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YSSP Report

Young Scientists Summer Program

Quantifying GHG emission from paddy field in China under climate change: based on the coupling of DNDC, DSSAT and AEZ models

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Contents

Abstract

Climate change and food security are critical issues to the world, and have aroused the interest of scientists, policymakers, and ordinary people. Rice is the major food in the Chinese diet, the Chinese government and scientists had put great efforts on improving the rice production to guarantee the food security, but rice paddy field also emits great amount of greenhouse gases (GHGs) to the atmosphere. So it is necessary to study how to reduce the GHGs emission while enhance the food security. In this research, a process-based model, Denitrification-Decomposition model (DNDC), is used to simulate rice growing and GHG emission in rice fields in China. However, DNDC is a site-level agroecosystem model that lacks rice cultivar parameters to represent crop diversity in China. In order to update and up-scale the DNDC model to evaluate the GHG emission from paddy field in China, Decision Support System for Agro-technology Transfer (DSSAT) and Agro-Ecological Zones (AEZ) models are used to provide abundant and detailed cultivar parameters and a more reliable upscaling method. By using the Generalized Likelihood Uncertainty Estimation module in DSSAT and reclassification of cropping zone map, which is based on original cropping zone map in AEZ, rice cultivar parameters and input data of each grid are translated into DNDC successfully. Then the updated DNDC model is applied at both site and regional scale. The site-level simulation result shows that new cultivar parameters improves the performance of the DNDC model greatly in each station. Furthermore, the application of nitrogenous fertilizer is higher than actual crop requirement by 5% to 35%. If the application of nitrogenous fertilizer is reduced to a balanced level, the N_2O emission will decrease significantly, the result shows an average reduction of 36% in nine stations. The regional-level result shows that the spatial distribution of rice yield loss and N_2O emission reduction are consistent with the site-level result in most regions. In the northeast area of China, less fertilizer application will reduce N_2O emission as well as rice yield. The balanced level of fertilizer application may decrease under A1B scenario in the future. The more advanced management practices should be considered and applied to find a scientific approach to mitigate CH_4 emission. Furthermore, crop rotation and different climate scenario datasets should be studied in the future.

Key words: climate change; GHG emission; rice yield; model coupling;

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About the Author

Yilong Niu received his bachelor's degree in landscape horticulture from Shanghai Institute of Technology, 2012. And he is currently a third research master in Shanghai Institute of Technology. His main research interests focus on the agricultural model coupling and the interrelationship between climate change and agricultural greenhouse gas emission, especially in paddy fields.

Quantifying GHG emission from paddy field in China under climate change: based on the coupling of DNDC, DSSAT and AEZ models

Yilong Niu

1 Introduction

Climate change and global warming impact greatly influenced the ecological system and human activity, it has become a critical research topic for scientists and policymakers in recent years. Global mean surface temperature has increased over 0.89℃ from 1901 to 2012 (IPCC. 2013). The most important driving factor of this warmer climate is greenhouse gases (GHGs) emission from anthropogenic activities, such as industrial production, fossil fuel consumption, transportation and agricultural practice. Agricultural practice is one of the main source of direct non-CO_2 GHG emissions (Smith, Trines. 2007; Smith. 2012). Warmer climate also has great impact on agricultural practice and crop production, even further influences the agricultural GHGs emission (Verburg, Chen et al. 2000; IPCC. 2014). Therefore, it is necessary to identify the interrelationship between climate change and agricultural GHG emission.

This research aims to study agricultural GHG emission from paddy fields in China. China accounted for 18.7% and 28.6% of the total rice growing area and worldwide rice production respectively in 2012. Rice production is the second largest among all the cereals in China (FAO. 2015). Because of rapidly urbanization and accelerating economic growth, ensuring food security in China is becoming more important. Rice is the major food in China and its production is critical to the food security. But current paddy rice practice of basin irrigation and excessive fertilizer application bring great CH_4 and N_2O emission. Statistics shows that agricultural practice contribute to 31.5% of the total CH_4 emission in 2005, while CH_4 emission from paddy field is the second major agricultural GHG emission resource in China after livestock enteric fermentation(NDRC. 2013). Therefore, it is important to balance the food security concern and agricultural GHG emission reduction, and improve the paddy field rice practice to control the GHG emission in paddy field and minimizing the rice yield loss.

To balance the trade-off relationship, some scientific and robust approaches should be found and employed. At site and farm level, most studies take observations from experiments and analyzing them, but such methods are not applicable to regional and national levels. Agricultural system models should be employed to simulate the crop growth dynamics and to evaluate agricultural GHG emission and food security trade-offs at the regional and national level in a systematical way. Previous studies from all over the world has employed many GHG emission model, such as ROTH-C, CENTURY, DNDC and GAINS, to estimate the crop growth and the related GHGs emissions quantitatively. In this research, the Denitrification-Decomposition(DNDC) model(Li. 2001) is employed to simulate rice growth and to evaluate the non-CO_2 GHG emission in China. The DNDC model is a biogeochemistry process-based model that simulates crop growing process and dynamics of chemical reaction in the soil based on biogeochemical mechanisms. The model is capable of simulating GHG emission from crop fields at site and farm level. With the development in the three decades, the Geographic Information System (GIS) technology is employed to prepare spatial weather and soil input data for the DNDC model regional application (Zhang, Li et al. 2011).

However, for regional and national level research, the default cultivar parameters in DNDC cannot represent richness and regional diversity of cultivar parameters in different parts of the research area. Besides, previous GIS-based upscaling method and the Most Significant Factor method for regional simulation in DNDC(Li, Xiao et al.

2003; Giltrap, Li et al. 2008) always focus on impact from climate and soil parameters, but do not fully consider uncertainties from crop cultivar input parameters and the DNDC modeling procedures(Heuvelink. 1998; Fumoto, Kobayashi et al. 2008). To improve the regional performance of the DNDC and estimate the GHGs emission, the Decision Support System for Agro-technology Transfer(DSSAT) model(Jones, Hoogenboom et al. 2003) and the Agro-Ecological Zone(AEZ) model(Fischer, Nachtergaele et al. 2008) will be employed to provide several detailed cultivar parameters and more reliable upscaling method. Tian et al.(2014) employ this cross-scale coupling method to accomplish the DSSAT and AEZ fusion and validated it. So similar upscaling strategy will be applied in this study.

This report is organized as follows. Section 2 shows all the data. Section 3 presents the method of cultivar parameter translation and up-scaling process. Section 4 discusses the results and evaluate the performance of the proposed coupling model. Section 5 provides conclusions and limitations of this research. Section 6 discusses the possible future research.

2 Model and dataset

2.1 DNDC model

The Denitrification-Decomposition(DNDC) model was originally developed by Li et al.(1992a, 1992b) and was first used to simulate the N_2O emission from agricultural system(US EPA. 1995). DNDC is a process-based model that focus on describing biogeochemical process and simulating redox-reaction in agro-ecosystem, especially on the process of carbon and nitrogen. With the two decades of development and updating, several useful modifications have been incorporated into the DNDC model. At present, the DNDC model has an array of sub-models. For instance, plant growth sub-model includes the procedure of N-uptake, water uptake and root/stem/leaf/grain daily growth. Aerobic decomposition sub-model shows the process of soil organic carbon reaction with oxygen. Fermentation sub-model describes CH_4 generation, transportation and oxidation in the soil(Li. 2000). The model has been employed by other researchers that from all over the world to simulate crop production, gases emission and soil organic carbon changing. To assess the impact of environmental factors on food security, climate change and non-point pollution(Babu, Li et al. 2006; Giltrap, Saggar et al. 2008; Levy, Mobbs et al. 2007; Li, Zhuang et al. 2001; Pathak, Li et al. 2005;). The input parameters required by the DNDC model are described below.

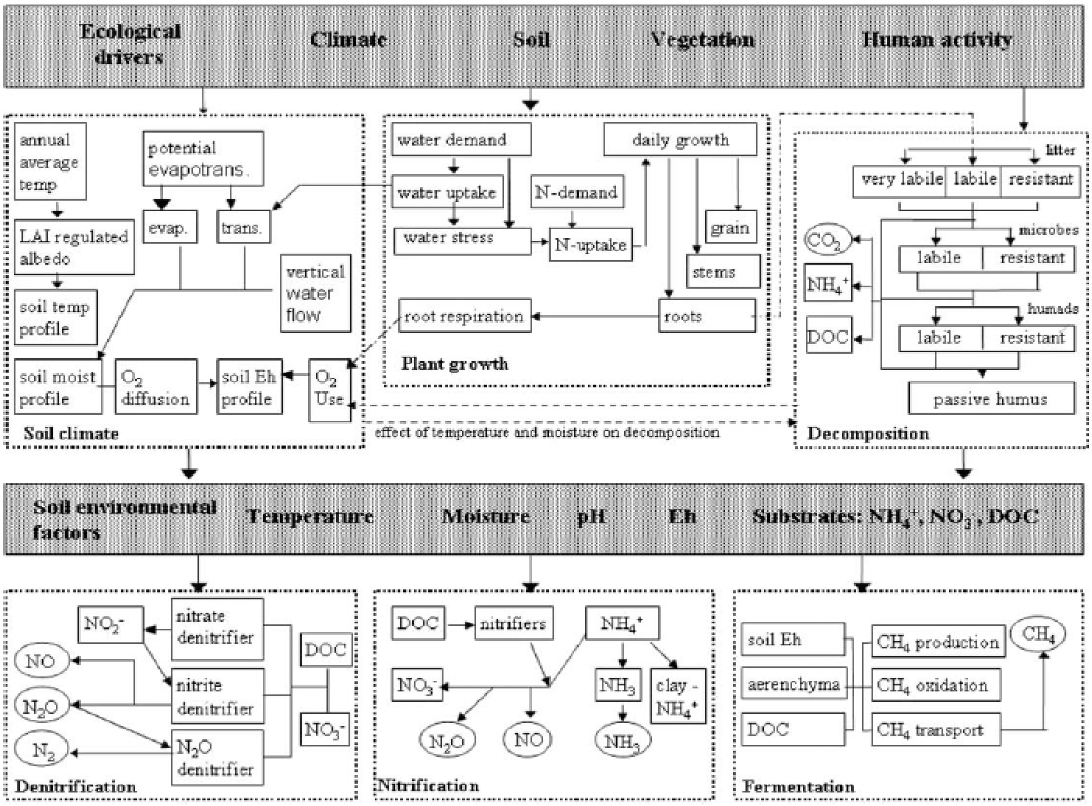

Figure 1. Schematic diagram of DNDC model structure(Li. 2000)

2.2 DSSAT model

The Decision Support System for Agro-technology Transfer(DSSAT) (Jones, Hoogenboom et al. 2003) was originally developed by the International Benchmark Sites Network for Argo-technology Transfer project(IBSNAT 1993). DSSAT is one of the most famous crop dynamic models and has been employed by researchers worldwide(Thorp, Dejonge et al. 2008; Seidl, Batchelor et al. 2001;). The core of the DSSAT system consists of 17 crop simulation models. This research employs the Crop Environment Resource Synthesis(CERES) model, which simulates cereal crops such as wheat, rice and maize. The CERES model simulates growth and development of cereal crops within a homogeneous plot on a daily time step. Crop yield is computed on harvest day. Required input information includes crop cultivar, management practices, environmental factors and weather conditions. The Generalized Likelihood Uncertainty Estimation(GLUE) method in DSSAT(He, Jones et al. 2010) will be employed to compute rice cultivar parameters and to translate the results into DNDC input format. These findings could supplement the parameters from observed record data.

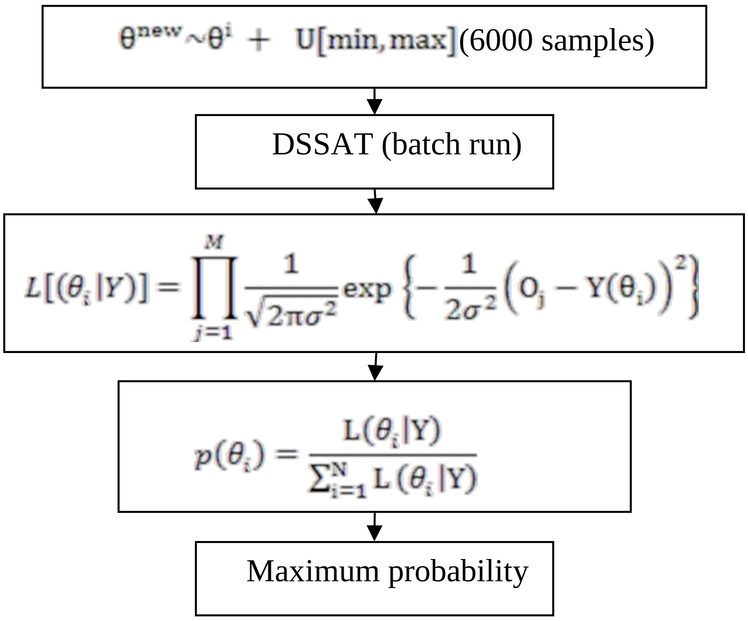

Figure 2. Flowchart of the GLUE method, where θ^i is the i-th parameter set; $(L(\theta_i|Y))$ is the likelihood value of parameter set θ^i, given observations O and with the predicted value of Y; N is the total number of parameter sets generated by the program, $Y(\theta_i)$ is the model output using parameter set θ^i; O is the observation; O_j is the j-th observation of O; σ^2 is the variance of model error; and M is the number of observations; $p(\theta_{i})$ is probability or likelihood weight of the i-th parameter set θ^i(Tian, Zhong et al. 2014)

2.3 AEZ model

The Agro-Ecological Zone(AEZ) model was jointly developed by the International Institute for Applied Systems Analysis(IIASA) and the Food and Agricultural Organization(FAO) of the United Nations(Fischer, van Velthuizen et al. 2002). AEZ is an up-bottom model that focuses on regional and national crop yield and production simulation under actual and potential situations. The AEZ model combines environmental factors and crop systems, and computes crop yield and production with different levels of input configuration and water supply systems. In this research, crop cultivar parameters in Land Utilization Types(LUTs) from AEZ will be employed to enhance the crop cultivar parameters in DNDC. Meanwhile, the cropping zones in China, which have been defined by AEZ, will be employed in the upscaling method to assist the DNDC model in accomplishing agricultural GHG emission for regional and national levels.

2.4 Climate data

Observed daily climate data (1981-2010) are employed to construct historical climate input files. Data were obtained from more than 700 meteorological stations nationwide and provided by the Chinese Meteorological Data Center. Input weather parameters include minimum and maximum air temperature, solar radiation, precipitation and relative humidity. The parameters required in DNDC include daily precipitation, maximum air temperature and minimum air temperature. Meanwhile, for simulation under future scenario, the IPCC SRES A1B scenario is employed to project the impact of climate change. Predictions come from Providing Regional Climates for Impacts Studies(PRECIS). PRECIS was designed by the UK Hadley Centre to run on a desktop personal computer to generate detailed climate change predictions at a 50×50 km scale. PRECIS is driven by initial and boundary conditions computed with HadAM3P, which is the updated version of the atmospheric component of the Hadley Centre coupled ocean-atmosphere GCM-HadCM3(Xu et al., 2006). In this research, PRECIS was used for a geographical window covering China to predict changes in precipitation and daily temperatures. With the PRECIS-simulated daily weather for 1981 to 2010 representing the present (baseline) climate, future daily weather simulations are generated from 2010 to 2040. The generally good agreement between observed and simulated data provided confidence in the results obtained when PRECIS was used to project climate change over China into the twenty-first century using described in the IPCC Special Report on Emission Scenarios (SRES) for future greenhouse gas emissions. Both historical and future climate data are interpolated into a 10km grid format.

2.5 Crop management data

Crop management data are critical to crop growing simulation and agricultural GHG emission from soil. Crop management practices in paddy fields from nine agro-meteorological stations from 1981 to 1999 were provided by Chinese Meteorological Data Center. The data were employed to enhance crop cultivar parameter library in DNDC and provide management input parameters during simulation. Management information includes sowing and harvesting dates, fertilizer application and irrigation method. For regional simulation, crop management practices in observation stations are generally better than the average within neighboring areas of the station (Tao, Yokozawa et al. 2006). Because the research goal is finding a GHG emission mitigation approach without decreasing yield, crop management practices in the station will represent crop management practices in the cropping zone.

Table 1. rice stations locations

Province	*Site*	*Longitude(°)*	*Latitude(°)*
Anhui	Hefei	117.23	31.87
Guangdong	Guangzhou	113.47	23.05
Henan	Xinyang	114.08	32.12
Jilin	Yanji	129.47	42.88
Jiangsu	Zhenjiang	119.47	32.18
Jiangxi	Nanchang	115.95	28.55
Liaoning	Dengta	123.32	41.42
Sichuan	Chengdu	103.83	30.7

Shandong	Linyi	118.35	35.05

2.6 Soil data

Harmonized World Soil Database (HWSD) is employed as the soil input data into DNDC, which is also employed by AEZ model. HWSD was developed by the Land Use Change and Agriculture Program of the International Institute for Applied Systems Analysis (IIASA) and the Food and Agriculture Organization of the United Nations (FAO). HWSD provides reliable and harmonized soil information at the grid cell level for the world, with a resolution of 1km ×1km for China. (FAO/IIASA/ISRIC/ISSCAS/JRC 2009). Soil input parameters that which DNDC requires include soil texture, basic profile characteristics of soil layer, bulk density, clay fraction, soil organic carbon content and pH. Because some additional soil parameters are required, other soil databases are also employed, such as ISRIC-WISE(Batjes 2009). Similar to climate data, soil input data are interpolated into a 10km grid format.

3. Methodology

3.1 Flow chart of the methodology

The operational steps for updating and up-scaling of the DNDC model are shown in Figure 3. The critical steps are as follows. First, calculation and translation of rice cultivar parameters are conducted for nine agro-meteorological stations based on DSSAT and AEZ. Second, a rice cultivar map is generating according to cropping zones reclassification. The map is based on the original cropping zones obtained from AEZ and the observation station locations. Third, using the updated and upscaled DNDC model, GHG emission results are simulated under different levels and scenarios.

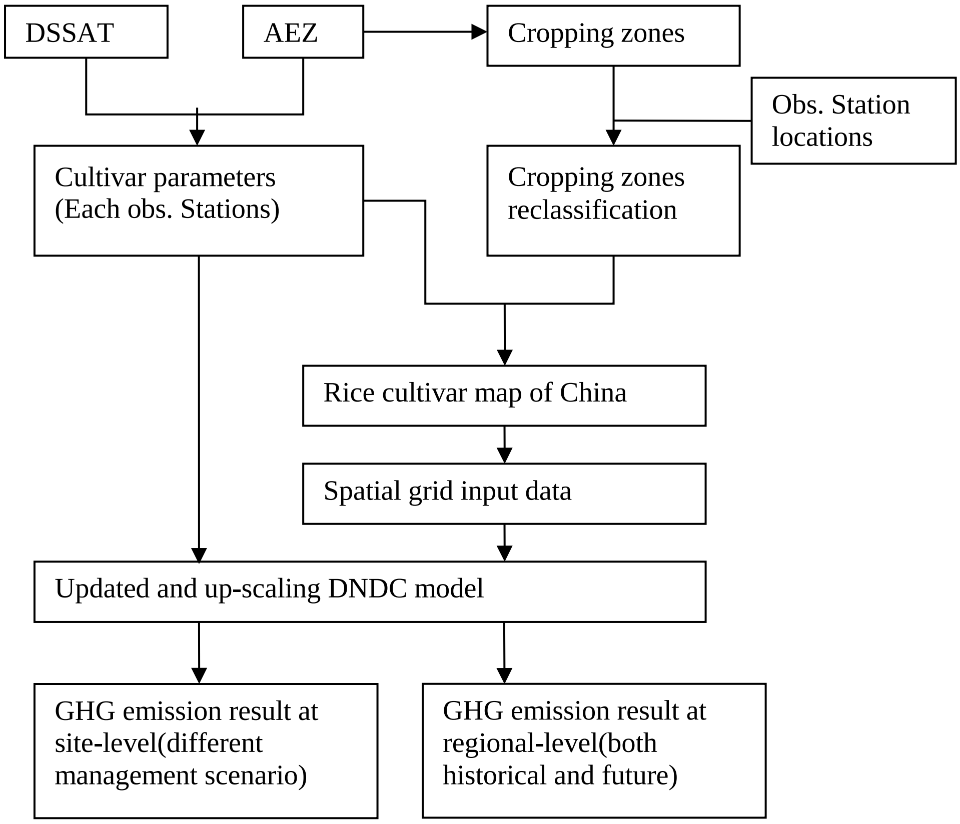

Figure 3. Flowchart of the Methodology

3.2 Rice cultivar parameters calculation

Proper parameter estimation would ensure accuracy of model prediction (Madson, Wilson et al. 2002). For the original DNDC model, the research target is a biogeochemical process in different ecosystems, such as agriculture and forestry. Therefore, only one array of default parameters is used to describe crop cultivar for each kind of plant in the crop cultivar library from original DNDC model. For site level simulation, a scientific approach to obtain accurate simulation result modifies the default parameters based on observed data in this site. However, for regional and national level simulation, no matter which station was chosen to provide rice cultivar parameters, this station is unable to present the entire rice cultivar diversity at a large scale. A rice cultivar database should be constructed to advance GHG emission simulation from rice fields in China.

Key rice cultivar parameters for GHG emission simulation in DNDC model includes maximum biomass of each part(grain, leaf, stem and root), carbon nitrogen ratio of each part, optimum temperature for rice growing and accumulative degree days for maturity(TDD). Maximum grain biomass should be calculated firstly because long-term yield records at agro-meteorological stations are actual yields, not potential yields. The GLUE module in DSSAT model is employed to estimate potential yield of each station based on observed data. Meanwhile, harvest index(HI) is estimated. With the potential yields and HI, maximum biomass of other parts would be estimated. The second step is computing the carbon nitrogen ratio of each part. Because no record data are available on carbon nitrogen ratio in agro-meteorological stations, the statistical record data of nitrogen uptake and rice production from FAO, International Rice Research Institute(IRRI) and United States Department of Agriculture(USDA) are employed to estimate the range of carbon nitrogen ratio for rice. The last step is computing temperature parameters of each cultivar. Optimum temperature for rice growing is translated from reference temperature in AEZ directly and the TDD is calculated based on the daily weather data of each rice growing season from 1981 to 2010.

Crop_name	grain-bio	Harvest	total biom	grain_fr	leaf_f	stem_	root_	totalC	N demand	Optim	TDD
Rice-AHHF	11436.33	0.5273	25516.4052	0.4482	0.201	0.201	0.15	52.658	209.588	27	3859
Rice-HNXY	11597.39	0.5179	26344.902	0.44021	0.205	0.205	0.15	52.913	215.382	25	3776
Rice-JLYJ	10761.25	0.5311	23840.098	0.45139	0.199	0.199	0.15	52.555	196.186	22	2965
Rice-JSZJ	11539.5	0.5078	26737.1765	0.43159	0.209	0.209	0.15	53.189	217.479	25	3884.3
Rice-JXNC	9055.583	0.6058	17585.4902	0.51495	0.168	0.168	0.15	50.522	150.094	30	2594.95
Rice-SCCD	9883.211	0.5644	20602.291	0.47971	0.185	0.185	0.15	51.649	172.349	25	3873.8
Rice-SDLY	12396.41	0.4958	29415.9862	0.42142	0.214	0.214	0.15	53.515	237.829	25	3808.6
Rice-LNTT	12908.6	0.5521	27504.5882	0.46933	0.19	0.19	0.15	51.982	228.716	22	3471.55
Rice-GDGZ	7801.4	0.5486	16731.1373	0.46628	0.192	0.192	0.15	52.079	138.883	30	3351.45

Figure 4. The new rice cultivar library in DNDC

3.3 Cropping zones re-classification

The cropping zone system defines the land use units by climate, soil and terrain characteristics that are relevant to specific crop production. Cropping zones often represent the spatial distribution of crop cultivars in historical climate conditions(Tian, Zhong et al. 2014). In this research, the original rice cropping zone map of China which is defined by AEZ model is employed. Given that nine stations are available out of 14 cropping zones, cropping zones reclassified to make suitable match between cropping zones and rice cultivars at nine agro-meteorological stations.

The methodology of re-classifying followed certain guidelines. First, if a station is in a cropping zone, the rice cultivar parameters of this cropping zone are the same as those in this station. Second, if no station is in a zone, the closest suitable cultivar station is chose for the zone. The original rice cropping zones map of China are presented in Figure 5 and the reclassified one is shown in Figure 6.

After reclassification, the cropping zone map of China is matched with the land use map of China in 2000, HWSD map and climate data map. Because the research region comprises rice fields in China, rice field grid would be chosen from the land use map of China. Finally, the rice cultivar map of China is presented in Figure 7, and the input information of each grid cell will be generated.

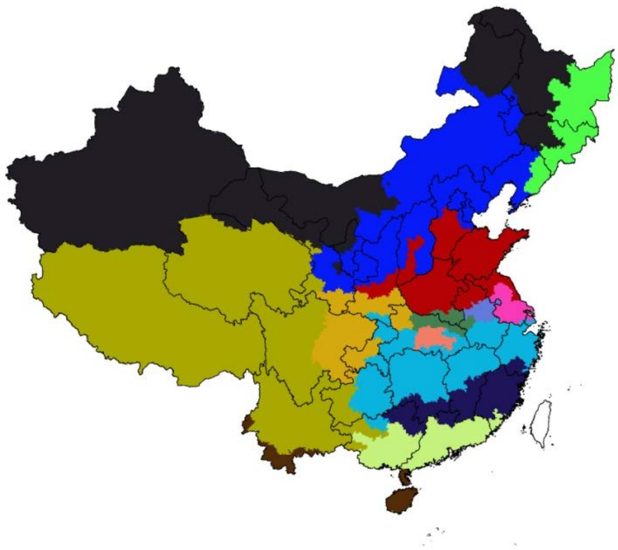

Figure 5. Original rice cropping zones map of China

Figure 6. Reclassified rice cropping zones map of China

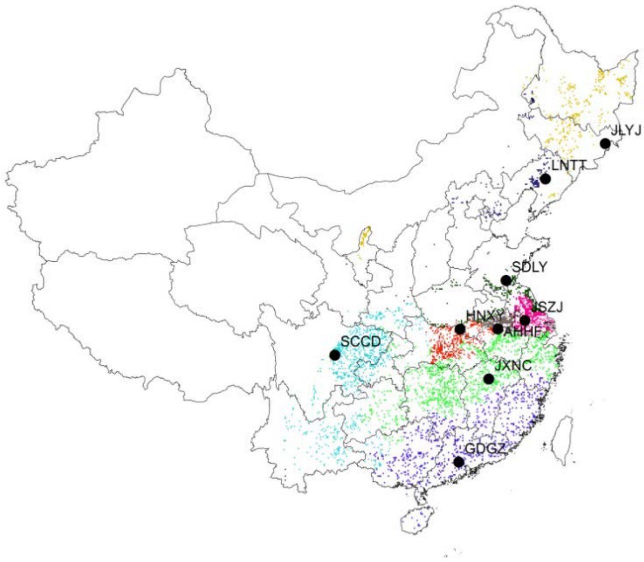

Figure 7. Rice cultivar map of China

4. Result and analysis

4.1 Yield validation

The accuracy of the updated DNDC model should be tested and validated before simulating rice growth and GHG emission. Observed data from the nine agro-meteorological stations are employed. The ideal field management parameters are used as input to ensure the rice growing without any water and nitrogen stress. This choice is made in the simulation to ensure that crop growth is only influenced by weather and soil factors. The observed maximum attainable yield from 1981 to 2010 is chosen to compare with the simulation result. The Relative Absolute Error(RAE, percentage, Equation 1) is selected to evaluate the departure between observed data and simulation values.

$$\mathrm{RAE} = \frac{|\mathrm{Obs}-\mathrm{Simu}|}{\mathrm{Obs}} \times 100\% \,, \qquad (1)$$

where Obs is the observation values and Simu is the model simulated values.

The value of RAE in total 9 stations are calculated (Table 2 and Figure 8). The result shows that the range of average RAE for yield in nine stations is 1.51%-8.14%. The simulation yield without water stress and nitrogenous stress is more or less equal to the observed maximum attainable yield. Hence, the updated DNDC with new cultivar parameters from observed record and DSSAT and AEZ model could simulate rice growth accurately and properly in all stations.

Table 2. The average RAE values in 9 stations

Site	*average RAE*
AHHF	5.45%
HNXY	3.20%
JLYJ	4.68%
JSZJ	4.69%
JXNC	2.25%
SCCD	1.51%
SDLY	7.72%
LNTT	4.72%
GDGZ	8.14%

Figure 8. Comparison between maximum observed record and simulation result in 9 stations

4.2 Site-level simulation

The site-level simulation focuses on rice growth under different scenarios of nitrogenous fertilizer application, which is the main factor impact on rice growth and N_2O emission in rice fields. Excessive application of nitrogenous fertilizer is also a main contributor to water and soil pollution. Therefore, finding the balanced level of fertilizer application is meaningful for crop growing and agro-ecosystem development sustainability. In this simulation, maximum values of fertilizer application in different stations from observed record are chosen as the control group, which means the fertilizer application is 100%, and other groups are generated based on variation from the control group. In every station, 21 groups needs simulation. The result of rice yield in AHHF station under different fertilizer scenarios from 1981 to 2010 is presented in Figure 9, the result shows that in AHHF the balanced fertilizer application is 85%, which means rice yield will not decrease if nitrogenous fertilizer application reaches this level. With this simulation, the balanced fertilizer application in each station could be calculated. The balanced fertilizer application level of each stations is presented in Figure 10. The result shows that fertilizer application in all nine stations are higher than actual crop requirement by a scale of 5% to 35%. The historically most balanced station is SCCD. In GDGZ and JLYJ, the extreme application of nitrogenous fertilizer needs to be controlled.

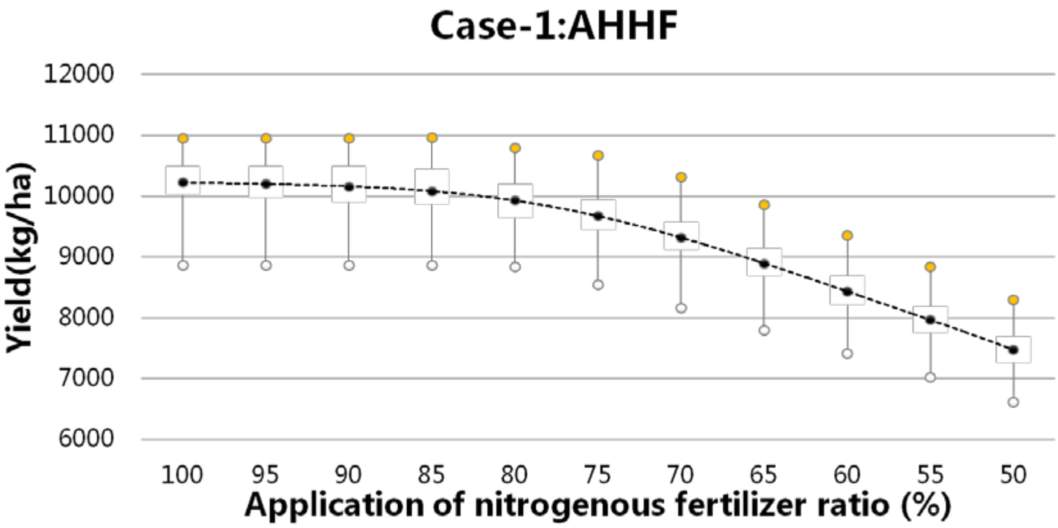

Figure 9. Yield in AHHF under different fertilizer application scenarios during 1981 to 2010

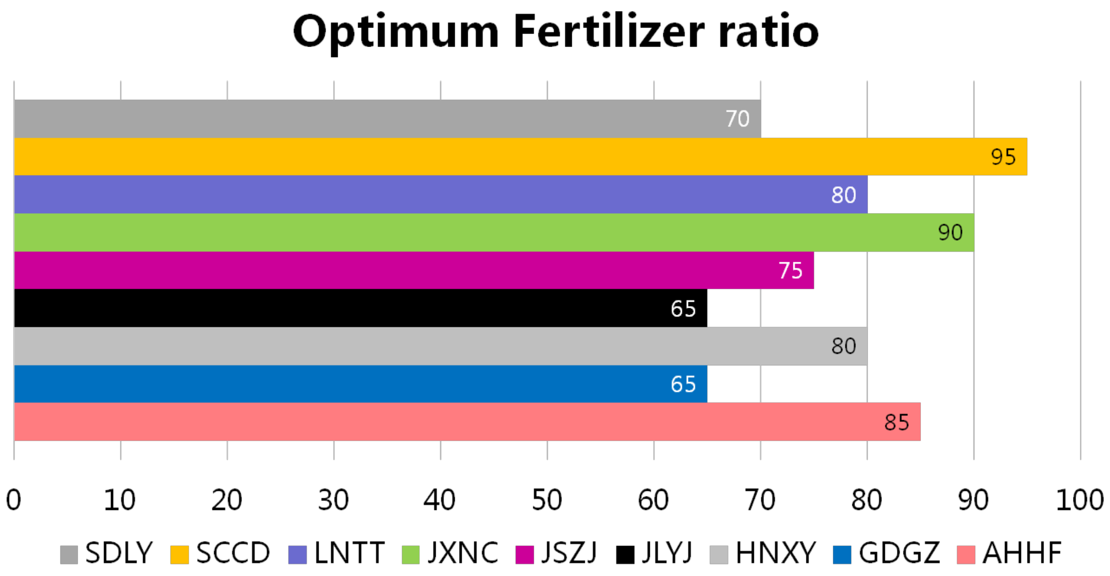

Figure 10. The balanced fertilizer application level in 9 stations

With the result of balanced fertilizer application level in nine stations, GHG emission changes between 100% fertilizer application scenario and balanced fertilizer application level in each station could be simulated. The GHG emission changing result is presented in Table 3. The result shows that it is not a simple phenomenon which is not limited to simply reducing fertilizer application to mitigate N2O emission. The factors that affect GHG emission do not just include application of nitrogenous. Based on this result, adopting balanced application level could mitigate N_2O emission significantly, given that the average of N_2O emission reduced ratio is 36%. However, the CH_4 emission change is irregular and insignificant.

Table 3. The GHG emission changing in 9 stations under different scenarios

	Actual fertilizer use (kgN/ha)	*Balanced fertilizer application ratio*	*GHG emission changing(kg/ha/year)*	
			CH_4	N_2O
AHHF	335	85%	0.402(0.11%)	-0.671(-27.96%)
GDGZ	255.3	65%	1.058(0.49%)	-0.913(-22.65%)
HNXY	330.5	80%	-2.580(-0.75%)	-0.055(-29.85%)
JLYJ	273	65%	6.072(4.25%)	-0.241(-68.65%)
JSZJ	334.5	75%	3.130(0.89%)	-0.486(-44.82%)
JXNC	203.6	90%	-0.882(-0.58%)	-0.148(-12.42%)
LNTT	252.9	80%	-0.234(-0.12%)	-2.587(-76.66%)
SCCD	186	95%	1.355(0.58%)	-0.059(-9.76%)
SDLY	250	70%	11.410(3.15%)	-0.430(-32.53%)

4.3 Regional-level simulation

After site-level simulation, regional-level simulation should be considered. In regional-level simulation, 4244 grid cells are classified based on cropping zone map and land use map. Like site-level simulation, rice growth simulation is only for a single growing season. Regardless of the location of rice planting and growing, the double season rice and triple season rice are not included. Based on the gap result of yield change and GHG emission changing between 100% fertilizer application and balanced fertilizer application, the regional-level simulation should focus on this gap with historical climate observed data and future scenario data.

The average yield and N_2O emission change from 1981 to 2010 are presented in Figures 11 and 12. The result shows that if employ the balanced fertilizer application level, the average rice yield during 1981-2010 in most areas of China could hold well. The decreasing range is from 0% to 4%. However, in some areas, such as northeast of China, north of Ningxia province and east of Jiangsu province, rice yield will decrease rapidly, and the highest decreasing ratio is 13.5%. Further research should focus on these areas to capture the reasons for rice yield decreasing and to determine another balanced level of fertilizer application.

N_2O emission change result shows that, like mitigation at site level, the mitigation of N_2O emission is significant at regional level. The range of N_2O emission decreasing ratio is from 4% to 98%, and the value is higher than 20% in most areas. The distribution of decreasing ratio is correlated with the distribution and decreasing values in different stations but not including GDGZ.

The yield changing and N_2O emission results indicate that in northeast of China, fertilizer application impact on rice growing and GHG emission is significant. Given that this area is a main rice planting region in China, future research could focus on this area to provide scientific evidence in the reduction of N_2O emission without decreasing rice yield.

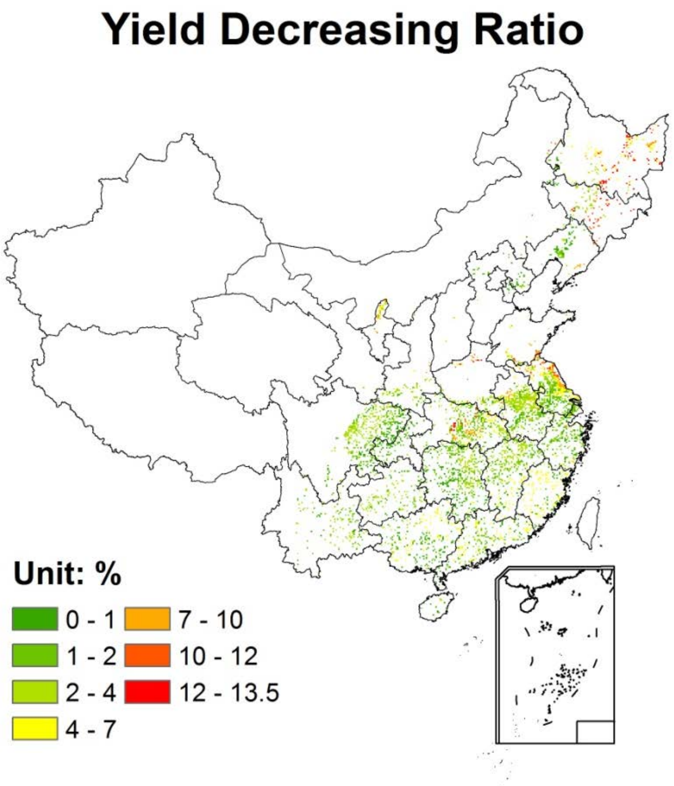

Figure 11. The yield decreasing ratio during 1981-2010

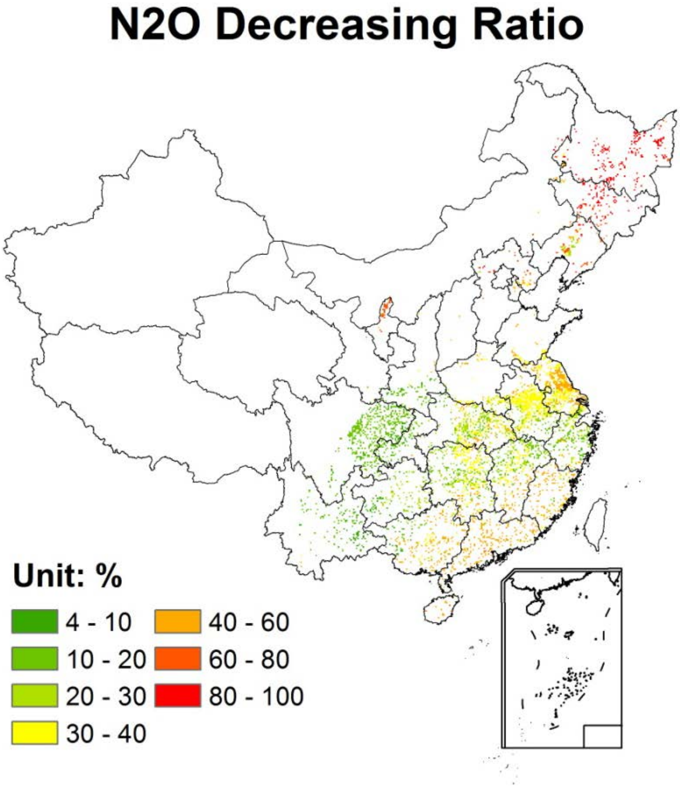

Figure 12. The N_2O decreasing ratio during 1981-2010

The average yield and N_2O emission changes from 2010 to 2039 are presented in Figures 13 and 14. Compared with historical result, the distribution of yield and N_2O are similar. The reduce ratio of N_2O emission is also similar, but the average yield change in the future will alleviate. The yield decreasing ratio is 2% smaller than the value from 1981 to 2010 in most areas, it means that the balanced fertilizer application level may decrease in the future in most areas, which is a good news for mitigating the GHG emission and pollution.

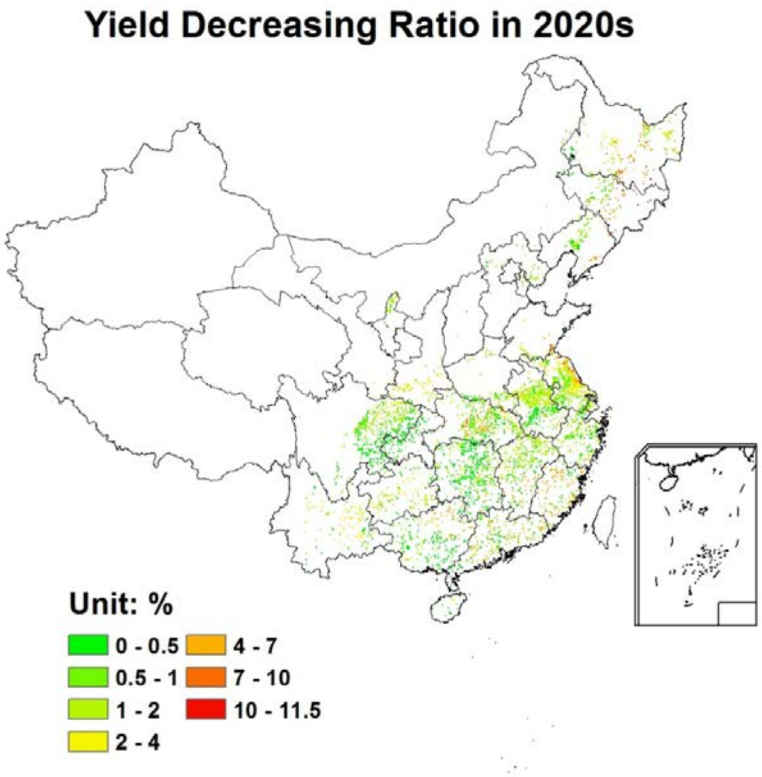

Figure 13. The yield decreasing ratio during 2010-2039

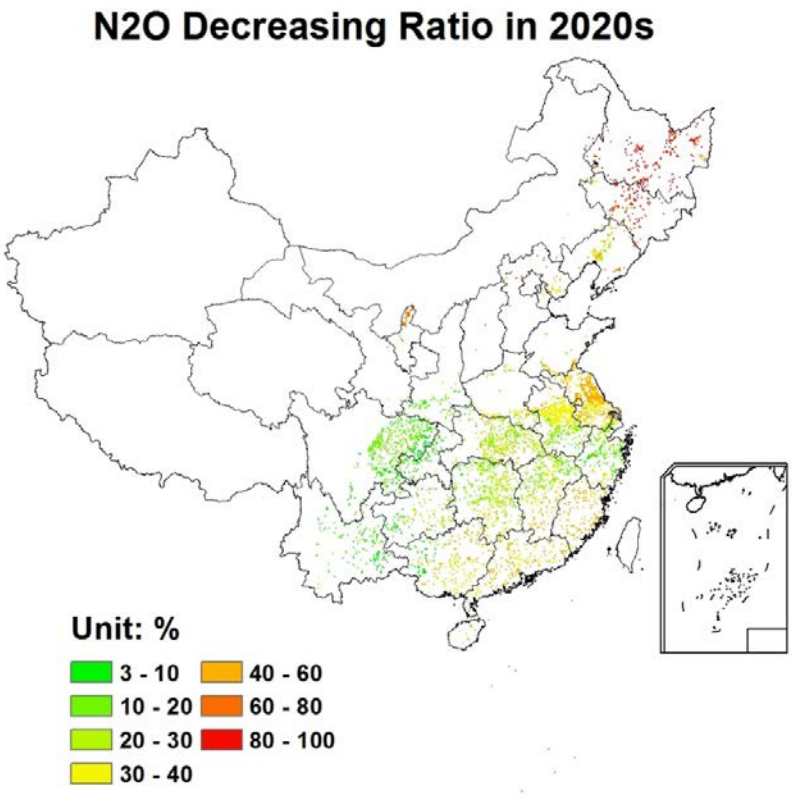

Figure 14. The N_2O decreasing ratio during 2010-2039

5. Conclusions and discussion

Scientific upscaling methodology for a site-level agro-ecosystem model is important. It could improve the accuracy and decrease the uncertainty for the region-level simulation. Further, it is a scientific approach to provide evidence for policy choices at regional and national levels. In this research, a scientific method based on coupling different models was employed together with upscaling a process-based biogeochemistry model, DNDC. The method started with rice cultivar parameters calculation. Cultivar parameters then matched with the cropping zone map, which reclassified from original cropping zone map in AEZ. This method combined the database in AEZ with the DNDC model and directly applied DNDC at the grid cell level. With the updated and upscaled DNDC model, the simulation for both site and regional levels under different scenarios are accomplished.

The conclusions of this research can be summarized as follow:

1) The rice cultivar parameters in DNDC have been successfully enhanced and the site simulation was validated based on field observations, the result shows that the updated DNDC with new cultivar parameters from observed record and DSSAT and AEZ model could simulate rice growth accurately and properly in all stations.
2) Based on simulation results and observed records, the application of nitrogenous fertilizer is higher than the actual crop requirement. Fertilizer application is excessive in all stations. Thus, extreme fertilizer management should be controlled.
3) Reduction of the application of nitrogenous fertilizer to the balanced level will significantly mitigate N_2O emission without negative consequences on yield. However, for CH_4 emission, this approach couldn't result in a significant mitigation. The mitigation approach for CH_4 emission needs to consider other factors.
4) Reduction of the application of nitrogenous fertilizer to the balanced level is also a good approach to mitigate regional N_2O emission except in northeast of China. For this region, more factors should be considered. A new balanced fertilizer application level should be determined.
5) The balanced level of fertilizer application may decrease under climate change scenario in the future. With the new balanced level, more N_2O emission could be reduced.

6. Work plan in the future

In this research, mitigation approach for N_2O emission has been discovered. However, for CH_4 emission, a scientific approach for mitigation still needs to be discovered. Many advanced management methods in rice fields are available, such as more effective irrigation method, increasing straw back ratio and non-tillage farming. These management practices may have a good impact on rice growth and CH_4 emission mitigation. Hence, the next step should be to construct scenarios for these advanced management practices. Rice yield and GHG emissions under these scenarios should be evaluated. These methods should result in the discovery of a good approach to mitigate CH4 emission without decreasing rice yield.

The other research goal in the future is considering the impact of crop rotation on the GHG emission in rice fields. For most areas in China, ensuring food security requires rotating the planting of rice with other kinds of rice or other crops. In this methodology, soil and management parameters are different from the single rice planting fields. This practice could impact on the microbe's activity and chemical reaction in the soil, thereby influence the GHG emission. Therefore, crop rotation information should be added in the model simulation to improve result accuracy.

For future simulation, other climate change scenarios and other climate model datasets should be employed as climate input data. Data could then be compared with different climate datasets. Evaluation of the yield and GHG emission with different climate datasets is also a meaningful research goal.

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