use constant mortality and stomatal conductance, or it can read annually varying mortality and/or conductance defined by a text file (mortality_transient.txt, mortality_normal.txt, conductance_transient.txt, conductance_normal.txt – the filenames are fixed) which is/are supposed to be present next to the model executable (during spinup only constant mortality and conductivity is possible). The structure of these files is the same as the structure of the annually varying CO_2 concentration file or the annually varying N deposition file. Note that the current model version does NOT take into account the year field in the mortality.txt or conductance.txt file (this is also true for the CO_2 and N deposition file): for the first year of the simulation the first line is used (regardless of the value of the year field); for the second year the second line is used etc. If external file(s) are provided by the User, the settings of whole plant mortality and/or maximum stomatal conductance within the EPC file are ignored by the model.

3.6.3   Groundwater file

Poorly drained forests (e.g. in boreal regions or in lowland areas) are special ecosystems where groundwater and flooding play an important role in soil hydrology and plant growth (Pietsch et al., 2003; Bond-Lamberty et al., 2007). In order to enable groundwater (vertically varying soil water saturation) effect on the ecosystems in BBGCMuSo we implemented an option to supply external information about the depth of the water table.

Groundwater depth is controlled by prescribing the depth of saturated zone (groundwater) within the soil. We assume that the User has information about groundwater depth from measurements or from another model (e.g. watershed hydrology model).

During the spinup and transient phase of the simulation the model can only use daily average data for one typical simulation year, defined by a text file (groundwater_spinup.txt; it must contain data exactly for 365 days). During the normal phase of the simulation the model can read daily groundwater information defined by another external text file (groundwater_normal.txt). These files are supposed to be present next to the model executable. If the files are not present, no groundwater manipulation is happening (using this logic groundwater effect can not be represented at all, or can be represented only in spinup run (including transient), only in normal run, or in both phases if both txt files are present).

The structure of groundwater.txt and groundwater_spinup.txt is simple (it is similar to the structure of the annually varying CO_2 concentration file or the annually varying N deposition file: day of year, then groundwater depth in meters (positive value!) for the given day; note that in the other external files the first column is typically the year, so this file format is a special one). Note that the current model version does NOT take into account the day of year field in the file: for the first day of the simulation the first line is used (regardless of the value of the day field); for the second day the second line is used etc. The User should check whether the length of the groundwater file is in accordance with the length of the normal simulation.

The handling of the externally supplied groundwater information is the following. If the depth of the water table reaches the bottom boundary of the given soil layer, the groundwater-affected part of the given layer becomes saturated, therefore the average soil water content of the given layer increases. If the depth of the water table reaches the upper boundary of the given soil layer, the given layer becomes saturated.

Note that groundwater simulation was tested with the Richards equation based soil water balance method. The tipping bucket method that can be optionally used for soil water balance calculations might cause water balance error in some situations when groundwater file is present. We propose to set line 9 in the EPC file to 0 (Richards method) when using groundwater simulation.

3.6.4   External file to control growing season ("onday" and "offday" files)

In order to prescribe the phenological phases of plants based on diverse information sources (e.g. based on remote sensing observations of from external phenology models), we implemented an option to use annual varying, but user-defined yearday to start new growth and yearday to end litterfall (in brief, onday and offday). As we mentioned above, setting the parameter in line 5 of the EPC file to 0 means that the User provides onday and offday in lines 12 and 13 within the EPC file, which will be the same in each simulation year. This new model feature overrides this restriction.

During the transient and the normal phase of the simulation the model can either use constant onday and/or offday, or it can read annually varying onday and/or offday defined by a text file (onday_transient.txt, onday_normal.txt, offday_transient.txt, offday_normal.txt – the names of the files are fixed) which is supposed to be present next to the model executable. During spinup only constant onday and offday are possible, that is defined by the EPC file.

The structure of these files is the same as the structure of the annually varying CO_2 concentration file or the annually varying N deposition file. Note that the current model version does NOT take into account the year field in the txt file (this is true for the CO_2 and N deposition file): for the first year of the simulation the first line is used (regardless of the value of the year field); for the second year the second line is used etc.

4. Output files

There are two different styles of output produced by BBGCMuSo. The first type includes the binary output files controlled through the initialization file with information from the OUTPUT_CONTROL, DAILY_OUTPUT, and ANNUAL_OUTPUT sections. This is the most flexible output mechanism, since the user can control exactly which model variables to include in the output files, and what level of averaging to perform. The second type of output is a very simple formatted text file that contains annual summary information for each year of the simulation. This text output file is produced for all non-spinup simulations, and it uses a fixed list of output variables. These two output types are described in greater detail below.

4.1 Binary output files

These are not text files, and you will not be able to read them with a text editor or word processor. Instead, they are data files containing binary representations of the values of the output variables (the common name of this file format is „flat binary"). Each value is written as a single precision IEEE floating point binary number (using 4 bytes of storage per number; see http://en.wikipedia.org/wiki/Single-precision_floating-point_format for details). These values can be read directly using simple code written in C/C++, FORTRAN, BASIC, PASCAL, IDL, Python, R and other programming languages. They can also be read by many commercially available software packages, typically those that specialize in manipulating large multidimensional data sets. There are lots of other possibilities for reading these files, and you might want to consult with a computer programmer about the methods best suited for the kind of analysis you want to do. In order to read the binary files, you need to know how output values are ordered in the file.

Consider a single simulation over 100 years, for which the user requested 5 daily output variables and 4 annual ouput variables, and requested that in addition to the daily output, the three variables also be summarized as monthly averages and annual averages. Below is a corresponding example of the OUTPUT_CONTROL, DAILY_OUTPUT, and ANNUAL_OUTPUT sections of the INI file:

```
OUTPUT_CONTROL (keyword - do not remove)
outputs/test        (text) prefix for output files
intvar/ctrl.txt     (text) file of the BBGC control variables
1 (flag) 1: write daily output 0: no daily output
1 (flag) 1: monthly avg of daily variables 0: no monthly avg
1 (flag) 1: annual avg of daily variables 0: no annual avg
1 (flag) 1: write annual output 0: no annual output
1 (flag) for on-screen progress indicator

DAILY_OUTPUT
  5        number of daily output variables
623        GPP
649        TR
 34        LHF
509        LAI
638        soilC

ANNUAL_OUTPUT
  4        number of annual output variables
545        ann max projLAI
636        vegC
638        soilC
639        totalC
```

Four binary output files will be created for this simulation, and each file can be considered as a multi-dimensional array of values. The first dimension in each output file is the number of variables (5 in the case of daily variables, 4 in the case of annual variables). The last dimension is the number of years of simulation (100 in this case). Daily and monthly files have another dimension which is either the number of days per year (365) or the number of months per year (12). The values in parentheses beside the filenames below show the dimensions for each file in this example:

outputs/test.dayout (5 x 365 x 100)
outputs/test.monavgout (5 x 12 x 100)
outputs/test.annavgout (5 x 100)
outputs/test.annout (4 x 100)

Values are stored sequentially in the file as dictated by these dimensions. As an example, for the *.dayout file, the first five values in the file are the five daily output variables for the first day of the first year of the simulation. The next five values in the file will be the five daily output variables for the second day of the first year of simulation, etc.

Note that within our virtual e-laboratory environment (http://ecos.okologia.mta.hu/bbgcdb/) the binary files are automatically converted to .csv format, so that model Users can easily read the results in e.g. Microsoft Excel. Please contact the authors for access to The Biome-BGC Projects Database & Management System.

4.2   Annual text output

Because it can take some time to get used to the binary output formats, we also include a formatted text output file with annual summary information. For many applications this may be all the information required. In any case it allows a quick look at the results before proceeding with more detailed analyses. The name of the file is the user-supplied output prefix plus the following suffix "_ann.txt". Note that in BBGCMuSo we have added new output types to the annual output file including NBP and management related lateral carbon fluxes.

4.3   Internal control variables file

In order to make it easier to study the most important internal model variables, we extended the model to create an additional text file during the simulation (its name can be set in INI file; line 2 in the OUTPUT_CONTROL block). This file contains soil temperature, growing degree day, daily soil water content, soil moisture stress index, soil, litter and plant carbon content, soil mineralized nitrogen content, gross primary production, total ecosystem respiration and evapotranspiration data. The main aim of this file is to support debugging of the model code, therefore it can be neglected by the User.

4.4   Log file

In BBGCMuSo some of the variables (mostly related to soil processes) are calculated internally by the model code, so they are not accessible by the user in a simple way. Also, due to options related to soil water content/temperature and phenology calculations, information about the actual configuration might not be available after model execution in a simplistic way. Another problem is that getting information about the successfulness of the simulation is not always possible in batch processing mode (e.g. during Monte-Carlo simulations).

Based on this reasoning we have extended the model to create another file with essential information about the model simulation in terms of configuration and technical aspects. This file is called as the log file (with .log extension; they are pure text files). Spinup and normal runs have their own log file. Using the log file it is easy to decide whether the model simulation was successful or not: the last line of the log file shows the simulation status [0 - failure; 1 - success]. If no log file is generated, then the model clearly failed, so this is another option to check model simulation status. The log file also contains information about the most important, model-calculated parameters and optional input files.

Appendix F contains an example for the log file.

5. Code History

The BBGCMuSo ecosystem process model has a long heritage, and many people have contributed extensively to its development over many years. The following is a short synopsis of some of the most prominent code versions preceeding the current version BBGCMuSo 4.0.

Biome-BGCMuSo v4.0, Dóra Hidy, 2015 (C/C++)
Biome-BGCMuSo v1.0-3.0.8, Dóra Hidy (C/C++)
Biome-BGC version 4.1.1, Peter E. Thornton, 2000 (C/C++)
Biome-BGC version 4.1, Peter E. Thornton, 2000 (C/C++)
Biome-BGC version 2.0 (CRB-BGC), Peter E. Thornton, 1995 (C/C++)
Biome-BGC version 1.37, E. Raymond Hunt, Jr., 1993 (Pascal)
Forest-BGC, Joseph C. Coughlan, 1986 (Pascal)
DAYTRANS-PSN, Steven W. Running, 1981
DAYTRANS, Steven W. Running, 1975

Others who have contributed to the code in various ways and at various stages include: Galina Churkina, Tom Gower, Kathy Hibbard, Bob Keane, John Kimball, Lars Pierce, Joseph White, Michael White, Peter Anthony, Emil Cienciala, Beverly Law, Shaoxiu Ma, Ryan Anderson, Nándor Fodor.
Please contact the authors for the source code of the model.

Acknowledgements

Appendix A
PLANT MORTALITY CALCULATION DUE TO SOIL MOISTURE STRESS

In BBGCMuSo soil moisture stress index (SMSI) is defined to control drought (soil water stress) related plant mortality. Beside senescence mortality process, SMSI is also used in calculations related to stomatal conductance closure and transpiration limitation (not discussed here).

Note that in BBGCMuSo the actual calculation of drought related stress uses information from multiple layers. In this documentation we only discuss a simplified, single-layer case, for clarity. Also note that in BBGCMuSo drought can only affect leaves, soft stem (if defined) and fine roots. Woody material is unaffected by drought (including coarse roots).

SMSI is the function of normalized soil water content.

Normalized soil water content (NSWC) is defined by the following equation:

$$\text{NSWC} = \frac{\text{SWC} - \text{SWC}_{wp}}{\text{SWC}_{sat} - \text{SWC}_{wp}}, \text{if SWC}_{wp} < \text{SWC}$$
$$\text{NSWC} = 0 \qquad\qquad , \text{if SWC}_{wp} \geq \text{SWC}$$

where SWC is the soil water content of the given soil layer (m^3 m^{-3}), SWC_{wp} and SWC_{sat} are the wilting point and the saturation value of soil water content, respectively. The User can set these parameters in the initialization file or they can be calculated by the model internally.

By definiton, NSWC is zero if soil water content drops below wilting point due to severe drought (when SWC can approximate hygroscopic water content). The maximum NSWC is 1.

SMSI is a function of NSWC and can vary between 0 and 1. If SMSI=1 then no soil moisture stress is present. If SMSI=0 then soil moisture stress is at its maximum.

The general form of SMSI is defined by the following equations:

$$\text{SMSI} = \frac{\text{NSWC}}{\text{NSWC}_{crit1}}, \quad \text{if NSWC} < \text{NSWC}_{crit1}$$
$$\text{SMSI} = 1, \qquad\qquad \text{if NSWC}_{crit1} < \text{NSWC} \leq \text{NSWC}_{crit2}$$
$$\text{SMSI} = \frac{1 - \text{NSWC}}{1 - \text{NSWC}_{crit2}}, \text{if NSWC}_{crit2} < \text{NSWC}$$

where NSWC_{crit1} and NSWC_{crit2} are the critical values (or characteristic points) of the normalized soil water contents, calculated from the relative soil water content or soil water potential values defined by parameters from ecophysiological file (lines 56-57, or 58-59). Conversion from relative values to normalized soil water content is made within the source code. If lines 56 and 57 are used to define these critical values, then NSWC_{crit1} is calculated from line 56 of the EPC file (RSWC_{FC}, i.e. actual soil water content divided by field capacity), while NSWC_{crit2} is calculated from line 57 of the EPC file (RSWC_{SAT}; actual soil water content divided by saturation value). Characteristic point NSWC_{crit1} is used to control drought related limitation, while NSWC_{crit2} is used to control excess water related limitation (e.g. anoxic soil related stomatal closure). The effect of excess water is not discussed here but will be presented in detail in Hidy et al. (2016) (in prep.).

SMSI_{crit} parameter (critical value of soil moisture stress coefficient; line 73 in the EPC file) sets the critical value of SMSI below which soil moisture stress related plant mortality begins.

Once stress related plant mortality starts, the model calculates the number of days since soil moisture stress is acted continuously (SMSI is less than $SMSI_{crit}$).

A so-called soil stress effect (SSE_{total}) is defined to calculate the amount of plant material that senescences in one day due to drought stress. SSE_{total} quantifies the severity of the drought for a given day. Severity of drought is the function of the number of days since soil moisture stress is present (NDWS) (i.e. since SMSI is less than $SMSI_{crit}$). It is assumed that after a longer time period with soil moisture stress the senescence is complete, and no living leaf, soft stem and fine root remains. This longer time period is quantified by an ecophysiological parameter, whic is the 'critical number of stress days after which senescence mortality is complete' ($NDWS_{crit}$; line 74 in the EPC file).

SSE_{total} varies between 0 (no stress) and 1 (total stress). According to the BBGCMuSo logic, SSE_{total} is the function of SMSI, NDWS, $NDWS_{crit}$, and $SMSI_{crit}$:

$$SSE_{total} = SSE_{SMSI} \cdot SSE_{NDWS}$$

$$SSE_{SMSI} = \left(1 - \frac{SMSI}{SMSI_{crit1}}\right); \text{if } SMSI < SMSI_{crit1}$$

$$SSE_{SMSI} = 0 \qquad\qquad ; \text{if } SMSI \geq SMSI_{crit1}$$

$$SSE_{NDWS} = \frac{NDWS}{NDWS_{crit}} \quad ; \text{if } NDWS < NDWS_{crit}$$

$$SSE_{NDWS} = 1 \qquad\qquad ; \text{if } NDWS \geq NDWS_{crit}$$

SEE_{total} is used to calculate the actual value of non-woody aboveground and belowground mortality defined by SMCA and SMCB, respectively. SMCA defines the fraction of living C and N that dies in one day within leaves and soft stem. SMCB does the same for fine roots. SMCA and SMCB are calculated using two additional EPC parameters: minimum mortality coefficient (minSMC) of non-woody aboveground (A) and belowground (B) plant material senescence (minSMCA and minSMCB; lines 62 and 63 in the EPC file, respectively):

$$SMCA = minSMCA + (1 - minSMCA) \cdot SSE_{total}$$

$$SMCB = minSMCB + (1 - minSMCB) \cdot SSE_{total}$$

minSMCA and minSMCB can vary between 0 and 1. In case of 0 no senescence occurs. In case of 1 all living C and N will die within one day after the occurence of drought stress.

In this sense SMCA and SMCB can vary between their minimum value (minSMCA and minSMCB, respectively; if SSE_{total} is zero) and 1 (if SSE_{total} is 1). This latter case occurs when NDWS>$NDWS_{crit}$ and SMSI = 1.

SMCA is used to calculate the amount of aboveground plant material (leaves and soft stem) transferred to the standing dead biomass pool due to soil moisture stress related mortality on a given day (note that standing dead biomass is tranferred to the litter pool gradually). In case of belowground mortality it defines the amount of fine root that goes to the litter pool directly.The actual weight of the senescense is calculated as SMCA (and SMCB) multipled with the actual living C and N pool.

Figure A1 demonstrates the senescence calculation with an example. The figure shows the connections between the change of soil water content, normalized soil water content, soil moisture stress index, different types of soil stress effect (SSE_{SMSI}, SSE_{NDWS}, SSE_{total}) and senescence mortality coefficient as function of number of days since water stress is present. The figure shows a theoretical situation in which soil water content decreases from field

capacity to hygroscopic water within 30 days. The calculation refers to a sandy soil (SWC_{sat} = 0.44 m^3 m^{-3}, SWC_{fc} = 0.25 m^3 m^{-3}, SWC_{wp} = 0.09 m^3 m^{-3}; SWC_{fc} refertTo field capacity). We assume that $relSWC_{crit1}$ is 1.0 (field capacity) and $relSWC_{crit2}$ = 0.9 (10% below saturation), the critical number of stress days after which senescence mortality is complete ($NDWS_{crit}$) is 30 and the critical soil moisture stress index ($SMSI_{crit}$) is 0.5.

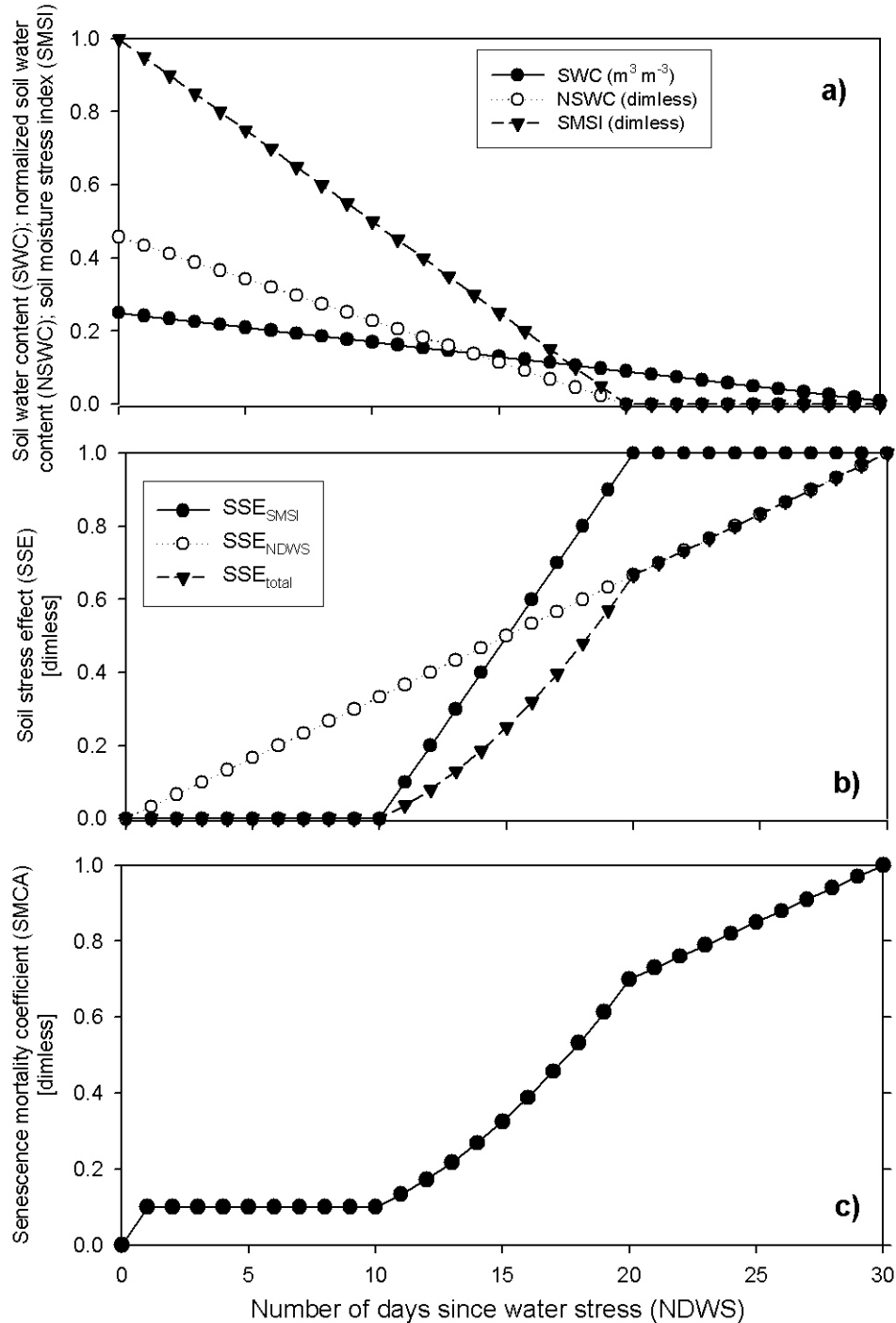Figure A1: a) Soil water content (SWC; black dots), normalized soil water content (NSWC; white dots) and soil moisture stress index (SMSI; black triangles). b) Soil stress effect based on soil moisture stress index (SSESMSI; black dots), soil stress effect based on number of days since water stress (SSENDWS) and total soil stress effect (SSEtotal). c) Aboveground senescence mortality coefficient.

Appendix B
EXAMPLE INI FILE FOR BBGCMUSO 4.0

```
BBGC_MuSo simulation

MET_INPUT
metdata/hhs_1901-2000.mtc43       (filename) met file name
4                                 (int) number of header lines in met file

RESTART
0                                 (flag) 1: read restart 0: dont read restart
1                                 (flag) 1: write restart 0: dont write restart
0                                 (flag) 1: use restart metyear 0: reset metyear
restart/test.endpoint             (filename) name of the input restart file
restart/test.endpoint             (filename) name of the output restart file

TIME_DEFINE
100                               (int) number of meteorological data years
100                               (int) number of simulation years
1901                              (int) first simulation year
1                                 (flag) 1: spinup run 0: normal run
6000                              (int) maximum number of spinup years

CLIM_CHANGE
0.0                               (degC) - offset for Tmax
0.0                               (degC) - offset for Tmin
1.0                               (degC) - multiplier for PRCP
1.0                               (degC) - multiplier for VPD
1.0                               (degC) - multiplier for RAD

CO2_CONTROL
1                                 (flag) 0=const 1=vary with file [trigger tansient run in spinup]
280                               (ppm) constant atmospheric CO2 concentration
co2/CO2_1901-2011.txt             (filename) name of the CO2 file

NDEP_CONTROL
0                                 (flag) 0=const 1=vary with file [trigger transient run in spinup]
0.001100                          (kgN/m2/yr) wet+dry atmospheric N-deposition
nitrogen/Ndep_1901-2011.txt       (filename)  name of the N-dep file

SITE
78.5 84.7 92.7 92.7 92.7 92.7 92.7          (%) sand percentage by volume (rock-free soil)
8.6  6.0   2.9 2.9 2.9 2.9  2.9             (%) silt percentage by volume (rock-free soil)
111.4                                       (m)  site elevation
46.69                                       (degrees) site latitude (- for S.Hem.)
0.20                                        (DIM) site shortwave albedo
11.00                                       (Celsius) mean annual air temperature
20.00                                       (Celsius) mean annual air temperature range
-9999                                       (DIM) user-defined RCN (NO DATA: -9999)
-9999 -9999 -9999 -9999 -9999 -9999 -9999   (g/cm3) user-defined bulk density (no data: -9999)
-9999 -9999 -9999 -9999 -9999 -9999 -9999   (m3/m3) user-defined SWC at SAT (no data: -9999)
-9999 -9999 -9999 -9999 -9999 -9999 -9999   (m3/m3) user-defined SWC at FC (no data: -9999)
-9999 -9999 -9999 -9999 -9999 -9999 -9999   (m3/m3) user-defined SWC at WP (no data: -9999)
-9999 -9999 -9999 -9999 -9999 -9999 -9999   (m3/m3) user-defined SWC at HW (no data: -9999)

EPC_FILE
epc/test_c3grass.epc     (filename) EPC file name

W_STATE
0.0                      (kg/m2)   water stored in snowpack
0.5                      (DIM)     initial soil water as a proportion of saturation

C_STATE
0.001                    (kgC/m2)  first-year maximum leaf carbon
0.0                      (kgC/m2)  first-year maximum stem carbon
0.0                      (kgC/m2)  coarse woody debris carbon
0.0                      (kgC/m2)  litter carbon, labile pool
0.0                      (kgC/m2)  litter carbon, unshielded cellulose pool
0.0                      (kgC/m2)  litter carbon, shielded cellulose pool
0.0                      (kgC/m2)  litter carbon, lignin pool
0.0                      (kgC/m2)  soil carbon, fast microbial recycling pool
0.0                      (kgC/m2)  soil carbon, medium microbial recycling pool
0.0                      (kgC/m2)  soil carbon, slow microbial recycling pool
```

```
0.0                          (kgC/m2)  soil carbon, recalcitrant SOM (slowest)

N_STATE
0.0                          (kgN/m2)  litter nitrogen, labile pool
0.0                          (kgN/m2)  soil nitrogen, mineral pool

GROWING_SEASON
5.0                          (kgH2O/m2) critical amount of snow limiting photosyn (no data: -9999)
1                            (flag) use GSI index to calculate growing season
5.00                         (Celsius) basic_temperature to calculate heatsum
1.00                         (Celsius) limit1 (under:full constrained) of HEATSUM index
10.00                        (Celsius) limit2 (above:unconstrained) of HEATSUM index
-2.00                        (Celsius) limit1 (under:full constrained) of TMIN index
5.00                         (Celsius) limit2 (above:unconstrained) of TMIN index
4000                         (Pa) limit1 (above:full constrained) of VPD index
1000                         (Pa) limit2 (under:unconstrained) of VPD index
0                            (s) limit1 (under:full constrained) of DAYLENGTH index
0                            (s) limit2 (above:unconstrained) of DAYLENGTH index
10                           (day) moving average (to avoid the effects of extreme events)
0.10                         GSI limit1 (greater that limit -> start of vegper)
0.01                         GSI limit2 (less that limit -> end of vegper)
intvar/GSI.txt               file of the estimated start and end of the VP

OUTPUT_CONTROL
outputs/test
intvar/ctrl.txt   file of the BBGC variables (control)
1                 (flag)  1: write daily output   0: no daily output
0                 (flag)  1: monthly avg of daily variables  0: no monthly avg
0                 (flag)  1: annual avg of daily variables   0: no annual avg
0                 (flag)  1: write annual output  0: no annual output
1                 (flag)  for on-screen progress indicator

DAILY_OUTPUT
5                 number of daily output variables
623               Gross Primary Production
649               Total Ecosystem Respiration
34                Latent heat flux [evapotranspiration]
509               projected LAI
638               soil C

ANNUAL_OUTPUT
4                 number of annual output variables
545               annual maximum projected LAI
636               vegetation C
638               soil C
639               total C

------------------
MANAGEMENT_SECTION
------------------
PLANTING
1              (flag) do PLANTING? 0=no1=yesfilename=from file
134 -9999 -9999 -9999 -9999 -9999 -9999  (yday)  PLANTING day
5.  -9999 -9999 -9999 -9999 -9999 -9999  (double) quantity of seed (kg seed/ha)
40. -9999 -9999 -9999 -9999 -9999 -9999  (%) C content of seed
90. -9999 -9999 -9999 -9999 -9999 -9999  (%) useful part of seed

THINNING
0                                        (flag) do THINNING? 0=no1=yesfilename=from file
200  -9999 -9999 -9999 -9999 -9999 -9999 (yday)  THINNING day
0.5  -9999 -9999 -9999 -9999 -9999 -9999 (prop) thinning rate
100. -9999 -9999 -9999 -9999 -9999 -9999 (%) transported part of stem
100. -9999 -9999 -9999 -9999 -9999 -9999 (%) transported part of leaf


MOWING
0                                        (flag) do MOWING? 0=no1=yesfilename=from file
0                                        (flag) mowing method? 0 - on fixday, 1 - fixed LAI
6.0                                      (int) fixed value of the LAI before MOWING (method1)
1.0                                      (int) fixed value of the LAI after MOWING (method1)
150 234 -9999 -9999 -9999 -9999 -9999    (yday) MOWING day
1.0 1.0  -9999 -9999  -9999 -9999  -9999 (int) value of the LAI after MOWING (method0)
95. 95. -9999 -9999 -9999 -9999 -9999    (%) transported part of plant material


GRAZING
0                                        (flag) do GRAZING? 0=no, 1=yes filepath=from file
156   262  -9999 -9999 -9999 -9999 -9999 (yday) first day of GRAZING
```

```
202   311   -9999 -9999 -9999 -9999 -9999      (yday) last day of GRAZING
381.  381.  -9999 -9999 -9999 -9999 -9999      (kg/LSU) weight equivalent of one unit
0.69  1.15  -9999 -9999 -9999 -9999 -9999      (LSU/ha) animal stocking rate
13.0  13.0  -9999 -9999 -9999 -9999 -9999      (kg dry matter/LSU*) daily ingested dry matter
1.50  1.50  -9999 -9999 -9999 -9999 -9999      (prop) trampling effect (standing dead biome to litter)
25.0  25.0  -9999 -9999 -9999 -9999 -9999      (%) ratio of DM intake formed excrement
100.  100.  -9999 -9999 -9999 -9999 -9999      (%) ratio of excrement returning to litter
40.0  40.   -9999 -9999 -9999 -9999 -9999      (%) carbon content of dry matter
2.0   2.0   -9999 -9999 -9999 -9999 -9999      (%) N content of manure
40.0  40.   -9999 -9999 -9999 -9999 -9999      (%) C content of manure
0.01  0.01  -9999 -9999 -9999 -9999 -9999      (kgN2O-N:kgN) manure emission factor for N2O emissions
0.35  0.35  -9999 -9999 -9999 -9999 -9999      (kgN/1000 kg animal mass/day) default N excretion rate
8.0   8.0   -9999 -9999 -9999 -9999 -9999      (kgCH4/LSU/yr) manure emission factor for CH4 emission
58.0  58.0  -9999 -9999 -9999 -9999 -9999      (kgCH4/LSU/yr) fermentation emission factor for CH4 emission


HARVESTING
1                                              (flag)do HARVESTING? 0=no,1=yesfilename=from file
200  -9999 -9999 -9999 -9999 -9999 -9999       (yday) HARVESTING day
0.1  -9999 -9999 -9999 -9999 -9999 -9999       (kgC/m2) carbon content of soft stem after harvest
91.0 -9999 -9999 -9999 -9999 -9999 -9999       (%) transported part of plant material


PLOUGHING
0                                              (flag) do PLOUGHING? 0=no,1=yesfilename=from file
201  -9999 -9999 -9999 -9999 -9999 -9999       (yday) PLOUGHING day
1    -9999 -9999 -9999 -9999 -9999 -9999       (type) PLOUGHING depth (0:shallow, 1:medium,2:deep)
0.10 -9999 -9999 -9999 -9999 -9999 -9999       (prop) dissolving coefficient


FERTILIZING
0                                              (flag) do FERTILIZING?0=no,1=yesfilename=from file
60    200  -9999 -9999 -9999 -9999 -9999       (yday) FERTILIZING day
30.0 30.0 -9999 -9999 -9999 -9999 -9999        (kg/ha/day) weight of fertiler per day
17.0 17.0 -9999 -9999 -9999 -9999 -9999        (%) nitrate content of fertilizer
17.0 17.0 -9999 -9999 -9999 -9999 -9999        (%) ammonium content of fertilizer
5.0  5.0  -9999 -9999 -9999 -9999 -9999        (%) carbon content of fertilizer
70.0 70.0 -9999 -9999 -9999 -9999 -9999        (%) labile fraction of fertilizer
20.0 20.0 -9999 -9999 -9999 -9999 -9999        (%) unshielded cellulose fraction of fertilizer
0.0  0.0  -9999 -9999 -9999 -9999 -9999        (%) shielded cellulose fraction of fertilizer
10.0 10.0 -9999 -9999 -9999 -9999 -9999        (%) lignin  fraction of fertilizer
0.05 0.05 -9999 -9999 -9999 -9999 -9999        (prop) dissolving coefficient
90.0 90.0 -9999 -9999 -9999 -9999 -9999        (%) useful part
0.01 0.01 -9999 -9999 -9999 -9999 -9999        (kgN2O-N:kgN) emission factor for N-additions


IRRIGATION
0                       (flag) do IRRIGATION? 0=no,1=yesfilename=from file
150 250 -9999 -9999 -9999 -9999 -9999    (yday) IRRIGATION day
30. 30. -9999 -9999 -9999 -9999 -9999    (kgH2O/m2/day) amount of water


END_INIT
```

Appendix C
EXAMPLE EPC FILE FOR BBGCMUSO 4.0

```
ECOPHYS        C3 grass
0        (flag) biome type flag (1 = WOODY 0 = NON-WOODY)
1        (flag) leaf habit flag (1 = EVERGREEN 0 = DECIDUOUS)
0        (flag) photosyn. type flag (1 = C3 PSN 0 = C4 PSN)
1        (flag) phenology flag (1 = MODEL PHENOLOGY 0 = USER-SPECIFIED PHENOLOGY)
1        (flag) Q10 flag (1=temperature dependent Q10 value; 0=constans Q10 value)
0        (flag) acclimation flag (1 = acclimation 0 = no acclimation)
0        (flag) CO2 conductance reduction flag (0 = no effect, 1 = multiplier)
0        (flag) soil hydrology calculation (0: R, 1: T (up+down), 2: T (down only))
0        (int) discretization level of SWC calculation (0: low, 1: medium, 2: high)
0        (flag) soil temperature calculation method (0: Zheng, 1: DSSAT)
120      (yday) yearday to start new growth (when phenology flag = 0)
360      (yday) yearday to end litterfall (when phenology flag = 0)
1.0      (prop.)transfer growth period as fraction of growing season
1.0      (prop.)litterfall as fraction of growing season
5        (Celsius) base temperature
405      (Celsius) growing degree day for start of fruit allocation
1000     (Celsius) growing degree day for start of phenological leaf senescence
1.0      (1/yr)  annual leaf and fine root turnover fraction
0.00     (1/yr)  annual live wood turnover fraction
0.05     (1/yr)  annual whole-plant mortality fraction
0.0      (1/yr)  annual fire mortality fraction
1.0      (ratio) (ALLOCATION) new fine root C : new leaf C
0.0      (ratio) (ALLOCATION) new fruit c : leaf c (0: no fruit)
0.5      (ratio) (ALLOCATION) soft stem c : leaf c
0.0      (ratio) (ALLOCATION) new woody stem C : new leaf C
0.0      (ratio) (ALLOCATION) new live wood C : new total wood C
0.0      (ratio) (ALLOCATION) new croot C : new stem C
0.5      (prop.) (ALLOCATION) current growth proportion
25.0     (kgC/kgN)       C:N of leaves
45.0     (kgC/kgN)       C:N of leaf litter, after retranslocation
50.0     (kgC/kgN)       C:N of fine roots
25.0     (kgC/kgN)       C:N of fruit
25.0     (kgC/kgN)       C:N of soft stem
0.0      (kgC/kgN)       C:N of live wood
0.0      (kgC/kgN)       C:N of dead wood
0.68     (DIM)   leaf litter labile proportion
0.23     (DIM)   leaf litter cellulose proportion
0.34     (DIM)   fine root labile proportion
0.44     (DIM)   fine root cellulose proportion
0.68     (DIM)   fruit litter labile proportion
0.23     (DIM)   fruit litter cellulose proportion
0.68     (DIM)   soft stem litter labile proportion
0.23     (DIM)   soft stem litter cellulose proportion
0.0      (DIM)   dead wood cellulose proportion
0.01     (1/LAI/d) canopy water interception coefficient
0.5      (DIM)   canopy light extinction coefficient
2.0      (DIM)   all-sided to projected leaf area ratio
49.0     (m2/kgC) canopy average specific leaf area (projected area basis)
2.0      (DIM)   ratio of shaded SLA:sunlit SLA
0.2      (DIM)   fraction of leaf N in Rubisco
0.03     (DIM)   fraction of leaf N in PEP Carboxylase
0.006    (m/s)   maximum stomatal conductance (projected area basis)
0.00006 (m/s)    cuticular conductance (projected area basis)
0.04     (m/s)   boundary layer conductance (projected area basis)
1        (prop)  relative SWC (prop. to FC) to calc. soil moisture limit 1 (-9999: field cap.)
1        (prop)  relative SWC (prop. to SAT) to calc. soil moisture limit 2 (-9999 or 1: saturation)
-9999    (prop)  relative PSI (prop. to FC) to calc. soil moisture limit 1 (-9999: field cap.)
-9999    (prop)  relative PSI (prop. to SAT) to calc. soil moisture limit 2 (-9999 or 1: saturation)
1000     (Pa)    vapor pressure deficit: start of conductance reduction
5000     (Pa)    vapor pressure deficit: complete conductance reduction
0.05     (prop.) min. mortality coefficient of non-woody aboveground plant material senescence
0.01     (prop.) min. mortality coefficient of non-woody belowground plant material senescence
0.0      (prop.) mortality coefficient of phenological leaf senescence
0.01     (prop.) turnover rate of wilted standing biomass to litter
0.05     (prop.) turnover rate of cut-down non-woody biomass to litter
0.01     (prop.) N denitrification proportion
0.068    (prop.) bulk N denitrification proportion (WET)
0.01     (prop.) bulk N denitrification proportion (DRY)
0.1      (prop.) N mobilen proportion
```

```
0.0005 (kgN/m2/yr) symbiotic+asymbiotic fixation of N
0.5     (prop.) maturity coefficient
0.1     (prop.) ratio of the storage and the actual pool mortalitay due to management
0.5     (prop.) critical value of soilstress coefficient
30      (days)  critical number of stress days after wchich senescence mortality is complete
0.8     (m)     maximum depth of rooting zone
3.67    (DIM) root distribution parameter
0.3     (prop.) growth resp per unit of C grown
2.0     (DIM) c parameter of DSSAT TSOIL estimation
0.218   (kgC/kgN/d) maintenance respiration in kgC/day per kg of tissue N
0.39    (DIM) respiration fractions for fluxes between compartments (l1s1)
0.55    (DIM) respiration fractions for fluxes between compartments (l2s2)
0.29    (DIM) respiration fractions for fluxes between compartments (l4s3)
0.28    (DIM) respiration fractions for fluxes between compartments (s1s2)
0.46    (DIM) respiration fractions for fluxes between compartments (s2s3)
0.55    (DIM) respiration fractions for fluxes between compartments (s3s4)
0.7     (DIM) rate constant scalar of  labile litter pool
0.07    (DIM) rate constant scalar of cellulose litter pool
0.014   (DIM) rate constant scalar of lignin litter pool
0.07    (DIM) rate constant scalar of  fast microbial recycling pool
0.014   (DIM) rate constant scalar of  medium microbial recycling pool
0.0014  (DIM) rate constant scalar of  slow microbial recycling pool
0.0001  (DIM) rate constant scalar of  recalcitrant SOM (humus) pool
0.001   (DIM) rate constant scalar of  physical fragmentation of coarse woody debris
41.18   (DIM) param1 for N2O calculations (empirical function of C:N)
0.249   (DIM) param2 for N2O calculations (empirical function of C:N)
-0.224  (DIM) param1 for N2O calculations (empirical function of VWC)
0.961   (DIM) param2 for N2O calculations (empirical function of VWC)
1.898   (DIM) param3 for N2O calculations (empirical function of VWC)
7.461   (DIM) param4 for N2O calculations (empirical function of VWC)
0.125   (DIM) param1 for N2O calculations (empirical function of Tsoil)
212.5   (DIM) param1 for CH4 calculations (empirical function of BD)
1.81    (DIM) param2 for CH4 calculations (empirical function of BD)
-1.353  (DIM) param1 for CH4 calculations (empirical function of VWC)
0.2     (DIM) param2 for CH4 calculations (empirical function of VWC)
1.781   (DIM) param3 for CH4 calculations (empirical function of VWC)
6.786   (DIM) param4 for CH4 calculations (empirical function of VWC)
0.010   (DIM) param1 for CH4 calculations (empirical function of Tsoil)
```

Appendix D
OUTPUT VARIABLES IN BBGCMUSO 4.0 [WITH UNITS]

Group 1: daily meteorological variables
```
output_map[0]:  prcp [cm]
output_map[1]:  tmax [°C]
output_map[2]:  tmin [°C]
output_map[3]:  tavg [°C]
output_map[4]:  tday [°C]
output_map[5]:  tnight [°C]
output_map[6]:  tsoil_avg_totalsoil [°C]
output_map[7]:  vpd [Pa]
output_map[8]:  swavgfd [W m^-2]
output_map[9]:  swabs [W m^-2]
output_map[10]: swtrans [W m^-2]
output_map[11]: swabs_per_plaisun [W m^-2]
output_map[12]: swabs_per_plaishade [W m^-2]
output_map[13]: ppfd_per_plaisun [umol m^-2 s^-1]
output_map[14]: ppfd_per_plaishade [umol m^-2 s^-1]
output_map[15]: par [W m^-2]
output_map[16]: GDD [°C]
output_map[17]: pa [Pa]
output_map[18]: co2 [ppm]
output_map[19]: dayl [s]
```

Group 2: water state variables $[kg\ H_2O\ m^{-2}]$
```
output_map[20]: soilw_SUM
output_map[21]: snoww
output_map[22]: canopyw
output_map[23]: prcp_src
output_map[24]: runoff_snk
output_map[25]: soilevap_snk
output_map[26]: snowsubl_snk
output_map[27]: canopyevap_snk
output_map[28]: trans_snk
output_map[29]: deeppercolation_snk
output_map[30]: deepdiffusion_snk
output_map[31]: deeptrans_src
output_map[32]: groundwater_src
```

Group 3: water flux variables $[kg\ H_2O\ m^{-2}\ day^{-1}]$
```
output_map[34]: evapotransp
output_map[35]: prcp_to_canopyw
output_map[36]: prcp_to_soilw
output_map[37]: prcp_to_snoww
output_map[38]: canopyw_evap
output_map[39]: canopyw_to_soilw
output_map[40]: snoww_subl
output_map[41]: snoww_to_soilw
output_map[42]: soilw_evap
output_map[43]: soilw_trans_SUM
output_map[44]: prcp_to_runoff
output_map[46]: canopyw_to_MOW
output_map[47]: canopyw_to_GRZ
output_map[48]: canopyw_to_HRV
output_map[49]: canopyw_to_PLG
```

Group 4: carbon state variables $[kg\ C\ m^{-2}]$
```
output_map[50]: leafc
output_map[51]: leafc_storage
output_map[52]: leafc_transfer
output_map[53]: frootc
output_map[54]: frootc_storage
output_map[55]: frootc_transfer
output_map[56]: livestemc
output_map[57]: livestemc_storage
output_map[58]: livestemc_transfer
output_map[59]: deadstemc
output_map[60]: deadstemc_storage
output_map[61]: deadstemc_transfer
```

```
output_map[62]: livecrootc
output_map[63]: livecrootc_storage
output_map[64]: livecrootc_transfer
output_map[65]: deadcrootc
output_map[66]: deadcrootc_storage
output_map[67]: deadcrootc_transfer
output_map[68]: gresp_storage
output_map[69]: gresp_transfer
output_map[70]: cwdc
output_map[71]: litr1c
output_map[72]: litr2c
output_map[73]: litr3c
output_map[74]: litr4c
output_map[75]: soil1c
output_map[76]: soil2c
output_map[77]: soil3c
output_map[78]: soil4c
output_map[79]: STDBc
output_map[80]: CTDBc
output_map[81]: psnsun_src
output_map[82]: leaf_mr_snk
output_map[83]: leaf_gr_snk
output_map[84]: froot_mr_snk
output_map[85]: froot_gr_snk
output_map[86]: livestem_mr_snk
output_map[87]: livestem_gr_snk
output_map[88]: deadstem_gr_snk
output_map[89]: livecroot_mr_snk
output_map[90]: livecroot_gr_snk
output_map[91]: deadcroot_gr_snk
output_map[92]: litr1_hr_snk
output_map[93]: litr2_hr_snk
output_map[94]: litr4_hr_snk
output_map[95]: soil1_hr_snk
output_map[96]: soil2_hr_snk
output_map[97]: soil3_hr_snk
output_map[98]: soil4_hr_snk
output_map[99]: fire_snk
output_map[100]: fruitc
output_map[101]: fruitc_storage
output_map[102]: fruitc_transfer
output_map[103]: softstemc
output_map[104]: softstemc_storage
output_map[105]: softstemc_transfer
output_map[106]: THNsnk
output_map[107]: THNsrc
output_map[108]: MOWsnk
output_map[109]: MOWsrc
output_map[110]: GRZsnk
output_map[111]: GRZsrc
output_map[112]: HRVsnk
output_map[113]: HRVsrc
output_map[114]: PLGsnk
output_map[115]: PLGsrc
output_map[116]: PLTsrc
output_map[117]: FRZsrc
output_map[118]: SNSCsnk
output_map[119]: SNSCsrc
```

Group 5: carbon flux variables [kg C m^{-2} day^{-1}; variable 244 is an exception]

```
output_map[120]: m_leafc_to_litr1c
output_map[121]: m_leafc_to_litr2c
output_map[122]: m_leafc_to_litr3c
output_map[123]: m_leafc_to_litr4c
output_map[124]: m_frootc_to_litr1c
output_map[125]: m_frootc_to_litr2c
output_map[126]: m_frootc_to_litr3c
output_map[127]: m_frootc_to_litr4c
output_map[128]: m_leafc_storage_to_litr1c
output_map[129]: m_frootc_storage_to_litr1c
output_map[130]: m_livestemc_storage_to_litr1c
output_map[131]: m_deadstemc_storage_to_litr1c
output_map[132]: m_livecrootc_storage_to_litr1c
output_map[133]: m_deadcrootc_storage_to_litr1c
output_map[134]: m_leafc_transfer_to_litr1c
output_map[135]: m_frootc_transfer_to_litr1c
```

```
output_map[136]: m_livestemc_transfer_to_litr1c
output_map[137]: m_deadstemc_transfer_to_litr1c
output_map[138]: m_livecrootc_transfer_to_litr1c
output_map[139]: m_deadcrootc_transfer_to_litr1c
output_map[140]: m_livestemc_to_cwdc
output_map[141]: m_deadstemc_to_cwdc
output_map[142]: m_livecrootc_to_cwdc
output_map[143]: m_deadcrootc_to_cwdc
output_map[144]: m_gresp_storage_to_litr1c
output_map[145]: m_gresp_transfer_to_litr1c
output_map[146]: m_leafc_to_fire
output_map[147]: m_frootc_to_fire
output_map[148]: m_leafc_storage_to_fire
output_map[149]: m_frootc_storage_to_fire
output_map[150]: m_livestemc_storage_to_fire
output_map[151]: m_deadstemc_storage_to_fire
output_map[152]: m_livecrootc_storage_to_fire
output_map[153]: m_deadcrootc_storage_to_fire
output_map[154]: m_leafc_transfer_to_fire
output_map[155]: m_frootc_transfer_to_fire
output_map[156]: m_livestemc_transfer_to_fire
output_map[157]: m_deadstemc_transfer_to_fire
output_map[158]: m_livecrootc_transfer_to_fire
output_map[159]: m_deadcrootc_transfer_to_fire
output_map[160]: m_livestemc_to_fire
output_map[161]: m_deadstemc_to_fire
output_map[162]: m_livecrootc_to_fire
output_map[163]: m_deadcrootc_to_fire
output_map[164]: m_gresp_storage_to_fire
output_map[165]: m_gresp_transfer_to_fire
output_map[166]: m_litr1c_to_fire
output_map[167]: m_litr2c_to_fire
output_map[168]: m_litr3c_to_fire
output_map[169]: m_litr4c_to_fire
output_map[170]: m_cwdc_to_fire
output_map[171]: leafc_transfer_to_leafc
output_map[172]: frootc_transfer_to_frootc
output_map[173]: livestemc_transfer_to_livestemc
output_map[174]: deadstemc_transfer_to_deadstemc
output_map[175]: livecrootc_transfer_to_livecrootc
output_map[176]: deadcrootc_transfer_to_deadcrootc
output_map[177]: leafc_to_litr1c
output_map[178]: leafc_to_litr2c
output_map[179]: leafc_to_litr3c
output_map[180]: leafc_to_litr4c
output_map[181]: frootc_to_litr1c
output_map[182]: frootc_to_litr2c
output_map[183]: frootc_to_litr3c
output_map[184]: frootc_to_litr4c
output_map[185]: leaf_day_mr
output_map[186]: leaf_night_mr
output_map[187]: froot_mr
output_map[188]: livestem_mr
output_map[189]: livecroot_mr
output_map[190]: psnsun_to_cpool
output_map[191]: psnshade_to_cpool
output_map[192]: cwdc_to_litr2c
output_map[193]: cwdc_to_litr3c
output_map[194]: cwdc_to_litr4c
output_map[195]: litr1_hr
output_map[196]: litr1c_to_soil1c
output_map[197]: litr2_hr
output_map[198]: litr2c_to_soil2c
output_map[199]: litr3c_to_litr2c
output_map[200]: litr4_hr
output_map[201]: litr4c_to_soil3c
output_map[202]: soil1_hr
output_map[203]: soil1c_to_soil2c
output_map[204]: soil2_hr
output_map[205]: soil2c_to_soil3c
output_map[206]: soil3_hr
output_map[207]: soil3c_to_soil4c
output_map[208]: soil4_hr
output_map[209]: cpool_to_leafc
output_map[210]: cpool_to_leafc_storage
output_map[211]: cpool_to_frootc
output_map[212]: cpool_to_frootc_storage
```

```
output_map[213]: cpool_to_livestemc
output_map[214]: cpool_to_livestemc_storage
output_map[215]: cpool_to_deadstemc
output_map[216]: cpool_to_deadstemc_storage
output_map[217]: cpool_to_livecrootc
output_map[218]: cpool_to_livecrootc_storage
output_map[219]: cpool_to_deadcrootc
output_map[220]: cpool_to_deadcrootc_storage
output_map[221]: cpool_to_gresp_storage
output_map[222]: cpool_leaf_gr
output_map[223]: transfer_leaf_gr
output_map[224]: cpool_froot_gr
output_map[225]: transfer_froot_gr
output_map[226]: cpool_livestem_gr
output_map[227]: transfer_livestem_gr
output_map[228]: cpool_deadstem_gr
output_map[229]: transfer_deadstem_gr
output_map[230]: cpool_livecroot_gr
output_map[231]: transfer_livecroot_gr
output_map[232]: cpool_deadcroot_gr
output_map[233]: transfer_deadcroot_gr
output_map[234]: leafc_storage_to_leafc_transfer
output_map[235]: frootc_storage_to_frootc_transfer
output_map[236]: livestemc_storage_to_livestemc_transfer
output_map[237]: deadstemc_storage_to_deadstemc_transfer
output_map[238]: livecrootc_storage_to_livecrootc_transfer
output_map[239]: deadcrootc_storage_to_deadcrootc_transfer
output_map[240]: gresp_storage_to_gresp_transfer
output_map[241]: livestemc_to_deadstemc
output_map[242]: livecrootc_to_deadcrootc
output_map[243]: leafc_to_MOW
output_map[244]: STDBc_to_GRZ
output_map[245]: STDBc_to_MOW
output_map[246]: STDBc_to_HRV
output_map[247]: STDBc_to_PLG
output_map[248]: CTDBc_to_PLG
output_map[249]: CH4_flux_soil
output_map[250]: CH4_flux_FERMENT
output_map[251]: CH4_flux_MANURE
output_map[252]: m_vegc_to_SNSC
```

Group 6: nitrogen state variables [kg N m^{-2}]

```
output_map[280]: leafn
output_map[281]: leafn_storage
output_map[282]: leafn_transfer
output_map[283]: frootn
output_map[284]: frootn_storage
output_map[285]: frootn_transfer
output_map[286]: livestemn
output_map[287]: livestemn_storage
output_map[288]: livestemn_transfer
output_map[289]: deadstemn
output_map[290]: deadstemn_storage
output_map[291]: deadstemn_transfer
output_map[292]: livecrootn
output_map[293]: livecrootn_storage
output_map[294]: livecrootn_transfer
output_map[295]: deadcrootn
output_map[296]: deadcrootn_storage
output_map[297]: deadcrootn_transfer
output_map[298]: cwdn
output_map[299]: litr1n
output_map[300]: litr2n
output_map[301]: litr3n
output_map[302]: litr4n
output_map[303]: soil1n
output_map[304]: soil2n
output_map[305]: soil3n
output_map[306]: soil4n
output_map[307]: sminn_RZ
output_map[308]: retransn
output_map[309]: npool
output_map[310]: nfix_src
output_map[311]: ndep_src
output_map[312]: nleached_snk
output_map[313]: nvol_snk
```

```
output_map[314]: fire_snk
output_map[315]: THNsnk
output_map[316]: MOWsnk
output_map[317]: GRZsnk
output_map[318]: GRZsrc
output_map[319]: HRVsnk
output_map[320]: HRVsrc
output_map[321]: PLGsnk
output_map[322]: PLGsrc
output_map[323]: PLTsrc
output_map[324]: FRZsrc
output_map[325]: SNSCsnk
output_map[326]: SNSCsrc
output_map[327]: BNDRYsrc
output_map[328]: ndiffused_snk
output_map[329]: STDBn
```

<u>Group 7: nitrogen flux variables</u> [kg N m^{-2} day^{-1}; variable 457 is an exception]

```
output_map[340]: m_leafn_to_litr1n
output_map[341]: m_leafn_to_litr2n
output_map[342]: m_leafn_to_litr3n
output_map[343]: m_leafn_to_litr4n
output_map[344]: m_frootn_to_litr1n
output_map[345]: m_frootn_to_litr2n
output_map[346]: m_frootn_to_litr3n
output_map[347]: m_frootn_to_litr4n
output_map[348]: m_leafn_storage_to_litr1n
output_map[349]: m_frootn_storage_to_litr1n
output_map[350]: m_livestemn_storage_to_litr1n
output_map[351]: m_deadstemn_storage_to_litr1n
output_map[352]: m_livecrootn_storage_to_litr1n
output_map[353]: m_deadcrootn_storage_to_litr1n
output_map[354]: m_leafn_transfer_to_litr1n
output_map[355]: m_frootn_transfer_to_litr1n
output_map[356]: m_livestemn_transfer_to_litr1n
output_map[357]: m_deadstemn_transfer_to_litr1n
output_map[358]: m_livecrootn_transfer_to_litr1n
output_map[359]: m_deadcrootn_transfer_to_litr1n
output_map[360]: m_livestemn_to_litr1n
output_map[361]: m_livestemn_to_cwdn
output_map[362]: m_deadstemn_to_cwdn
output_map[363]: m_livecrootn_to_litr1n
output_map[364]: m_livecrootn_to_cwdn
output_map[365]: m_deadcrootn_to_cwdn
output_map[366]: m_retransn_to_litr1n
output_map[367]: m_leafn_to_fire
output_map[368]: m_frootn_to_fire
output_map[369]: m_leafn_storage_to_fire
output_map[370]: m_frootn_storage_to_fire
output_map[371]: m_livestemn_storage_to_fire
output_map[372]: m_deadstemn_storage_to_fire
output_map[373]: m_livecrootn_storage_to_fire
output_map[374]: m_deadcrootn_storage_to_fire
output_map[375]: m_leafn_transfer_to_fire
output_map[376]: m_frootn_transfer_to_fire
output_map[377]: m_livestemn_transfer_to_fire
output_map[378]: m_deadstemn_transfer_to_fire
output_map[379]: m_livecrootn_transfer_to_fire
output_map[380]: m_deadcrootn_transfer_to_fire
output_map[381]: m_livestemn_to_fire
output_map[382]: m_deadstemn_to_fire
output_map[383]: m_livecrootn_to_fire
output_map[384]: m_deadcrootn_to_fire
output_map[385]: m_retransn_to_fire
output_map[386]: m_litr1n_to_fire
output_map[387]: m_litr2n_to_fire
output_map[388]: m_litr3n_to_fire
output_map[389]: m_litr4n_to_fire
output_map[390]: m_cwdn_to_fire
output_map[391]: leafn_transfer_to_leafn
output_map[392]: frootn_transfer_to_frootn
output_map[393]: livestemn_transfer_to_livestemn
output_map[394]: deadstemn_transfer_to_deadstemn
output_map[395]: livecrootn_transfer_to_livecrootn
output_map[396]: deadcrootn_transfer_to_deadcrootn
output_map[397]: leafn_to_litr1n
```

```
output_map[398]: leafn_to_litr2n
output_map[399]: leafn_to_litr3n
output_map[400]: leafn_to_litr4n
output_map[401]: leafn_to_retransn
output_map[402]: frootn_to_litr1n
output_map[403]: frootn_to_litr2n
output_map[404]: frootn_to_litr3n
output_map[405]: frootn_to_litr4n
output_map[406]: ndep_to_sminn
output_map[407]: nfix_to_sminn
output_map[408]: cwdn_to_litr2n
output_map[409]: cwdn_to_litr3n
output_map[410]: cwdn_to_litr4n
output_map[411]: litr1n_to_soil1n
output_map[412]: sminn_to_soil1n_l1
output_map[413]: litr2n_to_soil2n
output_map[414]: sminn_to_soil2n_l2
output_map[415]: litr3n_to_litr2n
output_map[416]: litr4n_to_soil3n
output_map[417]: sminn_to_soil3n_l4
output_map[418]: soil1n_to_soil2n
output_map[419]: sminn_to_soil2n_s1
output_map[420]: soil2n_to_soil3n
output_map[421]: sminn_to_soil3n_s2
output_map[422]: soil3n_to_soil4n
output_map[423]: sminn_to_soil4n_s3
output_map[424]: soil4n_to_sminn
output_map[425]: sminn_to_nvol_l1s1
output_map[426]: sminn_to_nvol_l2s2
output_map[427]: sminn_to_nvol_l4s3
output_map[428]: sminn_to_nvol_s1s2
output_map[429]: sminn_to_nvol_s2s3
output_map[430]: sminn_to_nvol_s3s4
output_map[431]: sminn_to_nvol_s4
output_map[433]: retransn_to_npool
output_map[434]: sminn_to_npool
output_map[435]: npool_to_leafn
output_map[436]: npool_to_leafn_storage
output_map[437]: npool_to_frootn
output_map[438]: npool_to_frootn_storage
output_map[439]: npool_to_livestemn
output_map[440]: npool_to_livestemn_storage
output_map[441]: npool_to_deadstemn
output_map[442]: npool_to_deadstemn_storage
output_map[443]: npool_to_livecrootn
output_map[444]: npool_to_livecrootn_storage
output_map[445]: npool_to_deadcrootn
output_map[446]: npool_to_deadcrootn_storage
output_map[447]: leafn_storage_to_leafn_transfer
output_map[448]: frootn_storage_to_frootn_transfer
output_map[449]: livestemn_storage_to_livestemn_transfer
output_map[450]: deadstemn_storage_to_deadstemn_transfer
output_map[451]: livecrootn_storage_to_livecrootn_transfer
output_map[452]: deadcrootn_storage_to_deadcrootn_transfer
output_map[453]: livestemn_to_deadstemn
output_map[454]: livestemn_to_retransn
output_map[455]: livecrootn_to_deadcrootn
output_map[456]: livecrootn_to_retransn
output_map[457]: STDBn_to_GRZ
output_map[458]: STDBn_to_HRV
output_map[459]: STDBn_to_PLG
output_map[460]: STDBn_to_MOW
output_map[461]: N2O_flux_soil
output_map[462]: N2O_flux_GRZ
output_map[463]: N2O_flux_FRZ
output_map[464]: nplus
```

Group 8: phenological variables `[number of days]`

```
output_map[480]: remdays_curgrowth
output_map[481]: remdays_transfer
output_map[482]: remdays_litfall
output_map[483]: predays_transfer
output_map[484]: predays_litfall
```

Group 9: ecophysiological variables

```
output_map[500]: day_leafc_litfall_increment [kg C m-2 day-1]
```
output_map[500]: day_leafc_litfall_increment [kg C m^{-2} day^{-1}]

```
output_map[501]: day_frootc_litfall_increment  [kg C m⁻² day⁻¹]
output_map[502]: day_livestemc_turnover_increment  [kg C m⁻² day⁻¹]
output_map[503]: day_livecrootc_turnover_increment  [kg C m⁻² day⁻¹]
output_map[504]: annmax_leafc [kg C m⁻¹]
output_map[505]: annmax_frootc [kg C m⁻¹]
output_map[506]: annmax_livestemc [kg C m⁻¹]
output_map[507]: annmax_livecrootc [kg C m⁻¹]
output_map[508]: dsr [number fo days]
output_map[509]: proj_lai [m² m⁻²]
output_map[510]: all_lai [m² m⁻²]
output_map[511]: plaisun [m² m⁻²]
output_map[512]: plaishade [m² m⁻²]
output_map[513]: sun_proj_sla [m² kgC⁻¹]
output_map[514]: shade_proj_sla [m² kgC⁻¹]
output_map[515]: psi_avg_rootzone [MPa]
output_map[516]: vwc_avg_rootzone [m³ m⁻³]
output_map[517]: dlmr_area_sun [umolC m⁻² projected leaf area s⁻¹]
output_map[518]: dlmr_area_shade [umolC m⁻² projected leaf area s⁻¹]
output_map[519]: gl_t_wv_sun [m s⁻¹]
output_map[520]: gl_t_wv_shade [m s⁻¹]
output_map[521]: assim_sun [umol m⁻² s⁻¹]
output_map[522]: assim_shade [umol m⁻² s⁻¹]
output_map[526]: daily_gross_nmin [kgN m⁻² d⁻¹]
output_map[527]: daily_gross_nimmob [kgN m⁻² d⁻¹]
output_map[528]: daily_net_nmin [kgN m⁻² d⁻¹]
output_map[529]: m_tmin [dimless]
output_map[530]: m_soilstress [dimless]
output_map[531]: max_conduct [m³ s⁻¹]
output_map[532]: m_ppfd_sun [dimless]
output_map[533]: m_ppfd_shade [dimless]
output_map[534]: m_vpd [dimless]
output_map[535]: m_final_sun [dimless]
output_map[536]: m_final_shade [dimless]
output_map[537]: gl_bl [m s⁻¹]
output_map[538]: gl_c [m s⁻¹]
output_map[539]: gl_s_sun [m s⁻¹]
output_map[540]: gl_s_shade [m s⁻¹]
output_map[541]: gl_e_wv [m s⁻¹]
output_map[542]: gl_sh [m s⁻¹]
output_map[543]: gc_e_wv [m s⁻¹]
output_map[544]: gc_sh [m s⁻¹]
output_map[545]: ytd_maxplai [m2 m⁻²]
output_map[546]: vwc(0) [m³ m⁻³]
output_map[547]: vwc(1) [m³ m⁻³]
output_map[548]: vwc(2) [m³ m⁻³]
output_map[549]: vwc(3) [m³ m⁻³]
output_map[550]: vwc(4) [m³ m⁻³]
output_map[551]: vwc(5) [m³ m⁻³]
output_map[552]: vwc(6) [m³ m⁻³]
output_map[553]: n_limitation [flag]
```

Group 10: photosynthesis variables
(sunlit canopy fraction)
```
output_map[560]: sun.pa [Pa]
output_map[561]: sun.co2 [ppm]
output_map[562]: sun.t [°C]
output_map[563]: sun.lnc [kg N_leaf m⁻²]
output_map[564]: sun.flnr [kg N_Rub (kg N_leaf)⁻¹]
output_map[565]: sun.ppfd [umol m⁻² s⁻¹]
output_map[566]: sun.g [umol m⁻² s⁻¹]
output_map[567]: sun.dlmr [umol m⁻² s⁻¹]
output_map[568]: sun.Ci [Pa]
output_map[569]: sun.O2 [Pa]
output_map[570]: sun.Ca [Pa]
output_map[571]: sun.gamma [Pa]
output_map[572]: sun.Kc [Pa]
output_map[573]: sun.Ko [Pa]
output_map[574]: sun.Vmax [umol m⁻² s⁻¹]
output_map[575]: sun.Jmax [umol m⁻² s⁻¹]
output_map[576]: sun.J [umol m⁻² s⁻¹]
output_map[577]: sun.Av [umol m⁻² s⁻¹]
output_map[578]: sun.Aj [umol m⁻² s⁻¹]
output_map[579]: sun.A [umol m⁻² s⁻¹]
```

(shaded canopy fraction)
```
output_map[590]: shade.pa [Pa]
```

```
output_map[591]: shade.co2 [ppm]
output_map[592]: shade.t [°C]
output_map[593]: shade.lnc [kg N_leaf m^-2]
output_map[594]: shade.flnr [kg N_Rub (kg N_leaf)^-1]
output_map[595]: shade.ppfd [umol m^-2 s^-1]
output_map[596]: shade.g [umol m^-2 s^-1]
output_map[597]: shade.dlmr [umol m^-2 s^-1]
output_map[598]: shade.Ci [Pa]
output_map[599]: shade.O2 [Pa]
output_map[600]: shade.Ca [Pa]
output_map[601]: shade.gamma [Pa]
output_map[602]: shade.Kc [Pa]
output_map[603]: shade.Ko [Pa]
output_map[604]: shade.Vmax [umol m^-2 s^-1]
output_map[605]: shade.Jmax [umol m^-2 s^-1]
output_map[606]: shade.J [umol m^-2 s^-1]
output_map[607]: shade.Av [umol m^-2 s^-1]
output_map[608]: shade.Aj [umol m^-2 s^-1]
output_map[609]: shade.A [umol m^-2 s^-1]
```

Group 11: summarized variables

```
output_map[612]; abgc [kgC m^-2]
output_map[613]; cum_npp_ann [kgC m^-2]
output_map[614]; sum_ndemand [kgN m^-2]
output_map[615]: PLG_cpool [kgC m^-2]
output_map[616]: PLG_npool [kgC m^-2]
output_map[617]: litr_aboveground [kgC m^-2]
output_map[618]: litr_belowground [kgC m^-2]
output_map[619]: daily_nbp [kgC m^-2 day^-1]
output_map[620]: daily_npp [kgC m^-2 day^-1]
output_map[621]: daily_nep [kgC m^-2 day^-1]
output_map[622]: daily_nee [kgC m^-2 day^-1]
output_map[623]: daily_gpp [kgC m^-2 day^-1]
output_map[624]: daily_mr [kgC m^-2 day^-1]
output_map[625]: daily_gr [kgC m^-2 day^-1]
output_map[626]: daily_hr [kgC m^-2 day^-1]
output_map[627]: daily_fire [kgC m^-2 day^-1]
output_map[628]: cum_npp [kgC m^-2]
output_map[629]: cum_nep [kgC m^-2]
output_map[630]: cum_nee [kgC m^-2]
output_map[631]: cum_gpp [kgC m^-2]
output_map[632]: cum_mr [kgC m^-2]
output_map[633]: cum_gr [kgC m^-2]
output_map[634]: cum_hr [kgC m^-2]
output_map[635]: cum_fire [kgC m^-2]
output_map[636]: vegc [kgC m^-2]
output_map[637]: litrc [kgC m^-2]
output_map[638]: soilc [kgC m^-2]
output_map[639]: soiln [kgN m^-2]
output_map[640]: daily_litfallc [kgC m^-2 day^-1]
output_map[641]: Cchange_MOW [kgC m^-2]
output_map[642]: Cchange_HRV [kgC m^-2]
output_map[643]: Cchange_PLG [kgC m^-2]
output_map[644]: Cchange_GRZ [kgC m^-2]
output_map[645]: Cchange_FRZ [kgC m^-2]
output_map[646]: Cchange_PLT [kgC m^-2]
output_map[647]: Cchange_SNSC [kgC m^-2]
output_map[648]: daily_sr [kgC m^-2 day^-1]
output_map[649]: daily_tr [kgC m^-2 day^-1]
output_map[650]: cum_ET [kg H_2O m^-2]
output_map[651]: tsoil(0) [°C]
output_map[652]: tsoil(1) [°C]
output_map[653]: tsoil(2) [°C]
output_map[654]: tsoil(3) [°C]
output_map[655]: tsoil(4) [°C]
output_map[656]: tsoil(5) [°C]
output_map[657]: tsoil(6) [°C]
output_map[658]: tsoil_surface [°C]
```

Appendix E
EXAMPLES FOR ANCILLARY MANAGEMENT FILES

Examples are given here for the content of the externally defined ancillary management types that is a new feature of BBGCMuSo. Note that these examples assume that the simulation is performed for 3 years (i.e. the 7-event-lines are repeated 3 times). In any case, the 7-event lines have to be defined separately for each simulation years in each block.

Ancillary file for annually varying planting
```
PLANTING day
134 -9999 -9999 -9999 -9999 -9999 -9999
115 -9999 -9999 -9999 -9999 -9999 -9999
142 -9999 -9999 -9999 -9999 -9999 -9999
quantity of seed (kg seed/ha)
5.  -9999 -9999 -9999 -9999 -9999 -9999
10. -9999 -9999 -9999 -9999 -9999 -9999
12. -9999 -9999 -9999 -9999 -9999 -9999
C content of seed
40. -9999 -9999 -9999 -9999 -9999 -9999
40. -9999 -9999 -9999 -9999 -9999 -9999
40. -9999 -9999 -9999 -9999 -9999 -9999
useful part of seed
90. -9999 -9999 -9999 -9999 -9999 -9999
90. -9999 -9999 -9999 -9999 -9999 -9999
90. -9999 -9999 -9999 -9999 -9999 -9999
```

Ancillary file for annually varying thinning
```
THINNING day
200  -9999 -9999 -9999 -9999 -9999 -9999
250  -9999 -9999 -9999 -9999 -9999 -9999
300  -9999 -9999 -9999 -9999 -9999 -9999
thinning rate
0.5  -9999 -9999 -9999 -9999 -9999 -9999
0.7  -9999 -9999 -9999 -9999 -9999 -9999
0.6  -9999 -9999 -9999 -9999 -9999 -9999
transported part of stem
100. -9999 -9999 -9999 -9999 -9999 -9999
100. -9999 -9999 -9999 -9999 -9999 -9999
100. -9999 -9999 -9999 -9999 -9999 -9999
transported part of leaf
100. -9999 -9999 -9999 -9999 -9999 -9999
100. -9999 -9999 -9999 -9999 -9999 -9999
100. -9999 -9999 -9999 -9999 -9999 -9999
```

Ancillary file for annually varying mowing
```
MOWING day
150  234  -9999 -9999 -9999 -9999 -9999
200 -9999 -9999 -9999 -9999 -9999 -9999
140  224  -9999 -9999 -9999 -9999 -9999
value of the LAI after MOWING (method0)
1.0 1.0  -9999 -9999  -9999 -9999 -9999
1.0 1.0  -9999 -9999  -9999 -9999 -9999
1.0 1.0  -9999 -9999  -9999 -9999 -9999
transported part of plant material
95. 95.  -9999 -9999 -9999 -9999 -9999
95. 95.  -9999 -9999 -9999 -9999 -9999
95. 95.  -9999 -9999 -9999 -9999 -9999
```

Ancillary file for annually varying grazing
```
first day of GRAZING
156  262   -9999 -9999 -9999 -9999 -9999
156  262   -9999 -9999 -9999 -9999 -9999
156  262   -9999 -9999 -9999 -9999 -9999
last day of GRAZING
202  311   -9999 -9999 -9999 -9999 -9999
202  311   -9999 -9999 -9999 -9999 -9999
202  311   -9999 -9999 -9999 -9999 -9999
weight equivalent of LSU
```

```
650  650   -9999 -9999 -9999 -9999 -9999
650  650   -9999 -9999 -9999 -9999 -9999
650  650   -9999 -9999 -9999 -9999 -9999
animal stocking rate
0.69 1.15  -9999 -9999 -9999 -9999 -9999
0.69 1.15  -9999 -9999 -9999 -9999 -9999
0.69 1.15  -9999 -9999 -9999 -9999 -9999
daily ingested dry matter
13.0 13.0  -9999 -9999 -9999 -9999 -9999
13.0 13.0  -9999 -9999 -9999 -9999 -9999
13.0 13.0  -9999 -9999 -9999 -9999 -9999
trampling effect
1.50 1.50  -9999 -9999 -9999 -9999 -9999
1.50 1.50  -9999 -9999 -9999 -9999 -9999
1.50 1.50  -9999 -9999 -9999 -9999 -9999
ratio of DM intake formed excrement
25.0 25.0  -9999 -9999 -9999 -9999 -9999
25.0 25.0  -9999 -9999 -9999 -9999 -9999
25.0 25.0  -9999 -9999 -9999 -9999 -9999
ratio of excrement returning to litter
100. 100.  -9999 -9999 -9999 -9999 -9999
100. 100.  -9999 -9999 -9999 -9999 -9999
100. 100.  -9999 -9999 -9999 -9999 -9999
carbon content of dry matter
40.  40.   -9999 -9999 -9999 -9999 -9999
40.  40.   -9999 -9999 -9999 -9999 -9999
40.  40.   -9999 -9999 -9999 -9999 -9999
N content of manure
2.0  2.0   -9999 -9999 -9999 -9999 -9999
2.0  2.0   -9999 -9999 -9999 -9999 -9999
2.0  2.0   -9999 -9999 -9999 -9999 -9999
C content of manure
40.  40.   -9999 -9999 -9999 -9999 -9999
40.  40.   -9999 -9999 -9999 -9999 -9999
40.  40.   -9999 -9999 -9999 -9999 -9999
manure N2O emission factor
0.02 0.02  -9999 -9999 -9999 -9999 -9999
0.02 0.02  -9999 -9999 -9999 -9999 -9999
0.02 0.02  -9999 -9999 -9999 -9999 -9999
fraction of nitrogen excretion left at site
0.95  0.95 -9999 -9999 -9999 -9999 -9999
0.95  0.95 -9999 -9999 -9999 -9999 -9999
0.95  0.95 -9999 -9999 -9999 -9999 -9999
manure CH4 emission factor
33.0 33.0  -9999 -9999 -9999 -9999 -9999
33.0 33.0  -9999 -9999 -9999 -9999 -9999
33.0 33.0  -9999 -9999 -9999 -9999 -9999
fermentation CH4 emission factor
58.0 58.0  -9999 -9999 -9999 -9999 -9999
58.0 58.0  -9999 -9999 -9999 -9999 -9999
58.0 58.0  -9999 -9999 -9999 -9999 -9999
```

Ancillary file for annually varying harvesting

```
HARVESTING day
200  -9999 -9999 -9999 -9999 -9999
200  -9999 -9999 -9999 -9999 -9999 -9999
200  -9999 -9999 -9999 -9999 -9999 -9999
remaining soft stem weight (kgC/m2)
0.01  -9999 -9999 -9999 -9999 -9999 -9999
0.01  -9999 -9999 -9999 -9999 -9999 -9999
0.01  -9999 -9999 -9999 -9999 -9999 -9999
transported part of plant material
91.0 -9999 -9999 -9999 -9999 -9999 -9999
91.0 -9999 -9999 -9999 -9999 -9999 -9999
91.0 -9999 -9999 -9999 -9999 -9999 -9999
```

Ancillary file for annually varying ploughing

```
PLOUGHING day
201  -9999 -9999 -9999 -9999 -9999 -9999
201  -9999 -9999 -9999 -9999 -9999 -9999
201  -9999 -9999 -9999 -9999 -9999 -9999
PLOUGHING depth (1:shallow, 2:medium,3:deep)
1    -9999 -9999 -9999 -9999 -9999 -9999
1    -9999 -9999 -9999 -9999 -9999 -9999
1    -9999 -9999 -9999 -9999 -9999 -9999
```

```
dissolving coefficient
0.10 -9999 -9999 -9999 -9999 -9999 -9999
0.10 -9999 -9999 -9999 -9999 -9999 -9999
0.10 -9999 -9999 -9999 -9999 -9999 -9999
```

Ancillary file for annually varying fertilizing

```
FERTILIZING day
60    200   -9999 -9999 -9999 -9999 -9999
60    200   -9999 -9999 -9999 -9999 -9999
60    200   -9999 -9999 -9999 -9999 -9999
total weight of fertilizer per day
30.0 30.0 -9999 -9999 -9999 -9999 -9999
30.0 30.0 -9999 -9999 -9999 -9999 -9999
30.0 30.0 -9999 -9999 -9999 -9999 -9999
nitrate content of fertilizer [%]
17.0 17.0 -9999 -9999 -9999 -9999 -9999
17.0 17.0 -9999 -9999 -9999 -9999 -9999
17.0 17.0 -9999 -9999 -9999 -9999 -9999
ammonium content of fertilizer [%]
17.0 17.0 -9999 -9999 -9999 -9999 -9999
17.0 17.0 -9999 -9999 -9999 -9999 -9999
17.0 17.0 -9999 -9999 -9999 -9999 -9999
carbon content of fertilizer [%]
5.0   5.0   -9999 -9999 -9999 -9999 -9999
5.0   5.0   -9999 -9999 -9999 -9999 -9999
5.0   5.0   -9999 -9999 -9999 -9999 -9999
labile fraction of fertilizer
70.0 70.0 -9999 -9999 -9999 -9999 -9999
70.0 70.0 -9999 -9999 -9999 -9999 -9999
70.0 70.0 -9999 -9999 -9999 -9999 -9999
unshielded cellulose fraction of fertilizer
20.0 20.0 -9999 -9999 -9999 -9999 -9999
20.0 20.0 -9999 -9999 -9999 -9999 -9999
20.0 20.0 -9999 -9999 -9999 -9999 -9999
shielded cellulose fraction of fertilizer
0.0   0.0   -9999 -9999 -9999 -9999 -9999
0.0   0.0   -9999 -9999 -9999 -9999 -9999
0.0   0.0   -9999 -9999 -9999 -9999 -9999
lignin  fraction of fertilizer
10.0 10.0 -9999 -9999 -9999 -9999 -9999
10.0 10.0 -9999 -9999 -9999 -9999 -9999
10.0 10.0 -9999 -9999 -9999 -9999 -9999
dissolving coefficient
0.05 0.05 -9999 -9999 -9999 -9999 -9999
0.05 0.05 -9999 -9999 -9999 -9999 -9999
0.05 0.05 -9999 -9999 -9999 -9999 -9999
useful part
90.0 90.0 -9999 -9999 -9999 -9999 -9999
90.0 90.0 -9999 -9999 -9999 -9999 -9999
90.0 90.0 -9999 -9999 -9999 -9999 -9999
emission factor for N-additions
0.01 0.01 -9999 -9999 -9999 -9999 -9999
0.01 0.01 -9999 -9999 -9999 -9999 -9999
0.01 0.01 -9999 -9999 -9999 -9999 -9999
```

Ancillary file for annually varying irrigation

```
IRRIGATION day
150 250 -9999 -9999 -9999 -9999 -9999
150 250 -9999 -9999 -9999 -9999 -9999
150 250 -9999 -9999 -9999 -9999 -9999
amount of water
30. 30. -9999 -9999 -9999 -9999 -9999
30. 30. -9999 -9999 -9999 -9999 -9999
30. 30. -9999 -9999 -9999 -9999 -9999
```

Appendix F
EXAMPLE LOG FILE CREATED BY BBGCMUSO 4

Abbreviations:
SWC: soil water content
PSI: soil water potential
SGS: start of growing season
GSI: growing season index (Hidy et al., 2012)
EGS: end of growing season
WPM: annual whole plant mortality
MSC: maximum stomatal conductance

```
NORMAL RUN

Critical SWC (m3/m3) and PSI (MPa) values of top soil layer
saturation:                         0.440     -0.0007
field capacity:                     0.250     -0.0128
wilting point:                      0.090     -2.3146
hygroscopic water:                  0.059   -158.4893
bulk density:                       1.560
Clapp-Hornberger b parameter:       5.260

Soil calculation methods
hydrology  - MuSo
temperature - MuSo

Data sources
SGS data - GSI method
EGS data - GSI method
WPM data - constant
MSC data - constant
management  - YES
groundwater - NO

Limitation values of SWC (m3/m3) and PSI (MPa) in top soil layer
SWC (limit1 and limit2):         0.250        0.436
PSI (limit1 and limit2):       -0.0128       -0.0007

Information about SGS and EGS values (yday of onday and offday)
SGS value (min and max):      9     35
EGS value (min and max):    321    352

Some important annual outputs
Mean annual GPP (gC/m2/year):                           658.8
Mean annual NEE (gC/m2/year):                           -57.0
Maximum projected LAI (m2/m2):                           4.70
Recalcitrant SOM carbon content (kgC/m2):               10.0
Total soil carbon content (kgC/m2):                     11.5
Total soil mineralized nitrogen content (gN/m2):        0.06
Average SWC in rootzone on last simulation day (m3/m3): 0.19

SIMULATION STATUS [0 - failure; 1 - success]
1
```

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