Modelling soil formation along a loess toposequence

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Abstract
The Soilgen model now includes mechanistic and functional descriptions of soil forming processes such as physical and chemical weathering, organic matter turnover, migration of soluble salts and clay, bioturbation and erosion/sedimentation. With these processes, it is in principal possible to simulate the formation of Ah, E and Bt horizons at the pedon scale using the CLORP factors as exogenous inputs. The sensitivity of the model with respect to these factors was tested, and the model was applied on a toposequence in the Belgian loess belt to evaluate if differences in soil properties occuring as a result of slope angle and exposition with reference to prevailing rain-carrying winds could be reproduced. Results indicate that this is possible after calibration of the calcite dissolution constant and parameters affecting clay dispersion and transport. Additionally it is concluded that calibration protocols need to be developed that can deal with the situation that only the current state of the soil profile is known, the simulation model contains many parameters and runtimes are high.

Key Words
Modelling, pedogenesis, toposequence.

Introduction
Modelling of soil genesis is useful because it provides a deterministic temporal interpolator of soil status for the most common circumstance that only the current state can be measured and evidence of earlier situations is scarce or absent. Thus it can be used in soilscape reconstructions (e.g. for archaeological or palaeoclimatological research), but also to assess future soil behavior at pedogenetic timescales under scenarios of climatic change, and to explain observed soil diversity. Few models exist that are able to simulate changes in time of depth profiles of various soil characteristics, and most soil models focus on some aspects of soil development only (C-sequestration, chemical weathering and acidification processes and filtering and buffering functions) with little focus on long temporal extents. An early example on the pedon-scale was the Century model (Parton *et al*., 1987) for the biogeochemistry of carbon, nitrogen, phosphorus, and sulphur. Recently Finke and Hutson (2008) developed the SoilGen1 model describing various aspects of soil genesis in calcareous loess. The latter model has been successfully applied to evaluate differences in soil development as a function of climate evolution. It would be interesting if this model would also be able to explain soil diversity within one climate. For this reason the model was applied to a toposequence in the Belgian loess.

Methods
Soilgen model
Figure 1 gives a schematic overview of the processes simulated by Soilgen. Depending on the process dynamics, timesteps vary from minutes-hours (water, heat and solute flow), days (plant growth and OM dynamics, weathering) to one year (bioturbation, plowing, fertilization, erosion, sedimentation). The transport routines were taken from the mechanistic LEACHN-model (Hutson, 2003), and the OM turnover was modelled according to the descriptions of the functional RothC26.3 model (Coleman and Jenkinson, 2005). Recently, the processes of clay migration and weathering were added to the model. Clay migration is initiated at the surface by splash detachment. If the clay remains in dispersion and can be transported depends on ionic strength which is mimicked with soil pH and on filtering. Transport of the dispersed clay fraction is modelled like solute transport but with particle filtering as an additional sink term. Physical weathering is modelled as a probabilistic process, where the splitting probability of a particle depends on the temperature gradient over time. Chemical weathering is modelled as a first order degradation of minerals.

Loess toposequence
In central Belgium, a forest remains that has been used for hunting ground and timber production, but was probably never under agriculture, as documents from the 13th century onwards prove. The relief in this forest probably hardly changed since the deposition of the loess cover (of about 4 m constant thickness) on a

dissected landscape in tertiary marine deposits. A toposequence of a soil on a plateau position, on a SW facing slope and on a NE facing slope were sampled and described in detail (Van Ranst, 1981). The genesis of these profiles was simulated with the Soilgen2 model. The same climate evolution of 15000 years was applied as boundary condition, but as expositions and slope angles varied, so did net precipitation entering the soil. For this reason, decalcification depth at the plateau position and SW-facing slope is 3.50 m and more because of the higher exposition to the SW wind which brings most rain, while on the NE facing slope it is about 2 m. Also, the Bt-horizons were observed to be more pronounced at the plateau and SW-facing slope. These 2 soils were classified as stagnic albic cutanic Alisol (fragic, alumic, hyperdystric, siltic), while the soil on the NE slope was classified as cutanic lamellic Alisol (alumic, siltic).

Environmental factor		**Link to model**	**Modeled processes** **SoilGen1 (Finke&Hutson 2008)**	**SoilGen2**
CLimate	Temperature	**BC**	Heat flow	
	Precipitation: water	**BC**	Water flow	
	Precipitation: solutes	**BC**	Solute flow	
	Evaporation	**BC**	Evapotranspiration	
Organisms	Vegetation	**BC**	C-cycle	
		SIM	CO_2-production and diffusion	
		SIM	Selective cation uptake/release	
		BC	Root distribution	
	Fauna	**BC**	Bioturbation (as input)	
	Human influence	**BC**	Fertilization	+ Plowing
Relief	Slope	**IC**	Runoff	
	Erosion / sedimentation	**BC**		Input as events
	Variants of T, P, E	**BC's**	Heat/water/solute flow	+ P, E =f(exposition)
Parent material	Texture	**IC+SIM**	Chemical Diss./prec, bioturbation, C-cycling	+ Physical weathering + Clay migration
	Mineralogy	**IC**	Cation exchange	+ Weathering primary minerls
	Species of Ca, Al, Mg, K, Na	**IC+SIM**	Chemical equilibria	
Time	Change of all BC's	**BC**	Annual update of all BC's	

Figure 1. Processes simulated in Soilgen and linkage to the CLORP factors via BC or IC (Boundary or Initial Conditions, forcings) or simulation (SIM).

Calibration
The soilgen model was calibrated by adjusting the calcite dissolution equilibrium concentration until the depth of decalcification for a high precipitation surplus (472 mm/y) simulated by the model was equal to that of a metamodel by Egli and Fitze (2001) based on pan-European soil data. Thereafter, results were compared with data from this metamodel for lower precipitation surpluses. Clay migration was calibrated by adjusting a filtering coefficient so that the zone of clay accumulation appeared at a realistic depth in the soil. Faulty values lead to loss of clay from the entire profile or no clay migration at all.

Results and discussion
The comparison after calibration of calcite dissolution constant resulted in comparable times-to-decalcification at other precipitation surpluses (Figure 2) all though decalcification speed with Soilgen is slightly slower in dryer climates than with the metamodel. After calibration towards the appearance of a clay illuviation of the soil, the 3 profiles of the toposequence showed a marked difference in depth of decalcification and the distinctness of the development of an E and Bt horizon (Figure 3). At the SW-facing slope and the plateau, decalcification (shown by pH) is deep and a clear E and Bt develop. At the NE facing slope, decalcification is close to 200 cm, a clear E develops but the Bt is much less marked. This is in accordance with field observations, all though the whole profile lost clay in the simulations which is probably not realistic. Also (not shown, but see Finke and Hutson, 2008) the development of an Ah horizon was reproduced by the model. Simulation time was substantial, and calibration of the clay migration part done on a qualitative rather than a quantative basis.

Conclusion

Observed differences in soil formation on a toposequence could be reproduced by the soilgen2 model, and the presence of Ah, E, Bt and Ck horizons was simulated as well. Efficient calibration methods need to be developed for the situation that only current state measurements are available and simulation time is long.

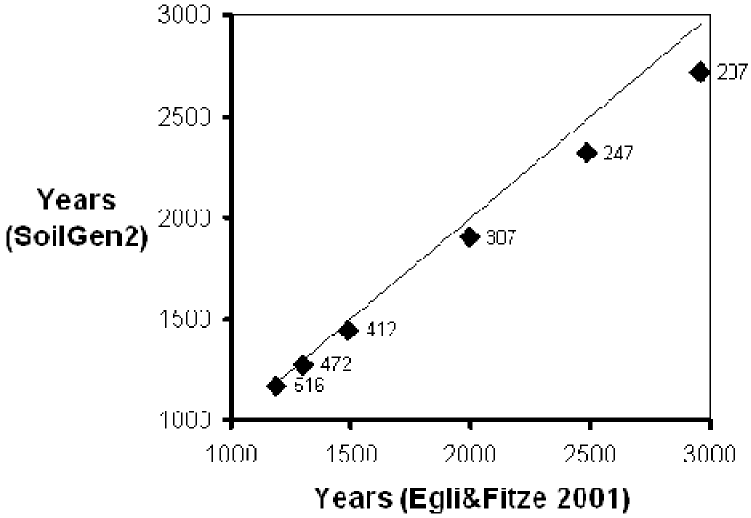

Figure 2. Comparison after calibration of time-to-decalcification of 1100 mm of soil with SoilGen2 and the Egli and Fitze (2001) metamodel. Numbers indicate precipitation surpluses.

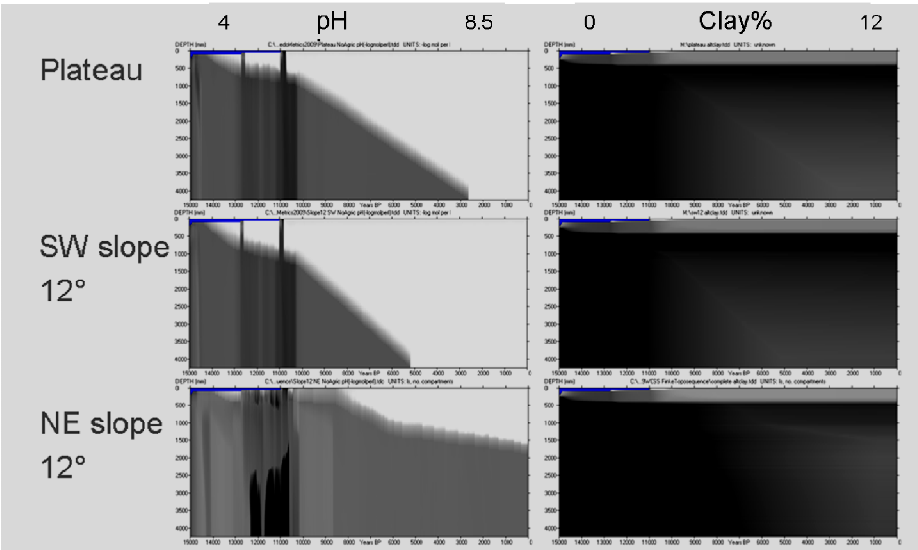

Figure 3. Time-depth diagrams for 3 profiles in the toposequence for pH and clay content with Soilgen2.

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