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Management opportunities to mitigate greenhouse gas emissions from Chinese agriculture

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ABSTRACT

Agriculture accounts for approximately 11% of China's national greenhouse gas (GHG) emissions. Through adoption of region-specific best management practices, Chinese farmers can contribute to emission reduction while maintaining food security for its large population (>1300 Million). This paper presents the outcome of a bottom–up assessment to quantify technical potential of mitigation measures for Chinese agriculture using meta-analysis of data from 240 publications for cropland, 67 publications for grassland and 139 publications for livestock, and provides the reference scenario for the cost analysis of identified mitigation measures. Management options with greatest mitigation potential for rice, or rice-based cropping systems are conservation tillage, controlled irrigation; replacement of urea with ammonium sulphate, nitrogen (N) inhibitor application, reduced N fertilizer application, integrated rice-fish-duck farming and biochar application. A 15% reduction in current average synthetic N fertilizer application for rice in China i.e., 231 kg N ha^{-1}, would result in 12% decrease in direct soil nitrous oxide (N_2O) emissions. Combined application of chemical and organic fertilizer, conservation tillage, biochar application and reduced N application are possible measures that can reduce overall GHG emissions from upland cropping systems. Conventional fertilizer inputs for greenhouse vegetables are more than 2–8 times the optimal crop nutrient demand. A 20–40% reduction in N fertilizer application to vegetable crops can reduce N_2O emissions by 32–121%, while not negatively impacting the yield. One of the most important mitigation measures for agricultural grasslands could be conversion of low yielding cropland, particularly on slopes, to shrub land or grassland, which is also a promising option to decrease soil erosion. In addition, grazing exclusion and reduced grazing intensity can increase SOC sequestration and decrease overall emissions while improving the largely degraded grasslands. For livestock production, where poor quality forage is commonly fed, improving grazing management and diet quality can reduce methane (CH_4) emissions by 11% and 5%, on average. Dietary supplements can reduce CH_4 emissions further, with lipids (15% reduction) and tannins or saponins (11% reduction) showing the greatest potential. We also suggest the most economically cost-effective mitigation measures, drawing on related work on the construction of marginal abatement cost curves for the sector.

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1. Introduction

China is one of the largest current emitters of anthropogenic greenhouse gases (GHG) globally, and currently emits around 20% of global GHGs (Leggett et al., 2008). China's GHG emissions are growing rapidly and, even with policy interventions designed to reduce emissions, are expected to rise until at least 2030. Agricultural GHG emissions have been estimated at 11% of China's national emissions i.e., 820 Mt CO_2-eq, of which the emissions from rice cultivation and agricultural land uses were 374 Mt CO_2-eq, accounting for 46%, and emissions from enteric fermentation and manure management were 445 Mt CO_2-eq, accounting for 54% (National Coordination Committee on Climate Change (NCCC), 2012). China has taken a series of measures to promoting climate change adaptation in agriculture. The Chinese government has also achieved better results in reducing GHG emissions by formulating relevant laws and regulations, promoting low-emission agricultural technologies, enhancing water use and fertilization management for agriculture, upgrading farming machinery, reinforcing intensive agricultural production, and developing biogas digesters (National Coordination Committee on Climate Change (NCCC), 2012). The IPCC Fourth Assessment Report (2007) suggests a technical mitigation potential in agriculture for East Asia (a large proportion of which is covered by China) of 620 Mt CO_2-eq year^{-1} (Smith et al., 2008). Since economic potential is around 33–50% of the technical potential, depending on the carbon price, the estimated economic mitigation potential for Chinese agriculture is 200–300 Mt CO_2-eq year^{-1}. China is a very large country and the soil, climate and management practices have spatial and temporal variation, so it is essential to estimate region- and crop- specific technical mitigation potentials, and also to consider local economic conditions to assess the economic potential in China.

The 3 major GHGs affected by most agricultural activities are carbon dioxide, methane and nitrous oxide (CO_2, CH_4 and N_2O, respectively). GHGs can be mitigated by sequestrating carbon or reducing ongoing losses in the soil, by reducing N_2O emissions, by reducing CH_4 emissions or increasing CH_4 uptake in the system. Often, a management practice affects more than one gas, by more than one mechanism and sometimes in opposite ways, so the net benefits depend on the combined effects on all gases (Robertson and Grace, 2004; Koga et al., 2006). A few systematic analyses on the impact of management practices on GHGs and SOC change for croplands and grasslands of China (Rui and Zhang, 2010; Wang et al., 2011; Feng et al., 2013) have been conducted, but all of the studies estimated the impact on either SOC change or GHGs, but not on both. Globally, there is a large body of research on methods for mitigating enteric methane (CH_4) emissions from livestock production; however data specifically from Chinese production systems are scarce (Veneman et al., 2015).

In this paper, we present the outcomes of a bottom–up assessment of mitigation options in an attempt to quantify technical and economic potential of different mitigation options for Chinese agriculture. The major agricultural systems included in this study are croplands i.e., upland crops and wetland-rice, grassland and livestock system. We compiled 3 databases of GHG emissions and SOC change for cropland, grassland and livestock systems, and through statistical meta-analysis of paired datasets, the technical mitigation potential of individual management practices were estimated. Statistical meta-analysis methods have been developed for quantitative analysis of research results, from multiple independent experiments (Guo and Gifford, 2002). They have been used effectively to estimate the effect of different management practices and land use changes on soil carbon stock change and GHG emissions (Guo and Gifford, 2002; Van Groenigen et al., 2011; Linquist et al., 2012; Feng et al., 2013). These methods usually provide advantages over narrative reviews or quantitative reviews that lack sampling rigor and robust statistical methods (Johnson and Curtis, 2001).

This paper also provides estimates of feasible economic mitigation potential by constructing a bottom–up marginal abatement cost curve (MACC). Such an approach allows the mitigation potential arising from the application of a subset of cost-effective measures above a notional baseline level of activity – namely-business as usual (BAU) to be assessed.

2. Material and methods

2.1. Database collation

2.1.1. Cropland (database 1) and grassland (database 2)

Data were extracted from 53 studies on CH_4 emission, 48 studies on N_2O emission and 50 studies on SOC dynamics (Appendix A) of Chinese rice agricultural ecosystems with different management practices from literature published in both English and Chinese. For upland crops, the database included 27 studies for N_2O analysis and 62 studies for SOC change analysis (Appendix A). The grassland database consists of 8 and 41 studies on GHGs and SOC change experiments, respectively (Appendix B). The following 3 criteria were applied to select appropriate studies. (1) Studies had to report treatment plot data and control plot data. (2) Studies included in our database were only field experiments; no data were included from pot or laboratory experiments. (3) The duration of experiment to study the effect of management on SOC change had to be at least 3 years. Reporting standard deviation and number of replicates was preferable, but not essential. For SOC data where no standard deviation or standard error was reported, we assigned standard deviations that are 1/10th of means (Luo et al., 2006). If the number of replicates were not reported, the number of replicates was assumed to be 3. The database was prepared in Microsoft Access and includes detailed information on location, climate, land use, treatment, management, fertilizer date and application rate, experiment duration, soil physical and chemical character, depth wise SOC data, GHG emission data, yield data and references.

2.1.2. SOC stock calculation and missing bulk densities

SOC data were either reported as carbon concentration (Cc%), SOC stock (kg ha^{-1}) or only soil organic matter (OM%). Where SOC was reported as OM%, C% was calculated according to Eq. (1).

$$\mathrm{Cc\%} = 0.58 \times \mathrm{OM\%} \quad (1)$$

SOC stock data were either directly available or calculated according to Eq. (2).

$$\mathrm{SOC\ stock}(\mathrm{t\,ha^{-1}}) = \sum_{i=0}^{n} \mathrm{Cc\%} \times \mathrm{BD}(\mathrm{g\,cm^{-3}}) \times D(\mathrm{cm}) \quad (2)$$

where n is number of soil layers, Cc% is C concentration, BD is bulk density (g cm^{-3}) and D is the sampling depth. For the studies where soil bulk density values were missing, bulk densities were estimated by using the equations of Xie et al. (2007) for paddy surface layer, paddy subsurface layer, upland surface layer and upland subsurface layer. The estimated bulk densities for paddy soils were also checked with the bulk densities calculated using the equations of Pan et al. (2004) and BD for rice paddy calculated by both methods (Pan et al., 2004; Xie et al., 2007) showed 99% similarity. For grassland data, 36% of the cases did not report bulk density, and BD was estimated using the equation for uncultivated soil as described in Song et al. (2005).

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