DeNitrification-DeComposition

DNDC is a process oriented model which simulates the main C and N turnover processes and associated exchange processes with the atmosphere and hydrosphere. The model was developed to integrate the complex interactions among primary drivers (e.g. climate, soil, vegetation, and anthropogenic activity), soil environmental factors (e.g. temperature, moisture, pH, Eh, and substrate concentration gradients), and various biogeochemical reactions, which finally control transformation and transport of C and N in the ecosystems (Li, 2000). DNDC (and Forest-DNDC) consist of several sub-models for predicting plant growth, soil climate, decomposition, nitrification and denitrification, respectively. The soil climate sub-module converts daily climate data into soil temperature and moisture profiles for up to 50 horizontal soil layers. It also calculates soil oxygen diffusion within the soil profile (Li et al., 2000). The plant (i.e. crop or forest) growth sub-module simulates crop/ forest growth at a daily time step driven by solar radiation, temperature, water stress and N stress, and passes litter production and water and N demands to the soil climate or decomposition sub-modules. The decomposition sub-module tracks turnover of litter (leaves, stem, roots) and other organic matter in the soil, and provides ammonium and dissolved organic carbon (DOC) for the nitrification and/or denitrification sub-modules. The nitrification sub-module predicts growth and death of nitrifiers, the nitrification rate as well as N2O and NO productions from nitrification regulated by soil temperature, moisture, and ammonium and DOC concentrations. The denitrification sub-module simulates denitrification and changes in population size of denitrifiers as a function of soil temperature, moisture, and substrates (e.g. DOC, NO3-, NO2-, NO and N2O) concentrations. The denitrification-induced N2O and NO fluxes are calculated based on the dynamics of soil aeration status, substrate limitation and gas diffusion.

Furthermore, chemo-denitrification is considered as a source of NO-production in soils. This process is controlled by the availability of nitrite and the soil pH. Since nitrification and denitrification can simultaneously occur in aerobic and anaerobic microsites, a kinetic scheme for anaerobic volumetric fraction (or so-called “anaerobic balloon”) was used in both models to calculate the anaerobic fraction of soil in a given soil layer in dependency of O2-diffusion and the respiratory activity of soil micro-organisms and roots (Li et al., 2000).

In DNDC denitrification is modeled with a series of biologically mediated reductive reactions from nitrate to N2. The key equations adopted in DNDC for modeling the microbial activities include the Nernst equation and Michaelis-Menten equation. The Nernst equation is a basic thermodynamic formula defining soil Eh based on concentrations of the oxidants and reductants existing in a soil liquid phase (Stumm & Morgan, 1981). The Michaelis-Menten equation is a widely applied formula describing the kinetics of microbial growth with dual nutrients (Paul & Clark, 1989), which usually include DOC (i.e., energy source) and an electron acceptor (i.e., oxidant) such as nitrate, nitrite, NO or N2O. The denitrification process will be depressed when either the energy source or the electron acceptor becomes limited. The values of the kinetic coefficients (i.e., Michaelis constant Km and maximum reaction rate Vmax) in the Michaelis-Menten equation used in DNDC were adopted from the laboratory incubation experiments done by Leffelaar and Wessel (1998). The Nernst and the Michaelis-Menten equations can be linked because they share a common factor, the oxidant concentration. The Nernst and the Michaelis-Menten equations are linked in DNDC through a simple kinetic scheme called the “anaerobic balloon”. By tracking the evolution of soil bulk Eh, DNDC allocates DOC and N oxides into the anaerobic balloon at an hourly time step, defining the effective anaerobic volumetric fraction of a soil. The Eh value for a soil layer is estimated based on the dominant oxidant species with the Nernst equation, determining the size of the anaerobic balloon and the allocation of soil substrates inside and outside of the balloon. Only the substrates allocated within the balloon are involved in the anaerobic
reactions (e.g., denitrification, methanogenesis etc.); substrates allocated outside the balloon are involved in the aerobic reactions (e.g., nitrification, methanotrophy etc.). The kinetics of transformations from nitrate to nitrite, to NO, to N₂O, and finally to N₂ are then handled by the Michaelis-Menten equation. When the anaerobic balloon grows, more substrates are allocated within the balloon, the rate of the reductive reactions (e.g., denitrification) increases based on the Michaelis-Menten equation, and the probability that intermediate product gases (e.g., N₂O, NO etc.), which take longer time to diffuse from the anaerobic to the aerobic fraction, increasing the probability will be further reduced to N₂ increases.

DNDC has been applied for various ecosystem types (grassland, arable land, steppe, temperate and tropical forests, etc.). Time scales are typically 1-3 yrs, but DNDC has also been run in long-term simulation up to 150 yrs. DNDC can be applied on the site scale as well as on the regional scale (coupling with GIS database). Applications on the regional scale were done for US, India and China (agricultural soils -> GHG balance, mitigation), Europe (agricultural and forest soils, N₂O+NO emissions from soils), Australia (tropical forests, N₂O emissions), and for tropical rainforests worldwide (N₂O emissions).

What is your view of the strengths and weaknesses of the denitrification estimates? Estimates of denitrification are still vague since datasets for model calibration for N₂ production are still scarce. Also, I still can see problem that DNDC is mainly run with a simulation depth of 30 cm, which is not sufficient to estimate site scale denitrification in the soil column.

What are the opportunities for adaptations and couplings of this model with other approaches? DNDC has already been coupled with a regional hydrological model. At IMK-IFU we currently develop a new coupling interface (MOBILE), which allows coupling of alternative submodules (plant growth, soil biology, soil hydrology) to meteorological as well as hydrological models.

How accessible is the model? The model is fully accessible. In some way it is user friendly and can be run after a short time. However, to address specific questions it will take some time and an idea about the code and its structure is helpful.

What would be needed to scale up the model to the whole watershed scale? In principal everything is available. One only needs to set up the GIS database.