Article

Regional application of process based biogeochemical model DNDC in Godavari Sub-basin

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Abstract
The denitrification decomposition (DNDC) model is a process-based computer simulation model of soil carbon and nitrogen biogeochemistry. The DNDC model is one of the few process-based bio-geo chemical crop simulation models for which both a site-specific mode and a regional mode were developed. For regional mode, a region is presented in a typical Geographic Information System (GIS) consisting of many polygons or grid cells. The database consists of spatially differentiated information of location, climate, soil properties, cropping systems, and farm management practices for each polygon or grid cell for the entire modeled region. An attempt was made to establish the methodology for the estimation of soil greenhouse gas fluxes like CH_4, CO_2 and N_2O on a sub-basin scale.

Keywords DNDC; GIS; Bio-geo chemical model; crop simulation.

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1 Introduction

The Denitrification-Decomposition (DNDC) model is a process based computer simulation model of carbon and nitrogen biogeochemistry in agro-ecosystems. It integrates crop growth and soil biogeochemical processes on a daily time step and simulates N and C cycles in agro-ecosystem. The DNDC model contains six interacting sub-models which quantify the generation, decomposition, and transformation of organic matter, and outputs the dynamic components of soil organic carbon and greenhouse gas fluxes. The six sub-models include: 1) a soil climate module which use soil physical properties, air temperature, and precipitation data to calculate soil temperature, moisture, and redox potential (Eh) profiles and soil water fluxes through time. The results of the calculation are then fed to the other sub-models; 2) a nitrification module; 3) a denitrification module, which simulates hourly denitrification rates and N_2O, NO, and N_2 production during periods when the soil Eh decreases due to rainfall, irrigation, flooding, or soil freezing etc; 4) simulation of SOC decomposition and CO_2 production through soil microbial respiration; 5) a plant growth module, which calculates daily root respiration, water, and N uptake by plants, and plant growth; and 6) a fermentation component, which calculates daily methane (CH_4) production and oxidation. The specific biochemical and geochemical reactions in the model are governed by classical laws of physics, chemistry and biology, as well as parameterised by empirical equations generated from laboratory studies. The DNDC model is one of the few process-based crop simulation models for which both a site-specific mode and a regional mode were developed. For regional mode (Landscape DNDC), a region is presented as a typical Geographic Information System (GIS) consisting of many polygons or grid cells (Giltrop et al., 2010; Ballestores and Qiu, 2012; Tahir et al., 2013). The database consists of spatially differentiated information of location, climate, soil properties, cropping systems, and farming management practices for each polygon or grid cell for the entire modeled region. Landscape DNDC is partly based on the DNDC model and contains a series of new features with regard to process descriptions, model structure and data architecture (Haas et al., 2012). Landscape DNDC incorporates functionalities of DNDC, PnET-N-DNDC/Forest-DNDC and was further developed from the MoBiLE model framework (Rahn et al., 2012). Landscape DNDC simulates carbon (C), nitrogen (N) and water related biospehere-atmosphere-hydrospehere fluxes for forest, arable and grassland ecosystems incorporating different management practices and vegetation types and allows dynamic simulation of land use change.

The model has been validated in India, China, the USA, Japan, and Thailand in against a number of field data sets observed in and widely used over the last 20 years by many researchers (Sinha, 1995; Pathak et al., 2005; Jain et al., 2000; Adhya et al., 2000; Butterbach-Bahl et al., 2004; Cai et al., 2003; Li et al., 1997; Li et al., 2000; Li et al., 2001; Li et al., 2003; Li et al., 2004; Smith et al., 2002; Smith et al., 2004; Zhang et al., 2002; Beheydt et al., 2007; Smith et al., 2008; Deng et al., 2011; Zhang et al., 2009; Han et al., 2013; Balashov et al., 2014). Simulated results showed that DNDC was able to simulate the basic patterns of NO, N_2O, CH_4 and NH_3 fluxes simultaneously (Li, 2000). DNDC model has been calibrated and validated for Indian rice field and up-scaled in to regional scale (Pathak et al., 2005). Though many researchers have documented the application of DNDC model on field scale in India, regional application of this type of process based bio-geo chemical model is not reported much. In this context the present study was undertaken with the objective of establishing a spatial framework for regional application of process based biogeochemical model DNDC. The preliminary findings with the detailed methodology are presented in this work.

2 Study Area

Maner is located in the semi-arid mid-Godavari river basin, occupying about 12,933 sq km of catchment area, where most rain fall during monsoon(June-October),where mean rainfall varies from 629-1391mm.About 35 % of the sub-basin is used for agriculture with net cultivated area and forest area of 455,000 ha. and 127,000 ha is forest respectively. Major crops of this area are rice, maize, chilly and cotton. Irrigated agriculture is prevalent in the Maner sub-basin through the use of water tanks and canals. Rice is the major irrigated crop accounting for about 46% of total irrigated area and more than 75 % of the total water use in the sub-basin. The entire sub-basin was divided in to 524 grids representing (Fig. 1) the unit of simulation for simulating the biogeochemical processes through DNDC model.

3 Denitrification-Decomposition (DNDC) Model

The Denitrification-Decomposition (DNDC) model is a process-based computer simulation model of carbon and nitrogen biogeochemistry in agroecosystems (Li et al., 1992a, b). The model consists of two components. The first component, consisting of the soil climate, crop growth and decomposition sub-models, predicting soil temperature, moisture, pH, redox potential (Eh) and substrate concentration profiles driven by ecological drivers like climate, soil, vegetation and anthropogenic activity etc. The second component consists of the nitrification, denitrification and fermentation sub-models that predicts emissions of carbon dioxide (CO_2), nitric oxide (NO), nitrous oxide (N_2O) and dinitrogen (N_2), methane (CH_4), ammonia (NH_3), from the agro-eco systems. A crop growth sub-model was built in DNDC to simulate the crop growth. The crop growth simulation will be driven by the accumulative temperature, N uptake, and water stress at a daily time step. Crop demand for N is calculated based on the optimum daily crop growth and the plant C/N ratio where as the actual N uptake by crop could be limited by N or water availability during the growing season. After harvest, the crop residue incorporated in the soil will be partitioned into three soil litter pools, namely very labile, labile and resistant litter pools, based on its C/N ratio. In DNDC, Soil Organic Matter (SOM) resides in four major pools: plant residue (i.e., litter), microbial biomass, humads (i.e., active humus), and passive humus. With the decomposition of Soil Organic Carbon (SOC) in a pool the carbon is partially lost as CO_2 with the rest allocated into other SOC pools. Soil microbes will consume the Dissolved organic carbon (DOC), produced as an intermediate during decomposition. Similarly, the nitrogen cycle progresses through mineralisation of ammonium (NH^{4+}).The free NH^{4+} concentration is in equilibrium with both the clay-adsorbed NH^{4+} and the dissolved ammonia in the soil liquid phase. Volatilization of NH_3 to the atmosphere is controlled by NH_3 and subject to soil environmental factors (e.g., temperature, moisture, and pH). Leaching of N takes place through rainfall or irrigation water into deeper layers with. The soil in each layer is divided into aerobic and anaerobic parts depending on the predicted redox potential where nitrification and denitrification occur, respectively. Gases NO and N_2O produced in either nitrification or denitrification are subject to further transformation during their diffusion through the soil system. Submergence for longer period will activate fermentation, which produces hydrogen sulfide (H_2S) and methane (CH_4) driven by decreasing of the soil Eh. The entire model is driven by four primary ecological drivers, namely climate, soil, vegetation, and management practices.

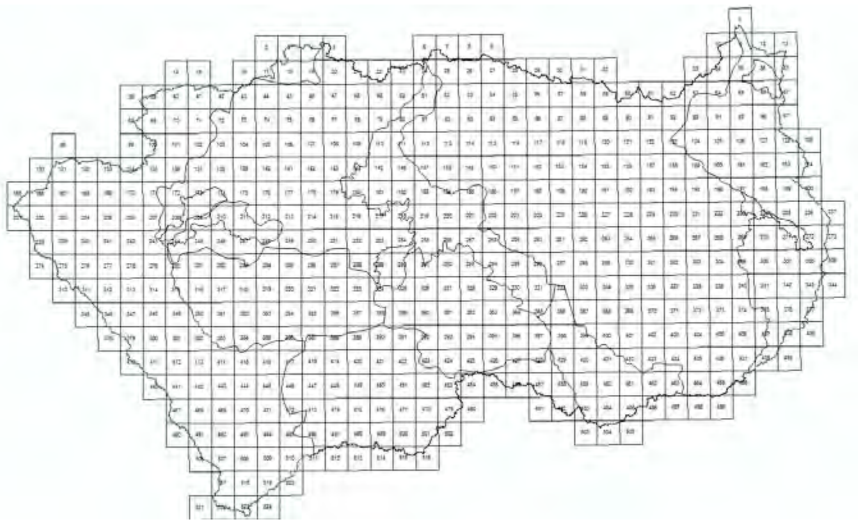

Fig. 1 Study area with grids superimposed.

4 Database Development

To run DNDC in the regional mode, we need to have all the input data compiled in a database in advance for the study region. The region is divided into many polygons or grid cells representing units of simulation. The database consists of spatial information of location, climate, soil properties, cropping systems, and farming management practices for each polygon or grid cell for the entire region. The comprehensive list of input required for running DNDC model on regional scale is presented in Table 1 and the methodology of the entire study is presented in Fig. 2

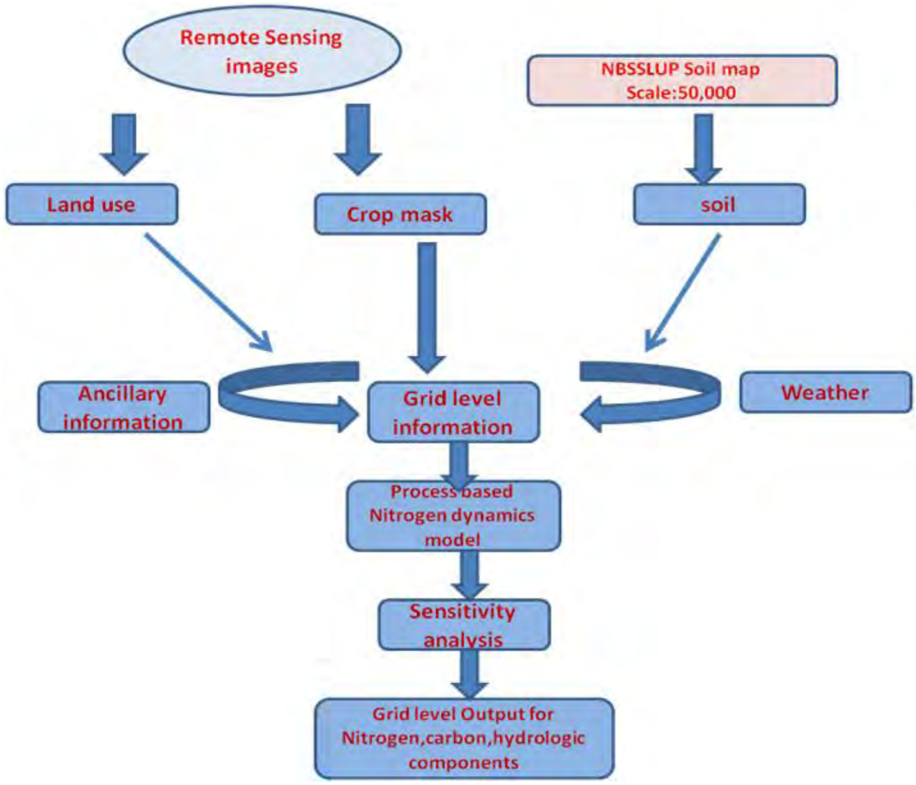

Fig. 2 Flow diagram of the methodology.

5 Crop Area Map

Crop classification was carried out using IRS-P6 (AWiFS) images. IRS-P6 (AWiFS) has a spatial resolution of 56 m, four spectral channels (green (0.52–0.59 μm), red (0.62–0.68 μm), near infrared (NIR: 0.77– 0.86 μm) and short-wave IR (SWIR: 1.55– 1.70 μm)) and a temporal resolution of 5 days with a 740 km swath width. Time series AWiFS images pertaining to the study area were processed in ERDAS IMAGINE software. AWIFS images were georeferenced with Survey of India (SOI) topographic map (1:250,000). With ground truthing, supervised classification was carried out using maximum likelihood algorithm. The accuracy of the classification was evaluated using classification error matrix. Spatial variation in crop area is presented as crop area map in Fig. 3.

6 Digital Elevation Model

DEM (Digital Elevation Model) Shuttle Radar Topography Mission (SRTM) derived DEM of 90 m resolution was used to generate the slope map of Maner sub-basin. The data were taken from http://srtm.usgs.gov/data/ obtaining.html. The study area was clipped, projected and then imported to the ArcGIS. Based on the data the slope map was generated and presented in Fig. 4.

Table 1 Comprehensive list of inputs required for regional simulation of DNDC.

Daily Max temp (^{0}C)
Daily min temp (^{0}C)
Daily rainfall(mm)
N dep – N concentration in precipitation (ppm);
SOC max – Maximum SOC content (kg C/kg);
SOC min – Minimum SOC content (kg C/kg);
CLAY max – Maximum soil clay fraction;
CLAY min – Minimum soil clay fraction;
PH max – Maximum soil pH;
PH min – Minimum soil pH;
DENS max – Maximum soil bulk density (g/cm^3);
DENS min – Minimum soil bulk density (g/cm^3);
Slope – soil surface slope (0-90);
Salinity Index – Soil salinity index (0-100);
Grid wise Crop area in Ha: derived from time series satellite data
Crop parameters based on popular variety and management practices
Maximum grain yield
TDD: thermal degree days
Water demand (mm)
Fertilizer application kg N/ha
Wetland crop flooding: start date/end date/method:
continuous flooding /mid season drainage/marginal flooding
Irrigation % irrigated area only for upland crop
Manure/amendment kg N/ha
Fraction of above ground crop residue incorporated
Tillage date and method
Planting and harvesting dates

7 Soil Map

For carrying out this study, a geo-referenced digital soil map, NBSSLUP soil map of 1:250,000 scale was used. The digital soil map of consists of polygons linked with an attribute table. The attributes selected for this study are: (1) Bulk density (2) Organic carbon (3) % of Clay fraction and soil pH. Spatial variability of the selected soil properties is presented in Fig. 5.

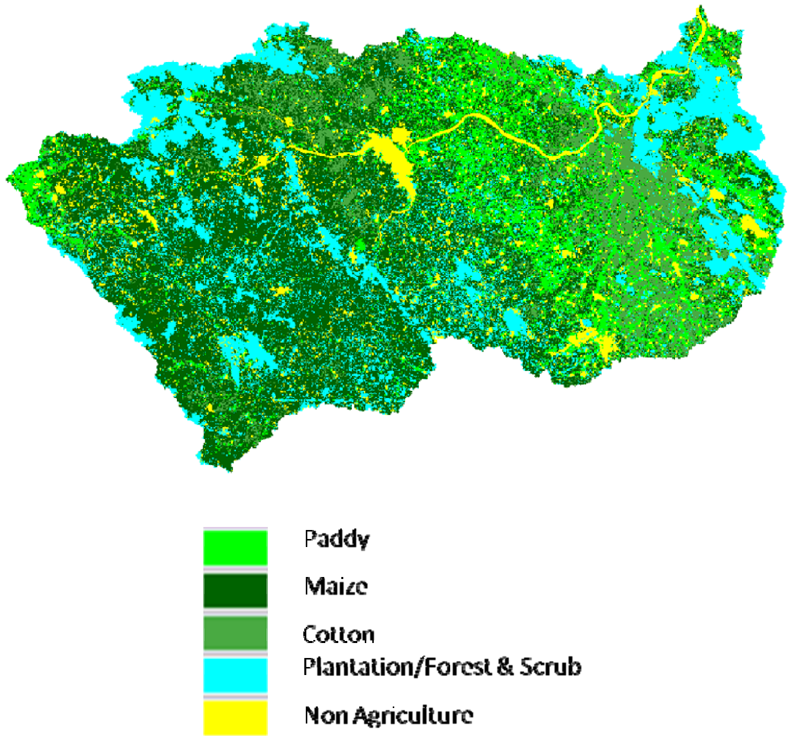

Fig. 3 Spatial distribution of agricultural crops in Maner sub-basin.

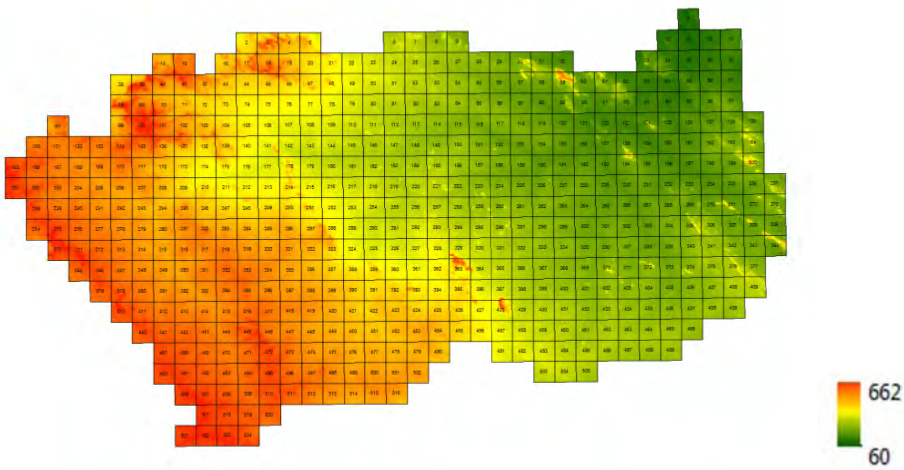

Fig. 4 Digital elevation model of the study region.

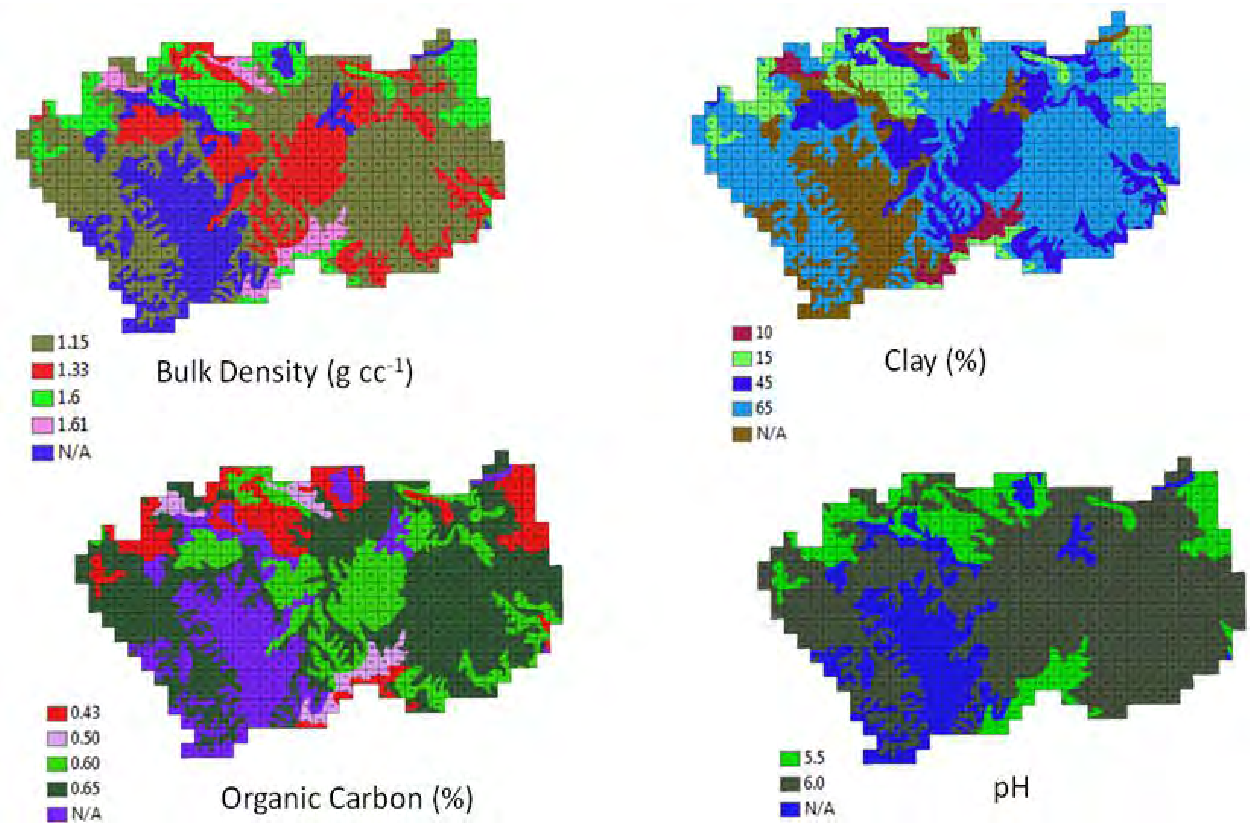

Fig. 5 Spatial variability of soil properties in Maner sub-basin.

8 Results and Discussion

During the regional simulations, DNDC runs for each cropping system in each grid cell for the defined years four times with the maximum and minimum values of the most sensitive soil factors depending on the user-defined “major concern” combined with irrigation and non-irrigation conditions. DNDC continuously runs cell by cell until reaching the end of the database. A regional simulation produces four files to record a same group of items (e.g., C, N or water pools or annual fluxes) but predicted with the four different soil-irrigation combination scenarios. The spatial maps of some of the simulated attributes are presented in Fig. 6 to 9. As seen in Fig. 6, simulated methane emission from the study area varied from 0-12 to 115-208 tonnes/year. Spatial variation of CH_4 emission from rice fields is regulated by a different of agronomic and environmental factors, as well as the complex interactions involving the rice plants, soil and atmosphere (Jean and Pierre, 2001; Wang and Li, 2002). Variations in CH_4 emission from continuously flooded rice soils in different locations with varying soil properties and climates reported by several researchers (Kimura et al., 1991; Yang and Chang, 2001; Kumar and Viyol, 2009). Soil organic carbon (SOC) plays a vital role for methanogens (Penning and Conrad, 2007), thus it has significant correlation with CH_4 production (Wassmann et al., 1998). Xiong et al. (2007) reported that clay soil produced much more CH_4 than loess soil during the flooding period.

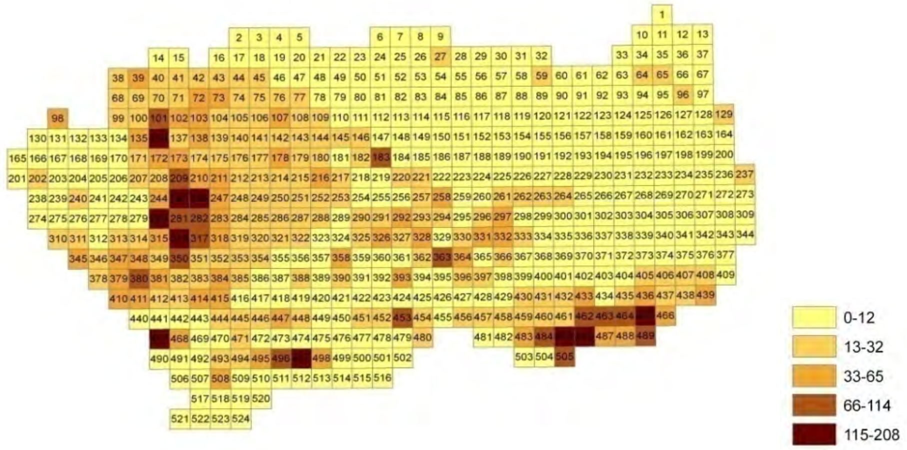

Fig. 6 Spatial distribution of simulated methane tonnes/yr (CH_4).

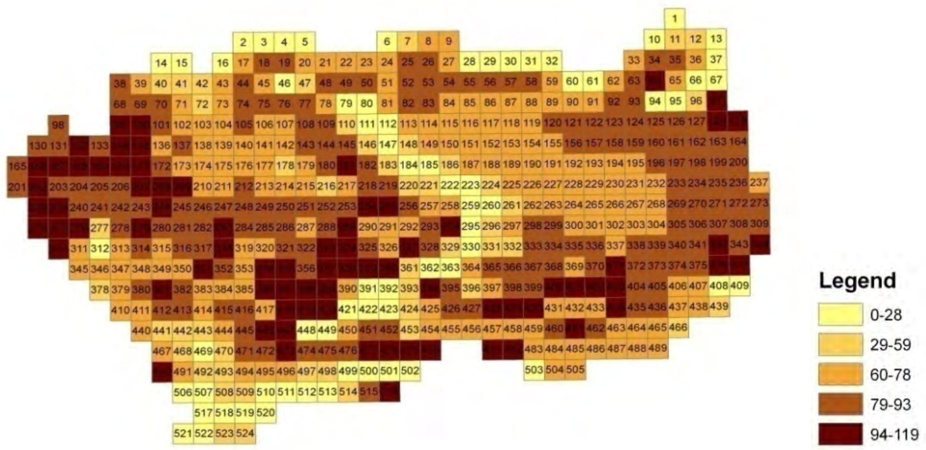

Fig. 7 Spatial distribution of simulated nitrous oxide (NO_2) tonnes/yr.

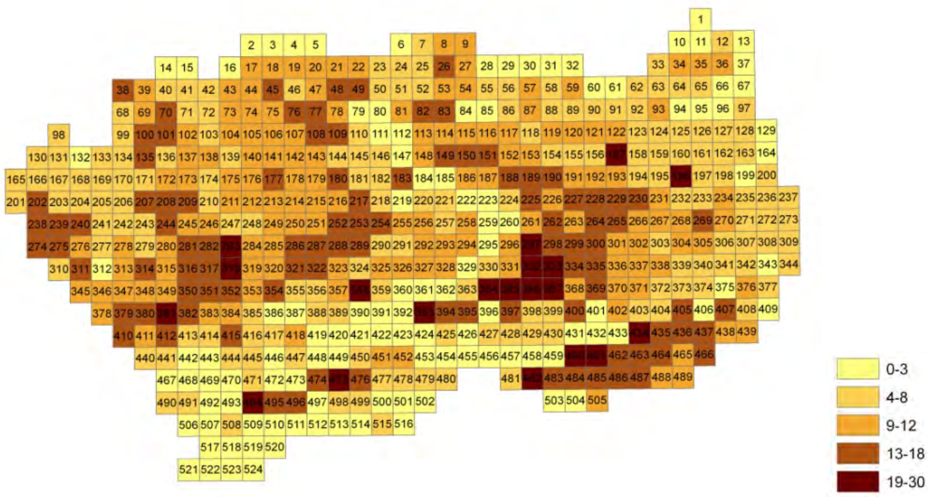

Fig. 8 Spatial distribution of simulated ammonia (NH_3) tonnes/yr

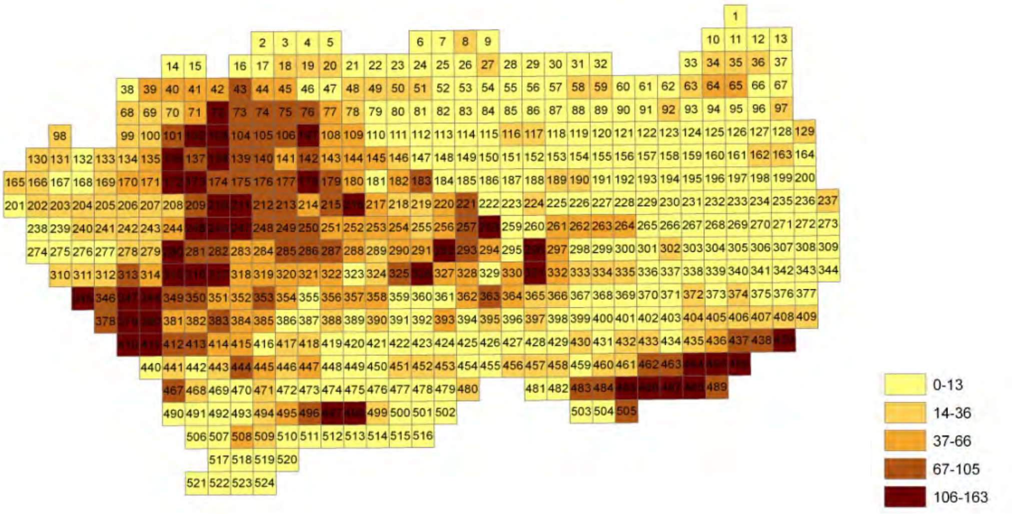

Fig. 9 Spatial distribution of simulated crop nitrogen uptake (tonnes/yr).

The result of simulated nitrous oxide (NO_2) is presented in Fig. 7. The value of simulated N02 varies from 0-20 to 94-119 tonnes/yr. The production and consumption of N_2O in soils mainly involve anaerobic process of denitrification as well as the aerobic process of nitrification. The factors that significantly influence agricultural N_2O emissions are agricultural practices like fertiliser N application rate, crop type, fertilizer type and physic-chemical properties of soil like soil moisture, soil organic C content, soil pH and texture (Henault et al., 2012). Spatial distribution of simulated ammonia (NH_3) is presented in Fig. 8. It varies from 0-3 to 19-30 tonnes/year. The process of ammonia volatilisation leading to emission from the surface of manures or soils in the field is influenced by a wide range of chemical, biological and physical factors that greatly increase complexity. Modelling is needed at a range of scales to aid understanding of the complex processes and interactions involved. Spatial distribution of simulated crop nitrogen uptake is presented in Fig. 8. It varies from 0-13 to 106-163 tonnes/year. The rate of N uptake of crops is highly variable during crop development and between years and sites. However, under ample soil N availability, crop N accumulation is highly related to crop growth rate and to biomass accumulation. Therefore, N uptake and distribution in plants and crops involves many aspects of growth and development

9 Conclusion

Attempt is made to demonstrate the methodology for regional simulation of nitrogen and carbon dynamics using biogeo-chemical model DNDC. Preliminary findings of the study are presented in this paper. The detailed analysis of cause and effect of these green house gases in the crop ecosystem of Maner sub-basin is under process. Further investigation needs to be carried out to explain the spatial variability of simulate methane emission from the study area.

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