Modeling SOC and Corn Yield Changes Under Alternative Management in Northeast China from 1980-2010

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***Abstract*—Conservation of SOC is of significant importance for maintaining soil fertility thus sustaining food production, particularly when soil erosion has been a tremendous issue facing the world. With abundant fertile black soil in cropland, Heilongjiang ranked the 2nd in terms of food production among 31 provinces of China in 2010. Meanwhile, soil erosion appeared severe due to specific geographic and climatic conditions thus the erosion of black soils of northeast caught much attentions of the Chinese government and investigators. This study adopted DNDC model to quantify the impact of alternative management practices on the preservation of SOC. Four scenarios of management alternatives were set including Base scenario, CR50% (50% of the straw were returned to cropland), CR90% (90% of the straw were returned to cropland), and MA (3600 kg C/ha manure were amended), for a 31-yr simulation. Results indicated that among all the farming alternatives, the straw return ratio appeared most potential to preserve the SOC content. Manure amendment, even though proved effective in other studies which transformed SOC from a decreasing to increasing trend, was a less role in our study due to the SOC background value in various regions as well as the limitation of the DNDC model. It could be concluded that urgent actions should be taken to prevent further loss of SOC and DNDC would play as an essential role for decision-making.**

***Index Terms*—SOC, straw return, China, manure amendment**

I. Introduction

Nearly 40% of all agricultural land in the world has undergone anthropogenic soil degradation [1]. Soil degradation is considered as one of the primary causes for the decline of global productivity growth from ~2% during the green revolution to ~1% nowadays [2], [3]. Maintenance and enhancement of soil quality in croplands are critical to sustaining agricultural productivity and environmental quality for future generations[4]. Intensive cropping and lack of conservation farming are responsible for soil degradation in east and south Asia particularly in China [5]. Increasing inputs and technologies in modern agricultural production systems tend to compensate for losses in productivity derived from soil quality reductions. Nevertheless, increased agricultural inputs not only reduce economical beneficial but also increase the potential for further soil degradation [6]. Notwithstanding, long-term studies have consistently shown the benefits of manure amendment, residue management, optimal fertilization and crop rotation on maintaining agronomic productivity by increasing carbon inputs into the soil [7]-[9].

Black soils, originally characterized as a deep, dark A-horizon, are widespread in Northeast China and have been one of the most fertile agricultural resources in China. However, for more than half century, intense farming management has gradually degraded the cropland productivity [10]-[12]. Black soil is mainly distributed in Heilongjiang Province and Jilin Province, which accounts for 79.6% and 20.1% respectively [13], [14]. As the primary food production region, Heilongjiang ranked the 2nd among 31 provinces of China in 2010 according to the China Statistical Yearbook. And thus the erosion of black soils of northeast caught much attentions of the Chinese government and investigators [13], [15], [16]. Numerous researches has been focused on the cropland soil erosion or grain production of northeast of China. However, most of the conclusions are based on observed soil organic carbon (SOC) dynamics or crop yields from one or several sites rather than analyze them simultaneously [17]-[19]. Besides, seldom research studied the regional change of cropland soils [20] and the grain production [14].

SOC is chosen as the most dominating indicator of soil quality and agronomic sustainability due to its impacts on other physical, chemical and biological indicators of soil quality [21]. In addition, the distribution and storage of SOC carbon serve as basic information for the study of soil productivity, soil hydrological properties, and balance of greenhouse gases (GHG) [22]. Thus our research incorporated DNDC model, a process-based model initially used to calculate the GHG emissions of cropland that can simulate SOC change [20], [23], [24] and grain production [25] as well, to calculate the

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cropland SOC change and grain production of Heilongjiang during 1980 and 2010 and further revealed the impacts of various straw residue ratios and manure amendment amount on SOC conservation. Meanwhile, we examined the adaption of DNDC model to crop yield prediction in northeast China which was crucial to food security in China.

II. METHODS

A. Validation of DNDC Model on the Northeast China's Black Soil

Before the application of DNDC for regional simulation, the validation of the model should be conducted in one or several sites within the simulation area. In previous studies DNDC has been tested against SOC dynamics and grain production in several sites of China [24], [25]. Located in the northeast black soils region, Gongzhuling experiment station was chosen in our research to validate whether DNDC model could be applied in black soils. The Gongzhuling experiment station was located in the geographical coordinates of longitude 124°48′33.9″, north latitude 43°30′23″ and altitude 220m. The annual mean temperature was 5～6℃, with annual precipitation of 500～650mm. This station represented typical northeast black soils with medium level soil nutrient levels and the cropland management was non-irrigated dryland with rainfed agriculture. The primary farming systems for the Gonzhuling site were continuous cropping of corn or corn-soybean rotation.

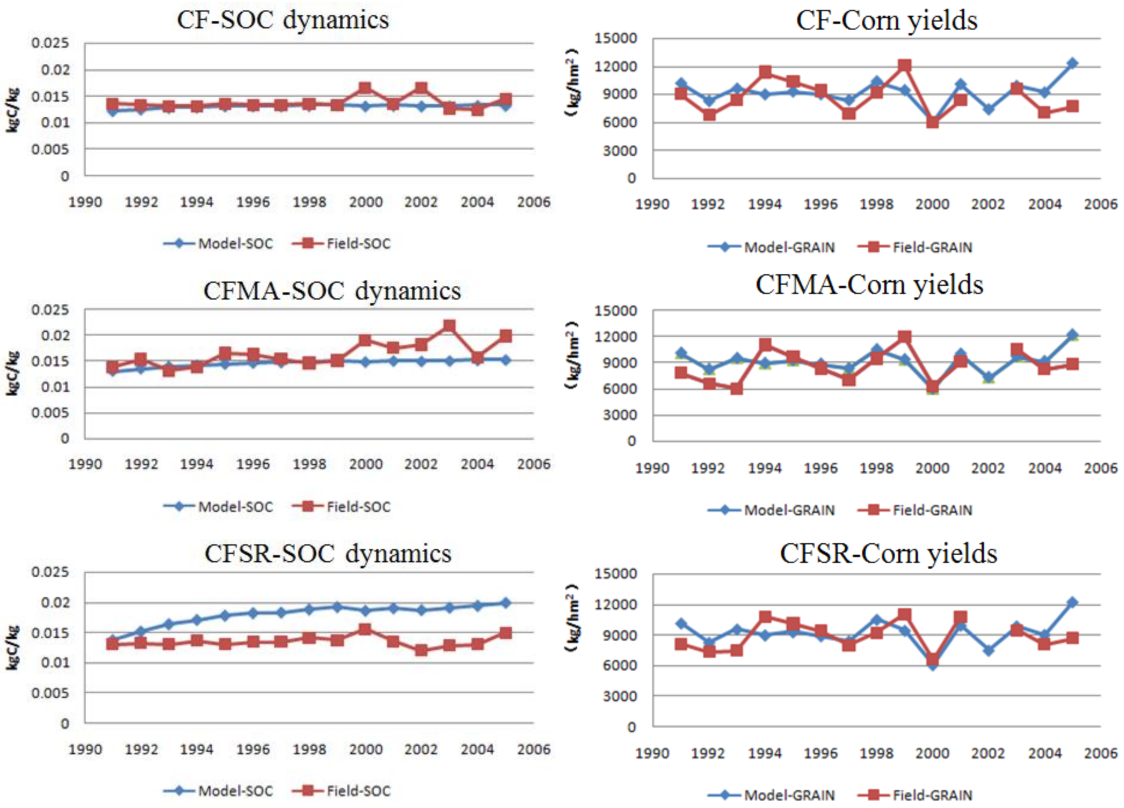


Figure 1. The comparison of model and observation results under various cropland management practices

The daily meteorological data for DNDC model were obtained from weather statistics of 1991 to 2005 in Siping weather station, China Meteorological Administration. The validation data including initial SOC and corn yields 1991 to 2005 were from the Gongzhuling experiment station.

The common cropland management practices for Gongzhuling experiment station were Conventional fertilization (CF), Conventional fertilization plus manure amendment (CFMA), and Conventional fertilization plus straw returning (CFSR). The application rates of fertilization and manure and the straw returning ratio were acquired as the model inputs: the fertilizer use amount was 165 kg N/ha and the manure amendment rate was approximately 5000 kg C/ha; the straw return ratio was 100% in the experimental station. Other management schemes like tillage, planting and harvest dates, irrigation have been embedded and parametrized into the DNDC model.

The comparison of model and observation results under various cropland management practices of Gongzhuling experiment station were shown in Fig. 1. The modeled results of SOC and grain yields under CF and CFMA fit a high degree with observed data. However, under CFSR, the simulated results of SOC were significantly higher than observed results while the grain yields agreed well. The obvious variation of SOC results between modeling and the observed data were partly due to the sieving process during the actual soil sampling for SOC, which deprived from that the litter did not fully decomposed while the model results incorporated all the litters into the calculation of SOC. Thus it would not affect the actual accumulation of SOC in the long-term simulation.

After comparing validation of DNDC in Gongzhuling experiment station under various cropland management measures, we concluded that DNDC model could capture the SOC change and corn yields in cropland of northeast China's black soils.

B. Sensitivity Test of DNDC Model in Black Soils

Previous simulation of regional cropland SOC change with DNDC model indicated that the annual SOC change of cropland was most sensitive to initial SOC content, crop residue incorporation and manure amendment [24]. In order to demonstrate how DNDC simulated the responses of SOC dynamics and corn yields to initial SOC and various farm managements in black soils of northeast China, we used the local soil and climate data of Gongzhuling station to construct a baseline scenarios for the sensitivity tests. Alternative scenarios were designed by varying parameters including fertilizer inputs and manure amendment amounts, the straw returning ratio and the initial soil organic carbon within commonly observed ranges in Heilongjiang and Jilin provinces.

The background scenarios of corn cropland managements of Heilongjiang and Jilin provinces were summarized in Table I. The dynamics of SOC and annual grain production were compared under four different scenarios (CFI, change of fertilizer input ; CMA, change of manure amendment; CSR, change of straw returning ratio; CIS, change of initial SOC).

TABLE I. RANGES OF PARAMETERS FOR SENSITIVITY TESTS

Input parameters	Range
Fertilizer inputs	50%base, base, 150%base , 200%base
Manure amendment amounts	base, 300%base, 600%base, 1000%base , 2000%base
Straw returning ratio	15% (base), 50%, 90%
initial soil organic carbon	0.01，0.015(base), 0.03, 0.06, 0.12

As showed in Fig. 2, the modeled corn yields remained almost unchanged under CMA, CSR and CIS scenarios which indicated that these management alternatives would not affect the grain production in short periods. While under CFI, increasing the application rate of chemical fertilizers from half of base scenario to the baseline essentially increased the grain production and 168 kg N/ha appeared an optimal rate for corn growth in black soils. On the other hand, the cropland SOC in depth 0-20cm changed dramatically under CMA and CSR scenarios. Manure amendment tended to increase the SOC content and 3600 kg C/kg manure (2000% of the Base) amendment per year would improve the SOC content from 0.015 to 0.025 in black soils in the 20-yr period. Moreover, straw returning was a more convincing practice which increased SOC content from 0.015 to 0.026 when the straw returning ratio went up to 50%. If the straw returning ratio reached 90%, the SOC content would arrive at 0.036 eventually. The initial SOC content was a vital indicator for the SOC dynamics. Fig. 2 illustrated that when the initial SOC was higher than 0.06 kg C/kg, the SOC declined by year under the base scenario. On the contrary, the SOC increased annually when the initial SOC was lower than 0.03 kg C/kg. And the SOC remained nearly unchanged when the initial SOC was between 0.03 and 0.06 kg C/kg. Since for more than half of the cropland areas in Heilongjiang and Jilin province, the mean SOC content was higher than 0.06 kg C/kg (Appendix A), preventing soil erosion would be more urgent. Similarly, previous research on the cropland SOC dynamics of China in recent 20 years demonstrated a 30-31% decrease of China's cropland SOC in the past 20 years particularly in northeast[26]. Meanwhile, changing chemical fertilizer input had no significant influence on the SOC in our sensitivity test. Results of the sensitivity test concluded that crop residue and manure amendment were effective measures to increase the SOC content in northeast China's black soils. In addition, corn yields would not be affected significantly.

C. Upscaling for Regional Simulation

In order to capture the SOC dynamics and corn yields of Heilongjiang province, a GIS database including all the input parameters (e.g., weather, soil property, crop acreage, and farming practices *et al.*) for DNDC modeling was constructed. The year 1980, the start year of the second national soil survey, was chosen as the baseline year for a 31-yr simulation of SOC dynamics and corn yields. The data of soil properties and the planting area of the crop of Heilongjiang province were from the second national soil census conducted in 1980s. The daily climate data derived from the China Meteorological Bureau. And the grain production amount of Heilongjiang province in 1986 was from the statistical yearbook.

As shown in Appendix A, the initial SOC value in Heilongjiang and Jilin were between 0.012-0.287 kg C/kg and presented an increasing tendency from south to north and from west to east. The soil clay content was between 3% and 34%. The soil pH and soil bulk density were uniformly distributed. Four scenarios of management alternatives were set including Base scenario, CR50% (50% of the straw were returned to cropland), CR90% (90% of the straw were returned to cropland), and MA (3600 kg C/ha manure were amended).

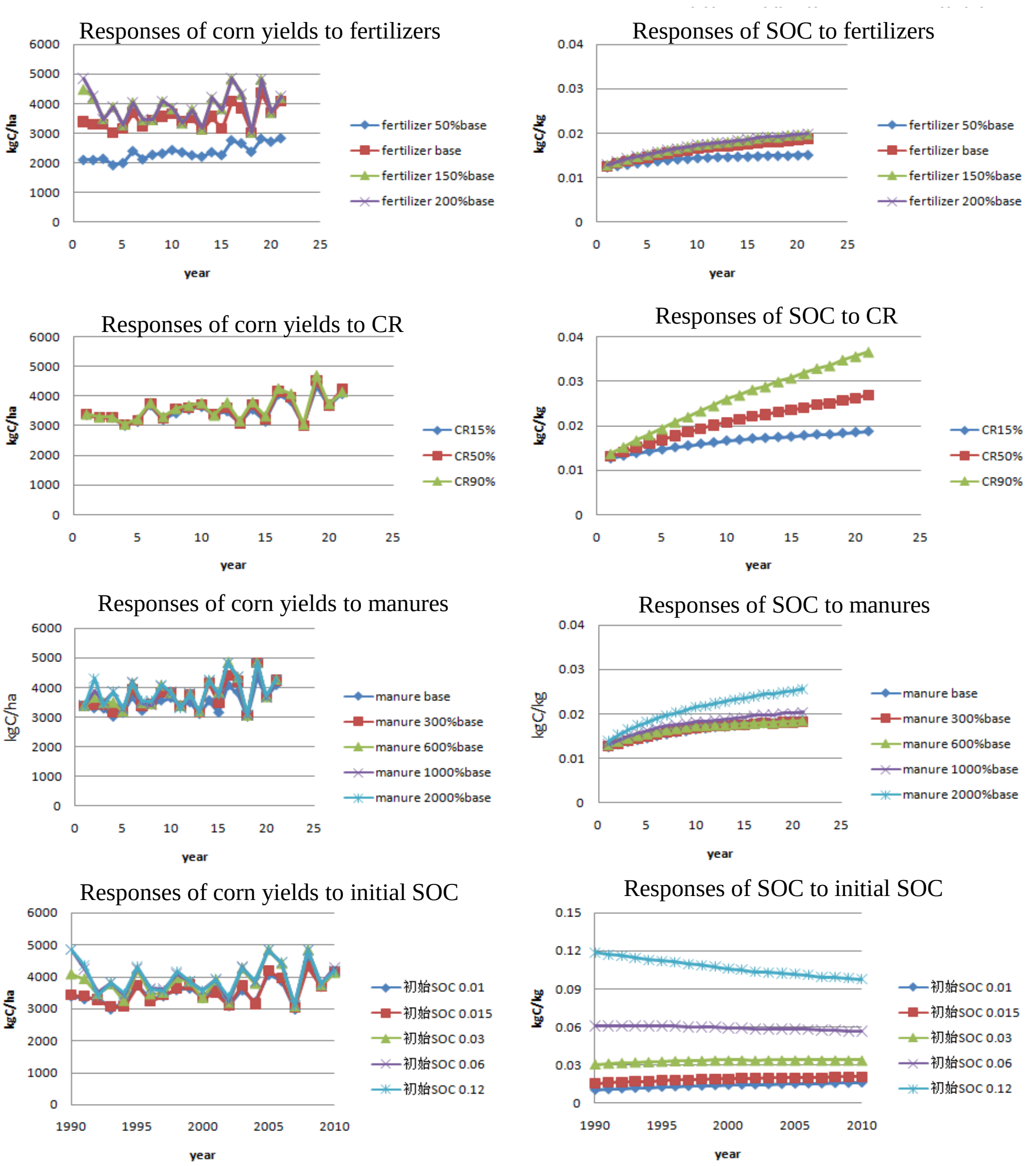


Figure 2. Sensitivity tests

III. Resultes and Discussion

A. SOC Dynamics

As shown in Appendix B, for the baseline scenario, the SOC content experienced a gradual descending tendency during the 31-yr simulation. For the CR50% scenario, the decreasing trend of SOC contents was suppressed, particularly in some parts the SOC appeared increasing. When straw were 100% returned to fields, SOC had been accumulating in most parts of the region except for several counties in the Songhuanjiang plain. In the MA scenario, SOC dynamics appeared consistent with that in the baseline scenario, which indicated that the manure amendment might not act as an essential practice to conserve SOC in Heilongjiang Province. This accorded with the sensitivity test and might derive from the high background value of SOC. In addition, the current DNDC could not capture the dynamics of soil properties, which might in turn influence the nutrient uptake, crop growth and litter production. Thus controversial conclusion had been drawn and argued that the application of manure would influence the physical and chemical properties of soil. This represented a further development of DNDC.

The initial SOC content was lower but decreased more dramatically in Songnen Plain than that of Sanjiang Plain. This might derive from specific environmental factors and climatic conditions. Songnen Plain covers the main region with black soil. Environmental factor including the low clay fraction, loose soil conditions, high resistance to corrosion and climatic factors like intense precipitation, the large catchment area both contribute SOC lose in this area.

B. Corn Yield Simulation

The comparison of modeled and observed corn yields in Heilongjiang in 1986 were shown in Fig. 3. It could be inferred that DNDC could capture the yield dynamics and the R square reached 0.67, thus DNDC would act a vital tool to predict corn yields for Heilongjiang Province.

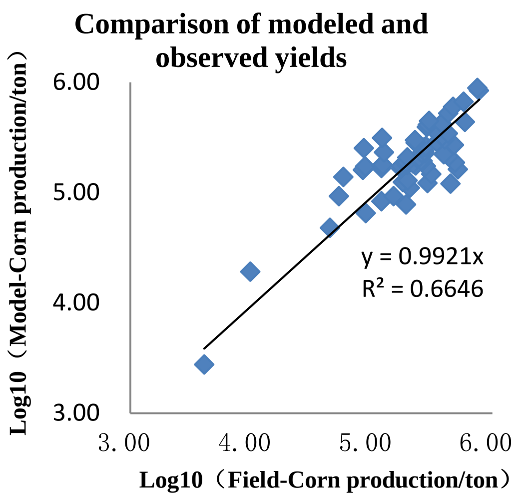


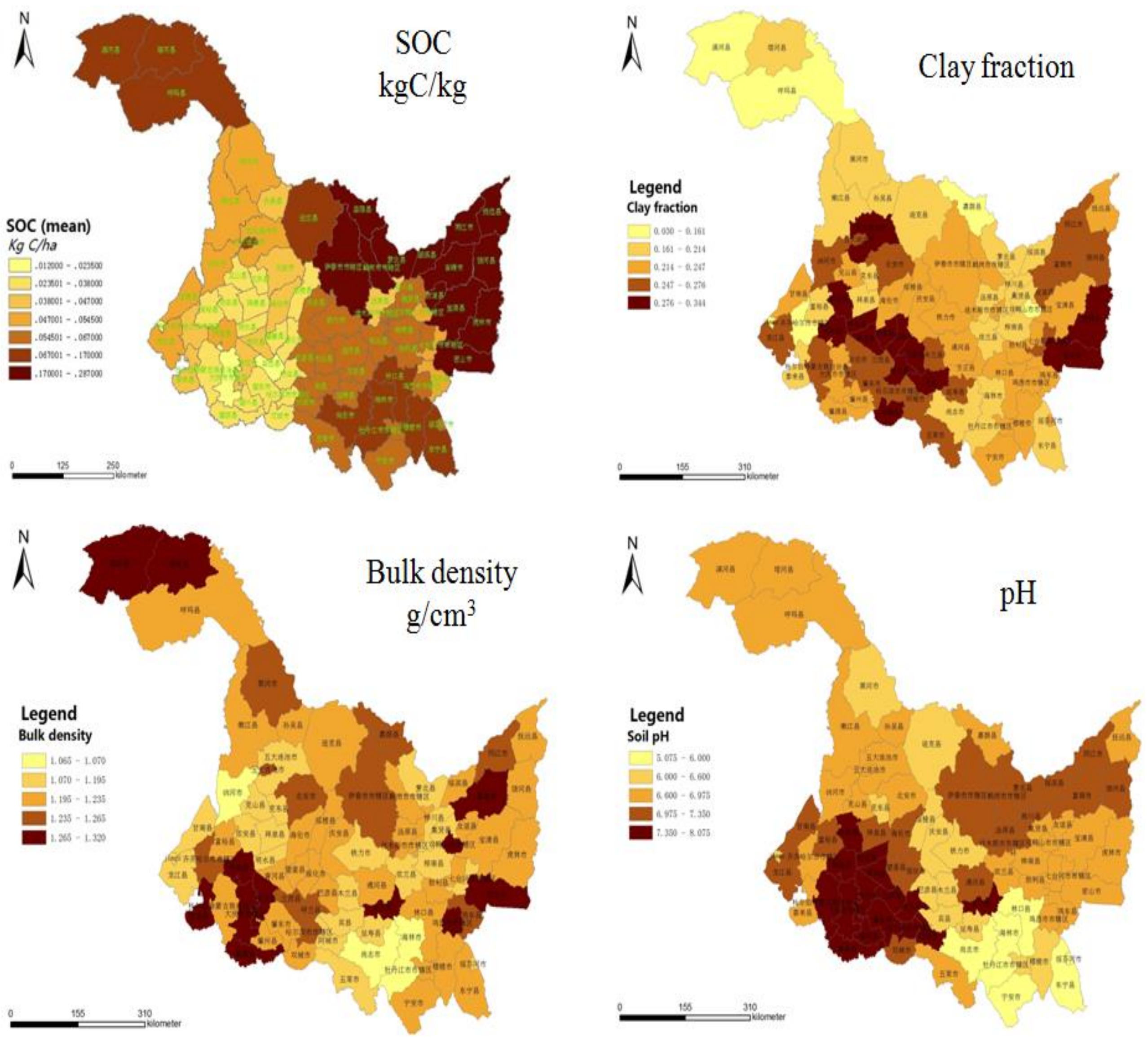
Figure 3. The comparison of modeled and observed corn yields in Heilongjiang in 1986

IV. Conclusions

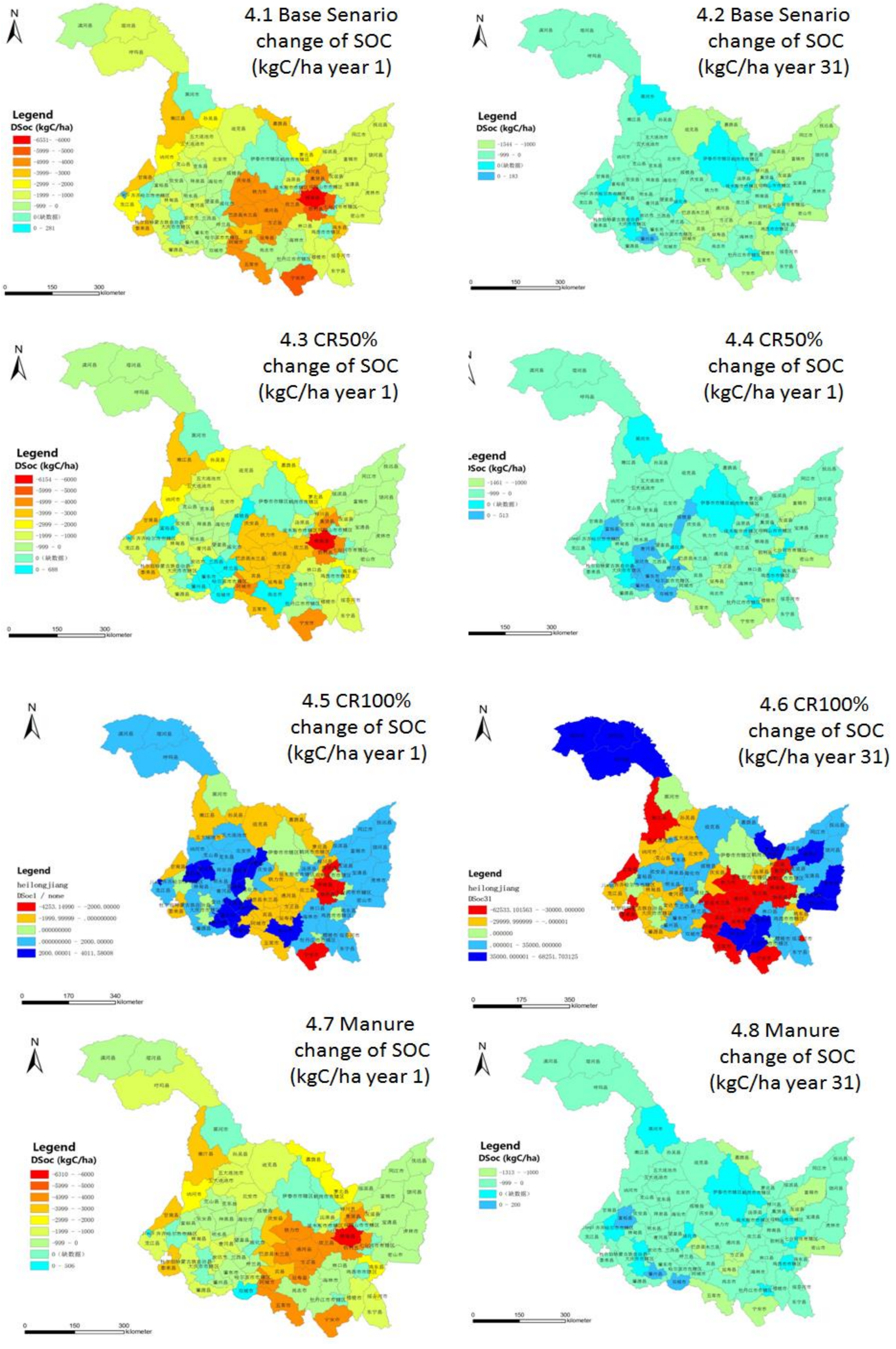
Using the DNDC model, our research demonstrated that among all the farming alternatives, the straw return ratio appeared most potential to preserve the SOC content. Manure amendment, even though proved effective in the cropland in Shanxi [20] which transformed SOC from a decreasing to increasing trend, was a less role due to the SOC background value in various regions as well as the limitation of the DNDC model. The high simulation accuracy of corn yields enabled DNDC to be a powerful tool for yield prediction and evaluate the optimal management alternatives in terms of both food production and environment benefits.

Conservation of SOC is of significant importance for maintaining soil fertility thus sustaining food production, particularly when soil erosion has been a tremendous issue facing the world. In addition, SOC dynamics influence carbon balance between the atmosphere and land which further induce climate change. This research in Heilongjiang Province has widened the application of DNDC in black soil and demonstrated the urgent actions to suppress the loss of SOC from cropland.

Appendix A: The Greenhouse Gas Emission Change in 2010



APPENDIX B: SOC DYNAMICS UNDER VARIOUS MANAGEMENT ALTERNATIVES FROM 1998 TO 2010



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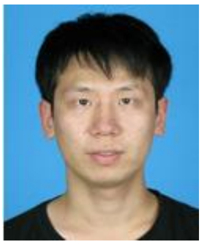

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