Quantifying Ecosystem Productivity of Seyhan Watershed under Human Disturbances

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1. Introduction

Ecosystems are complex, interactive open systems of abiotic and biotic components at a space and time scale of any magnitude (Tansley 1935). The biogeochemical cycles of C and N connect all the abiotic and biotic components of ecosystems to one another in a holistic way. The consumption of fossil fuels and changes in land-use and -cover in proportion to the increased population growth, though human activities at the local scale, are the main anthropogenic disturbances of C and N cycles that trigger climate change at the global scale (Wali et al. 1999a).

Since the coldest point of the last great ice age which ended about 10,000 years ago, the mean temperature of the Earth's surface has increased by only 5°C (9°F). Over the past century, the global mean air temperature has increased by about 0.5°C ($\pm$0.2) despite observed decreases in lower stratospheric ozone and increases in sulfate particles that both produce cooling effects (a negative radiative forcing) (Walker and Steffen 1997). During the period 1951 to 1990, the rise of the minimum nighttime temperature occurred at a rate three times that of the maximum daytime temperature for over 50% of landmass in the Northern Hemisphere and 10% of landmass in the Southern Hemisphere (Kukla and Karl 1993). General circulation models (GCMs) suggest a global mean temperature increase ranging from 1°C to 4.5°C with a doubled atmospheric CO_2 concentration (700 ppmv) by the year 2100 if mitigative measures are not taken to reduce the present rate of production of GHGs (IPCC 1996).

The disturbance of C and N cycles occurs through three principal processes: degradation and loss (1) of net primary productivity (NPP), (2) of soil organic matter (SOM), and (3) changes in ecosystem structure (Wali et al. 1999b). The underlying causes of these disturbances include rapid growth of human population and consumption, poverty and unequal economic growth, undervaluation of ecological goods and services (externalities), use of ecologically incompatible technologies, and degradative management practices (Evrend'lek and Doygun 2000). Degradation and loss of the biological productivity of ecosystems increase food insecurity and poverty in the face of rapid population growth and shrinking per-capita productive land area (Evrendilek and Ertekin 2002).

Qualitative and quantitative ecological constraints imposed by the disturbances of C-N cycles on ecosystem productivity and sustainability may adversely affect the well-being of humans. The development of preventive and mitigative measures at the local and regional scales depends on the understanding of effects of projected climate change on the structures and functions of ecosystems (Evrendilek and Wali 1998). Remotely sensed-data, Geographic Information Systems (GIS) and process-based simulation models have facilitated the quantification of ecological changes at a broader spatio-temporal scale since disruptive land-use/cover changes are difficult to estimate spatially and temporally (Oldeman et al. 1990).

The degree of model complexity increases as productivity-determining (e.g., solar radiation, temperature, and CO_2), productivity-limiting (e.g., nutrients, and water) and productivity-reducing (e.g., pests, and diseases) factors are incorporated into the models, respectively (Noordwijk and

Geijn 1996). Crop growth simulation models began in the late 1960s, and some examples of the process-oriented crop growth models include ELCROS, BACROS, ARID CROP, SUCROS, WOFOST, MACROS, PAPRAN, and LINTUL (Powlson et al. 1996). CANDY (Franko et al., 1996) CENTURY (Parton et al. 1987), DAISY (Hansen et al. 1991), DNDC (Li et al. 1992), and ROTHC (Jenkinson et al. 1987) are the major SOM models used in agricultural ecosystems, with such common features as the use of first-order kinetics, multi-compartments, and stoichiometrically coupled dynamics. In general, SOM models published represent the dynamics of C and N in such ecosystems as croplands, grasslands, and forests using the following differential equation form (Smith et al. 1997):

$$\frac{dX}{dt} = -kX + A$$

where dX = change in a state variable over time (dt), k = first order rate coefficient, A = input rate.

Objectives of the study are to (1) determine productivity and ecological disturbances of ecosystems of Seyhan watershed, and (2) develop sustainable watershed management under climate change scenarios.

2. Materials and Methods

Human-induced changes in land-use and land-cover and NPP of Seyhan watershed ecosystems of *ca.* 21,000 km^2 shall be detected by the comparison of past and actual satellite images in a GIS setting (Fig. 1). Normalized Difference Vegetation Index (NDVI) and Leaf Area Index (LAI) Soil Moisture Index (SMI) of the study area will be derived from remotely sensed data. Site-specific field measurements concerning micro climate, soils, water and plants shall be made along a toposequence gradient in a randomized way. Statistical analyses of explanatory and response variables for which monthly time series data will be collected between 2003 and 2006 will be performed through the correlation and multiple regression methods. The quantification of carbon (C) and nitrogen (N) budgets shall be made by developing a process-based ecosystem model through STELLA® simulation language.

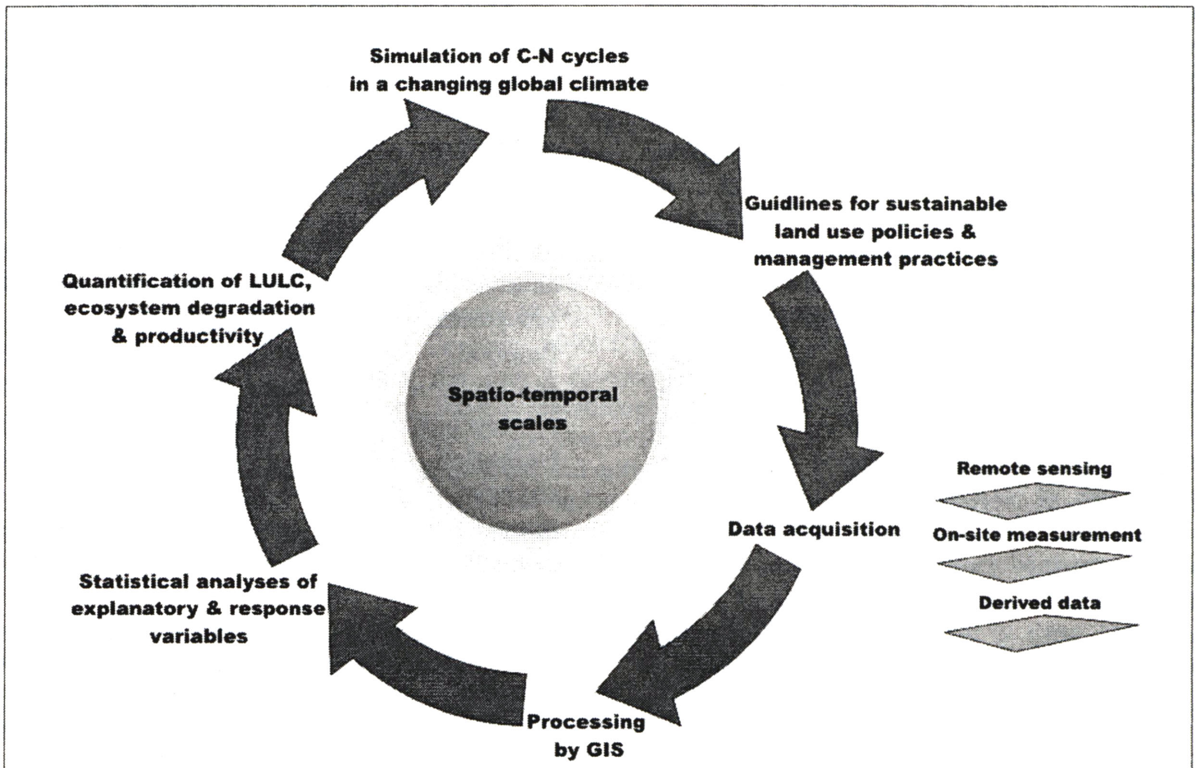

Fig. 1 A flow diagram of the research methodology: LULC, land use land cover changes; GIS, geographic information systems; C, carbon and; N, nitrogen (Drawn by Kayhan, 2003).

The model shall consist of three interacting submodels of plant production, plant residue, and soil organic C and N (SOC-N) (Fig. 2). Plant production submodel shall use such data as photosynthetically active radiation (PAR), min and max air temperature, precipitation, cloudiness, CO_2, N, and plant-specific parameters such as Radiation Use Efficiency (RUE), growing degree days (GDD), and base temperature for vegetative growth. Plant residue submodel shall be run as a function of conventional vs. conservation residue practice, and lignin/N ratios of organic residues. The SOC-N submodel shall consist of three SOC-N pools: (1) active C-N (2) slow C-N (fulvic acids) (3) passive C-N (humic acids) with potential turnover times of 1 yr, 10 yrs, and 100-1000 yrs, respectively, based on the CENTURY model (Parton et al. 1987). Precipitation, evapotranspiration rate, temperature, soil texture, and lignin content of residues are the main inputs to be used in the SOC-N submodel.

on a monthly basis as a function of four different categories of variables and parameters: climatic, edaphic, biotic, and management inputs. The model shall assist in the prediction of ecological effects of climate change on ecosystem productivity as well as the identification of management practices that secure ecosystem productivity.

3. Expected Results and their Significance

Results expected form the study can be divided into six main groups: (1) establishment of a generic database system through Remote Sensing (RS), Geographical Information Systems (GIS), statistical models and simulation models (2) classification of land uses and land covers (LULC), (3) determination of natural and agricultural ecosystem productivity, (4) quantification of human disturbances (5) simulation of what-if questions under climate change scenarios, and (6) recommendation of guidelines for sustainable land use policies

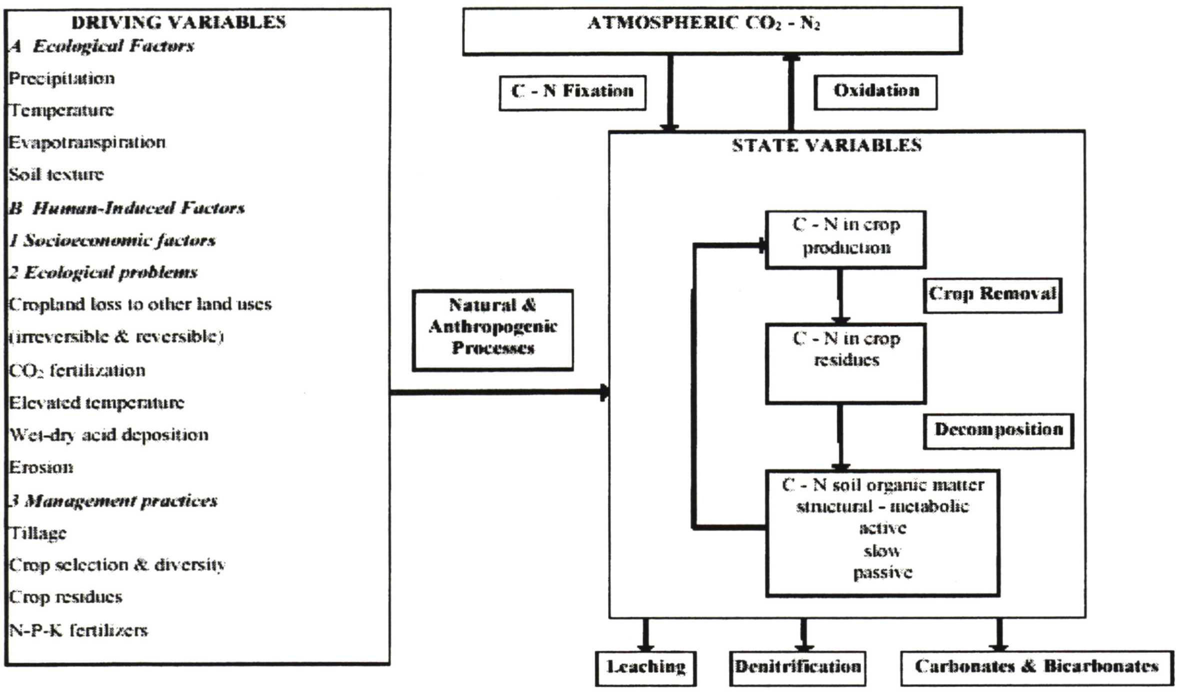

Fig. 2 A conceptual model of C-N dynamics in croplands (Evrendilek and Wali 2001).

The model shall be subjected to calibration, verification, validation and sensitivity analyses, respectively. E ffects of different management practices on agricultural productivity and mitigation of atmospheric C-N emissions will be simulated

and land management practices to the policy-and decision-makers.

The long-term productivity and C-N sequestration capacity of ecosystems depend on the selection of management practices and land use strategies. Sustaining the normalcy of global C-N cycles can enable food and fiber production to keep pace with the pressures of population and consumption growth. Simulation models help to clarify what-if-questions either economically unfeasible or time-consuming to investigate by laboratory and field experiments, thus providing scientific understanding for decision-making. Simulations of C-N dynamics in a changing global climate can enable the prediction of how ecosystems may response as well as the tailoring of human interventions that secure long-term cropland productivity and stabilize global GHG emissions. Modelling attempts at the regional (meso) scale play an important role in bridging the gap between the micro and mega models that fail to represent system behavior and local conditions, respectively.

Reliance on supplying nutrients through fertilizers rather than on mineralization of SOM contributes to global climate change as well as impoverishes the maintenance of soil and plant productivity. Mitigative measures involve the adoption of sustainable land use policies and management practices that would enhance C-N sequestration, retention of SOM and organic residues, soil aggregation, soil stabilization, rehabilitation of degraded lands, and protection of ecosystem productivity, biodiversity and integrity (Evrendilek and Wali 2001). These mitigative measures should be accompanied by such preventive measures as the reduction of fossil fuel consumption through renewable energy technologies.

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