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Modeling Soil Organic Matter Dynamics Under Intensive Cropping Systems on the Huang-Huai-Hai Plain of China*[1]

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ABSTRACT

A modified CQESTR model, a simple yet useful model frequently used for estimating carbon sequestration in agricultural soils, was developed and applied to evaluate the effects of intensive cropping on soil organic matter (SOM) dynamics and mineralization as well as to estimate carbon dioxide emission from agricultural soils at seven sites on the Huang-Huai-Hai Plain of China. The model was modified using site-specific parameters from short- and mid-term buried organic material experiments at four stages of biomass decomposition. The predicted SOM results were validated using independent data from seven long-term (10- to 20-year) soil fertility experiments in this region. Regression analysis on 1 151 pairs of predicted and measured SOM data had an r^2 of 0.91 ($P \leq 0.01$). Therefore, the modified model was able to predict the mineralization of crop residues, organic amendments, and native SOM. Linear regression also showed that SOM mineralization rate (MR) in the plow layer increased by 0.22% when annual crop yield increased by 1 t ha^{-1} ($P \leq 0.01$), suggesting an improvement in SOM quality. Apparently, not only did the annual soil respiration efflux merely reflect the intensity of soil organism and plant metabolism, but also the SOM MR in the plow layer. These results suggested that the modified model was simple yet valuable in predicting SOM trends at a single agricultural field and could be a powerful tool for estimating C-storage potential and reconstructing C storage on the Huang-Huai-Hai Plain of China.

Key Words: carbon dioxide emission, intensive cropping system, modeling, modified CQESTR model, soil organic matter

INTRODUCTION

Carbon and nitrogen cycles are very important to agricultural productivity and global climate stability. Human activities, for example, intensive farming and deforestation, also strongly affect these processes. On the Huang-Huai-Hai Plain of China the winter wheat-summer corn double cropping system has produced 99.77 million tons of grain, which has accounted for 80.0% and 27.5% of the total crop production in the region and the nation, respectively. Therefore, the sustainable utilization of agricultural soils in this area could affect China's food security. Since the early 1980s, some cropping practices have changed and caused soil organic matter (SOM) to rise in some sites (Kong *et al.*, 2003), but fall in other sites (Wang *et al.*, 1990) resulting in serious degradation of soil quality.

On account of the complexity of SOM turnover processes and the dynamic response of SOM to environmental conditions, simulation modeling has become an important tool to explore and evaluate the dynamics of SOM in agricultural soils. To study SOM numerous carbon and nitrogen models, for example, ROTHC, CENTURY, DAISY, VVV, DNDC, and ECOSYS, have been developed during the past 30 years (Powlson *et al.*, 1996). Mechanistic models, however, were often too complex, and it was

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difficult to obtain the required parameters or input data to run the models. For example, most of the above models needed information on daily soil water and temperature dynamics, which in many cases was not available, especially on the field scale. Since the 1980s, researchers in China have been searching for simple but useful mechanistic models to simulate SOM dynamics (Wang *et al.*, 1988; Yang and Janssen, 1997; 2000; Liu *et al.*, 2001), however these models still lack thorough validation on SOM dynamics under field conditions.

Douglas and Rickman (1992) first developed the D3R model to estimate the decomposition of cereal residues on the basis of cumulative degree-days calculated from daily mean air temperature. Curtin *et al.* (1998), under a greenhouse environment, used the D3R model to simulate the amount of wheat straw carbon remaining in the soil. Later, the D3R model was introduced into the CQESTR model to predict the effects of tillage and crop rotation on SOM decomposition and storage, using readily available input data at the field scale (Rickman *et al.*, 2001, 2002).

In this work, the CQESTR model was modified to evaluate the effects of intensive cropping on SOM dynamics at seven sites of the Huang-Huai-Hai Plain in North China and to estimate carbon dioxide emission from agricultural soils in this region.

MATERIALS AND METHODS

Research sites and long-term experiments

The Huang-Huai-Hai Plain covers an area of 320,000 km^2 in North China, with 18.67 million ha of farmland under cultivation. This is a highly productive agricultural area and is often referred to as China's breadbasket (Shi, 2003). Soil texture in the region ranges from sandy loam to loamy clay, and soil pH generally ranges between 7.4 and 8.6. The seven long-term experiments selected on this plain were: Changping (40° 02′ N, 116° 10′ E) of Beijing Municipality, Hengshui A and B (37° 42′ N, 115° 42′ E), Xinji A and B (37° 54′ N, 115° 13′ E) of Hebei Province, and Zhengzhou A and B (34° 46′ N, 113° 40′ E) of Henan Province. The mean annual air temperatures from 1981–2000 for Changping, Hengshui, Xinji, and Zhengzhou were 12.8, 13.2, 13.2, and 14.3 °C, respectively.

Soil samples were collected once a year after the wheat or corn crop harvest, and SOM was analyzed using a wet combustion procedure. Before the next planting, manure was spread on the soil surface and incorporated into the soil through plowing with adequate irrigation being provided during the crop growth season. The crop rotation system at the Changping site consisted of winter wheat in 1985 and 1986, and then changed to a cycle of three crops (winter wheat/summer corn and spring corn) within two years. Crop rotations at the other sites were a winter wheat–summer corn double cropping system.

Data required for the CQESTR model included: crop biomass (including roots applied to or remaining in the field after harvest), dates of crop residue or organic amendment application and tillage operations, fraction of the residues remaining on the surface after each tillage, nitrogen content of residues at initial decomposition, mean daily air temperature throughout the time of the study, soil texture, bulk density, and annual SOM content. Selected experimental characteristics of the seven sites that satisfied some of the data requirements are listed in Table I.

Estimation of crop biomass composition

In a study of crop biomass composition for winter wheat and summer corn Wang *et al.*, (1988) found ratios of grain yield to crop residue and of grain yield to root biomass in the top 20 cm to be 1:0.30 and 1:0.48 for winter wheat and 1:0.26 and 1:0.20 for summer corn, respectively. Crop yield in this study ranged from 3 750 to 4 500 kg ha^{-1}, and the ratio of winter wheat grain yield to straw biomass was 1:1.5 (Xin and Li, 1990; Campbell and Zentner, 1993). Table II lists the chemical properties of the organic material from results of this study and those of others (Wang *et al.*, 1989; Collins *et al.*, 1990) that are not observed in this work.