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The Chinese Grain for Green Programme: Assessing the carbon sequestered via land reform

Martin Persson [a], Jesper Moberg [a], Madelene Ostwald [a,b,*], Jintao Xu [c]

[a] Physical Resource Theory, Department of Energy and Environment, Chalmers University of Technology, 412 96 Göteborg, Sweden
[b] Centre for Climate Science and Policy Research, Department of Water and Environmental Studies, Linköping University, 601 74 Norrköping, Sweden
[c] College of Environmental Science and Engineering, Peking University, Beijing 100871, China

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ABSTRACT

The Grain for Green Programme (GGP) was launched in China in 1999 to control erosion and increase vegetation cover. Budgeted at USD 40 billion, GGP has converted over 20 million hectares of cropland and barren land into primarily tree-based plantations. Although GGP includes energy forests, only a negligible part (0.6%) is planted as such, most of the land (78%) being converted for protection. Future use of these plantations is unclear and an energy substitution hypothesis is valid. We estimate the overall carbon sequestration via GGP using official statistics and three approaches, based on i) net primary production, ii) IPCC's greenhouse gas inventory guidelines, and iii) mean annual increment. We highlight uncertainties associated with GGP and the estimates. Results indicate that crop- and barren-land conversion sequestered 222–468 Mt of carbon over GGP's first ten years, the IPCC approach yielding the highest estimate and the other two approaches yielding similar but lower estimates (approximately 250 Mt of carbon). The carbon stock in these plantation systems yields a mean of 12.3 t of carbon per hectare. Assessment uncertainties concern the use of growth curves not designed for particular species and locations, actual plantation survival rates, and discrepancies in GGP figures (e.g., area, type, and survival rate) at different authority levels (from national to local). The carbon sequestered in above- and below-ground biomass from GGP represents 14% (based on the median of the three approaches) of China's yearly (2009) carbon dioxide emissions from fossil fuel use and cement production.

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1. Introduction

As China continues its rapid development, dealing with the country's massive and growing emissions of greenhouse gases (GHG), i.e., 6.5 Gt of carbon dioxide (tCO_2) in 2007 corresponding to 22% of the global total, will be crucial in the context of global climate change (Caldwell et al., 2007). Afforestation and reforestation have become important measures in China to slow down wind and water erosion. In 1999, the Chinese government introduced the Grain for Green Programme (GGP), also known as the Slope Land Conversion Programme (Ostwald et al., 2007) or the Conversion of Cropland to Forest and Grassland Programme (Bennett et al., 2008). Large-scale afforestation under GGP will result in extensive new forest and hence enhance the carbon sequestration capacity of China's terrestrial ecosystems, hence producing landscape restoration and terrestrial carbon sink which has also been discussed as potential pathways in Europe (e.g., see Hastings et al. (2008) for calculations on reduced GHG emissions for *Miscanthus* grasses). The largest part (78%) of the programme has targeted protection of fragile lands, while only 0.6% has been deliberately directed for firewood (State Forestry Administration, 1999–2008). The carbon sequestration potential of general forest vegetation and of GGP on regional level have been assessed (e.g., Chen et al., 2009; Thomas et al., 2007), as well as carbon fluxes from China's past forest (Wang et al., 2007), while this assessment targets the whole Programme in China using statistics and various estimation methods. Given this background, the paper aims to: i) estimate how much carbon GGP has sequestered; ii) determine how a national assessment can be conducted and its potential strengths by using different approaches; and iii) determine the potential of using the biomass produced to replace fossil fuels.

* Corresponding author. Physical Resource Theory, Department of Energy and Environment, Chalmers University of Technology, 412 96 Göteborg, Sweden. Tel.: +46 708519311; fax: +46 317723450.
E-mail addresses: martin.persson@sp.se (M. Persson), jesper.moberg@gmail.com (J. Moberg), madelene.ostwald@liu.se, madelene.ostwald@chalmers.se (M. Ostwald), xujt@pku.edu.cn (J. Xu).

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2. The programme and setting

GGP features the conversion of steep-sloped and degraded cropland and barren land to forest and grassland by millions of small landholders in 25 provinces, municipalities, and autonomous regions (Fig. 1). The primary areas targeted by GGP were the Huang He and Yangtze river basins. The loess plateau located in the upper and middle reaches of the Huang He is part of this area. This area is well known for severe soil erosion and degraded land, and over 60% of its land suffers from various degrees of soil erosion due to unsustainable use, degraded vegetation cover, and the presence of deep, loose, yellow soils (Li et al., 2010). GGP mainly focuses on steep slopes that seriously threaten to degrade water quality in rivers.

3. Methods and materials

Estimating the carbon sequestered in the trees planted under GGP calls for information on plantation areas and locations. Information on these issues at the national and provincial level was taken from the State Forestry Administration (i.e., China Forestry Statistical Yearbook from 1999 to 2008). For information on the locations' physical and climatic characteristics a compilation of information was taken from the governmental homepages of each province (Table 1) with validation from climate data presented by Shaohong et al. (2010).

Information on species was taken from State Forestry Administration (1999–2008). When data on species used under the program in a particular region was missing an average value of available data for the conditions of regions was used. Increment per year (C_j) used three approaches with associated data requirements. i) Net Primary Production (NPP) from three source were applied; two China specific (Jian, 2003; Feng et al., 2007) and a global (Melillo et al., 1993). The NPP values were subtracted with a short-term turnover factor using the net carbon uptake of 38% of NPP as suggested by Pretzsch (2009) in order to obtain the net carbon uptake tC (ha yr)$^{-1}$. In a last step climate information on province level (Table 1) was combined. ii) Intergovernmental panel on climate change (IPCC) Guidelines for National Greenhouse Gas Inventories (GNGGI) Tier 1 default values were used for natural and managed forests (IPCC, 2006). Finally iii) Mean Annual Increment (MAI) for China divided into three regions (South West 1.8, South East 2 and North East 1.6 tC (ha yr)$^{-1}$ given by Xu et al. (2001) were used. When these values were missing, a global value of 1.6 tC (ha yr)$^{-1}$ (Sathaye et al., 2001) was used.

Despite some survival values with great differences (20–95%) from a few provinces (Yao et al., 2001; Xu and Cao, 2002; Jiao, 2005; Liu and Li, 2007; Bennett et al., 2008; Han and Li, 2008; Shixiong et al., 2009) a flat value of 70% was assumed for the calculation (75% being the required rate according to the Programme); hence uncertainties are inherent.

To estimate the carbon sequestration performance of GGP a baseline of what would plausibly happen in the absence of GGP implementation was assumed. Due to the targeted soils' degraded character, given high erosion and unsustainable agriculture, we assumed that carbon sequestration would be equal to zero. The carbon pools included in the calculations comprised below- and above-ground biomass using a root to shoot ratio of 0.26 taken for upland forests on a global level (Cairns et al., 1997). The value fits in the range found recently by Luo et al. (2012) for Chinese trees (0.16–0.32). The latter values for China were not used since the species did not correspond with those used in the programme.

The total carbon stock of each region (i.e., province) is calculated using Equation (1):

$$C_{\text{Total}} = \sum_j \left[\sum_i (A_{i,j} \times C_j \times (Y - i)) \right] \quad (1)$$

Fig. 1. Grain for Green Programme coverage in China (gray) indicating the sensitive areas around Huang He (Yellow River) and Yangtze Rivers.

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