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Climate change and its impact on soil and vegetation carbon storage in Kenya, Jordan, India and Brazil

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Abstract

The terrestrial biosphere is an important global carbon (C) sink, with the potential to drive large positive climate feedbacks. Thus a better understanding of interactions between land use change, climate change and the terrestrial biosphere is crucial in planning future land management options. Climate change has the potential to alter terrestrial C storage since changes in temperature, precipitation and carbon dioxide (CO_2) concentrations could affect net primary production (NPP), C inputs to soil, and soil C decomposition rates. Climate change could also act as a driver for land use change, thus further altering terrestrial C fluxes. The net balance of these different effects varies considerably between regions and hence the case studies presented in this paper (the GEFSOC project countries Kenya, Jordan, Brazil, and India) provide a unique opportunity to study climate impacts on terrestrial C storage. This paper first presents predicted changes in climate for the four case study countries from a coupled climate-C cycle Global Circulation Model (HadCM3LC), followed by predicted changes in vegetation type, NPP and soil C storage. These very coarse assessments provide an initial estimate of large-scale effects. A more detailed study of climate impacts on soil C storage in the Brazilian Amazon is provided as an example application of the GEFSOC system. Interestingly in the four cases studied here precipitation seems to control the sign of the soil C changes under climate change with wetter conditions resulting in higher soil C stocks and drier conditions in lower soil C stocks, presumably because increased NPP in wetter conditions here will override any increase in respiration. In contrast, globally, it seems to be temperature that controls changes in C stocks under climate change. Even if there is a slight increase in precipitation globally, a decrease in C stocks is predicted—in other words, the regional response to precipitation differs from the global response. The reason for this may be that whilst temperature increases under climate change were predicted everywhere, the nature of precipitation changes varies greatly between regions.

Keywords: Climate change; Soil carbon; Ecosystems; GCM; RothC; Net primary production; Modelling

1. Introduction

The GEFSOC project (Milne et al., 2007—Global Environment Facility (GEF) co financed project number GFL-2740-02-4381) developed the GEFSOC Modelling

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System, a generically applicable, spatially explicit system for estimating soil organic C (SOC) stocks and changes at the national and sub national scale. The system incorporates the RothC and Century soil C models and the empirical IPCC soil C method and was developed using data from four contrasting eco regions: the Brazilian Amazon, Jordan, Kenya and the Indian part of the Indo Gangetic Plains (Easter et al., 2007). However, the analyses performed with the GEFSOC system to date have focussed on land use change impacts, and have not yet included analysis of climate change impacts on soil C storage.

Climate change could alter terrestrial C storage as changes in temperature, precipitation and atmospheric CO_2 concentration could affect net primary production (NPP), C inputs to soil and soil C decomposition rates. Climate change could also act as a driver for land use change, thus further altering terrestrial C fluxes. Due to of the large size of terrestrial C pools, they have considerable potential to drive large positive climate feedbacks because increased CO_2 concentrations in the atmosphere will enhance climate change (Cox et al., 2000; Friedlingstein et al., 2001, 2003, 2006; Jones et al., 2003). Therefore, a better understanding of the interactions between land use change, climate change and the terrestrial biosphere is crucial in planning future land management options.

Cox et al. (2000) and Jones et al. (2003) presented global scale assessments of climate-C cycle feedbacks using a coupled climate-C cycle Global Circulation Model (GCM), HadCM3LC. In these studies, increased soil respiration due to rising temperatures during the 21st century exceeded enhanced biospheric C uptake due to elevated atmospheric CO_2 levels. Hence the rate of increase in atmospheric CO_2 and thus the rate of climate change were accelerated. Decreases in soil C stocks were predicted across most of the globe, even in areas where C inputs to soil from vegetation had increased (Jones et al., 2003), although the C stock had increased during the 20th century. Drying of the Amazon Basin as a result of climate change resulted in a dieback of the Amazon forest and a strong reduction in the C input to soil also resulting in soil C losses in this region, with the Amazon dieback accounting for around 11% of the global climate-driven C losses (Cox et al., 2004). Biogeophysical effects of the forest dieback are also important locally, acting to further reduce rainfall (Betts et al., 2004). Jones et al. (2005) compared global changes in soil C feedbacks predicted by HadCM3LC and RothC driven by HadCM3LC forcing data, concluding that there were strong similarities between the behaviour of the two soil C models although RothC tended to simulate slightly smaller changes in global soil C stocks for the same forcing.

The aim of this paper is to analyse the impacts of climate change on C storage (in vegetation and SOC (excluding soil inorganic C)) in the GEFSOC case study countries using two different SOC models and to assess (a) how the global scale approach of Jones et al. (2005) might be applied in the context of the GEFSOC project and (b) developments needed for future work. This paper first presents predicted changes in climate for the four case study countries from a coupled climate-C cycle Global Circulation Model (GCM), HadCM3LC, followed by predicted changes in vegetation type, vegetation C storage and soil C storage. Soil C storage estimates were provided both by the original single-pool soil C model of HadCM3LC, and from the RothC model driven by HadCM3LC input data as in Jones et al. (2005). These very coarse assessments provide an initial estimate of large-scale effects. A more detailed study of climate impacts on soil C storage in the Brazilian Amazon is provided as an example application of the GEFSOC Modelling System.

2. Models

The Hadley Centre's coupled climate-C cycle general circulation model (GCM) (HadCM3LC, Cox, 2001) is a version of the Hadley Centre's third generation climate model HadCM3 (Gordon et al., 2000) with lowered ocean horizontal resolution ($2.50^\circ \times 3.75^\circ$) coupled to terrestrial and ocean C cycle models (TRIFFID: Cox, 2001) and HadOCC (Palmer and Totterdell, 2001), respectively. HadCM3LC has recently been used in studies of climate-C cycle feedbacks (Cox et al., 2000; Jones et al., 2003). Soil C is modelled within HadCM3LC using a single pool with a single decay rate and takes no account of input quality. Hence it cannot simulate the dynamics of different classes of soil C. Jones et al. (2005) compared predictions of soil C changes under climate change from HadCM3LC and its single pool soil C model with simulations using the multi-pool soil C model RothC (Coleman and Jenkinson, 1999) driven by climate and litter output from HadCM3LC. These two soil C models have been described in detail by Cox (2001) and Coleman and Jenkinson (1999).

Briefly, the HadCM3LC soil C model uses a single pool of SOC with a single first-order decay rate dependent on soil temperature and soil moisture. The RothC model has four active SOC compartments, decomposable plant material (DPM), resistant plant material (RPM), microbial biomass (BIO) and humified organic matter (HUM) plus a pool of inert organic matter (IOM) that is resistant to decay. Each active pool has an individual decay rate, which is modified according to functions of moisture, temperature and plant cover and soil type. Organic C inputs to soil are split between DPM and RPM according to vegetation type—for example arable crops are assumed to be more readily decomposable than forest litter, and hence contain a greater proportion of DPM than RPM. All active pools decay to release CO_2 to the atmosphere and to form new BIO and HUM. The split between CO_2 released and BIO and HUM formed is also a function of soil texture.