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CHAPTER II

Carbon status and carbon sequestration potential in the world's grasslands

Abstract

The soil carbon (C) pool and the potential soil C sequestration in grasslands were estimated globally. The study is based on the latest available global data on land cover and land use, land degradation, protected areas, soil resources and climate. Demographic data were integrated within the Geographic Information System (GIS) environment to calculate potential per capita C sequestration and estimate potential people engagement in mitigation sequestration schemes while using the land for livelihoods.

The main bottleneck identified by the study is that gross assumptions related to grassland management and degradation had to be made on the global scale. The database and the associated emission simulation tool developed can be used at different Intergovernmental Panel on Climate Change (IPCC) reporting tiers, depending on the availability of locally derived data.

Key words: grasslands, organic carbon, sequestration, IPCC

INTRODUCTION

Implementation of a spatially explicit baseline for climate change estimations requires a number of information layers related to soil carbon (C), climate and land use. Recently, several studies focused on issues related to the topic of this study, namely, Gibbs (2006) mapped C actually stored in live vegetation, providing estimates and spatial distribution of the above- and below-ground C stored in living plant material; Rokityanskiy *et al.* (2007) generated a spatially explicit study of policy effects on land use and management change patterns with a view to sequestering C or to reducing deforestation; Smith *et al.* (2008) presented maps of their forecasts of total agriculture biophysical mitigation potentials per region; and the GLOBCARBON initiative, aiming at developing C modelled data with a global estimation of fire (location, timing, area affected), FAPAR (Fraction of Absorbed Photosynthetically Active Radiation) and LAI (leaf area index) and vegetation growth cycle – timing, duration, spatial and temporal variability (Plummer *et al*., 2006).

Other studies regarded nitrogenous emission in grassland areas, at a resolution of 9 by 9 km at the equator (FAO/IFA, 2001), showing a high correlation in the spatial distribution of nitrous and nitric emission with the soil organic carbon (SOC) content. Conant and Paustian (2002) simulated overgrazing effect on the C cycle on a world scale based on the Global Assessment of Soil Degradation (GLASOD) (Oldeman, Hakkeling and Sombroek, 1990; Oldeman, 1994). The International Global Biosphere Programme (IGBP) DISCover (Loveland and Belward, 1997) data sets defined the relation between sequestration/emission and atmospheric moisture status. A recently published global map of actual organic SOC is available (FAO/IIASA/ISRIC/JRC/CARS, 2008) at a resolution of 1 by 1 km at the equator which, in conjunction with other global data and bibliographic information on stock change factors, allowed the testing of the Intergovernmental Panel on Climate Change (IPCC) (2006) methodology for estimating C sequestration potentials on the global scale, specifically for grasslands. For this purpose, a scenario was defined in which it was assumed that both degraded and unmanaged grasslands do not change their present condition, while all other grasslands are susceptible to improvement in management.

GLOBAL EXTENT AND TYPOLOGY OF GRASSLANDS

The global extent of grasslands and their different typologies were estimated using the Global Land Cover (GLC) 2000 database. Four land cover classes were selected and considered as grassland, including (i) herbaceous closed-open cover; (ii) closed-open evergreen shrub cover; (iii) closed open and deciduous shrub cover; and (iv) sparse herbaceous and shrub cover. This selection excluded areas where grasslands are in minor association with other land covers, such as fodder crops in agricultural areas or grassland in natural vegetation below forested covers. Total area extent of these four covers approximately 31 percent of the Earth's land surface (Map 1 and Table 1).

The areas under grasslands were further classified into three categories of expected management status in order to define a scenario to estimate C sequestration potential. Following the methodology suggested by IPCC for estimating the relative C stock change subsequent to changes in management, three management states were identified and allocated to the grassland areas of the world, namely (i) natural grasslands where no management changes are expected to take place; (ii) degraded grasslands that are presumably poorly managed and where management improvements are not expected to take place in the short to mid-term; and (iii) areas that are potentially susceptible for improvement which, for this study, were considered as the remaining grassland area (Map 2). Following IPCC methodology, the level of management greatly affects the sequestration potential. The approach followed to define and map these management levels is briefly discussed below.

Natural grasslands

These grasslands are present in areas where there is no direct human influence. The extent of natural grasslands has been derived from the Land Degradation Assessment in Drylands (LADA) FAO/UNEP Map of Land Use Systems of the World (2008), by selecting the land categories of "Natural – Non-managed areas" and "Protected areas". Protected areas, derived from the World Database on Protected Areas (WDPA), are areas in which grasslands receive protection because of their environmental, cultural or similar value. These systems vary considerably from country to country, depending on national needs and priorities, and on differences in legislative, institutional and financial support. Protected areas are considered to be without the presence of livestock. In the Land Use Systems of the World, "Natural – Non-managed areas" are areas that are not protected and not under agricultural, urban or livestock use and are therefore supposed to be kept in an unaltered or natural state. Unmanaged areas may have different land covers. Land covers selected in this exercise are grasslands, shrub and sparsely vegetated areas. Some researchers have reported on initial and actual status of non-degraded/non-managed grasslands, and therefore emission coefficients for grasslands receiving no direct human influence could be derived for different climates and grassland typologies (Amézquita *et al*., 2008 a & b; Henry *et al*., 2009; San José and Montes, 2001; Oades *et al*., 1988; Thornley and Cannell, 1997; Solomon *et al*., 2007; Chan, 1997). For a few climate types, SOC change coefficients were derived from similar climatic conditions since there is a lack of adequate studies listing factors for natural (non-managed) areas in the different climate regions of the world.

Degraded grasslands

Degraded vegetation was derived from Bai *et al*. (2008) and defined in the proposed scenario as areas where net primary productivity (NPP) showed a downward trend from 1981 to 2003, independent of the effect of rainfall variability. For the purpose of our estimations, the degraded areas may represent overgrazed or moderately degraded grasslands with somewhat reduced productivity (relative to the native or nominally managed grasslands) and no management inputs. Degradation can occur by changing the vegetative community, including through overgrazing of plants. A specific forage utilization rate for overgrazing was not set, owing to a lack of information in many studies about these thresholds and assuming that the scientists reported reasonable assessments of grazing intensity (Ogle, Conant and Paustian, 2004). For some regions of the world, the IPCC default SOC change coefficients were applied, because of a lack of emission coefficient information on degraded areas referring to some climate regions of the world. A significant increment in SOC content is expected from the improvement of degraded grasslands as shown in a previous study that estimated the soil C potentially sequestered globally based on improvements of degraded grasslands (Conant and Paustian, 2002).

Possibly improved grasslands

The remaining grassland (non-natural, non-degraded) has been regarded as susceptible to improvement in the short to mid-term. Possibly, improved grassland represents grassland that is likely to be sustainably managed, with moderate grazing pressure, and receives at least one improvement (e.g. organic or inorganic fertilization, and species improvement including sowing legumes or irrigation).[1]

As mentioned above, the derived coefficients apply to a broad set of management improvements and, therefore, they do not refer to a specific management practice. This follows the IPCC assumption that the introduction of one or more management practices will lead to a given SOC change in a given climate region, and applying the concept that grassland management affects SOC storage by modifying C inputs to the soil, because of changes in NPP (Schuman, Janzen and Herrick, 2002).

[1] Since some of the studies we have reviewed analysed soil C accumulation under temporary exclosure, we conceptually include this management practice among the set of possible improvements that impact SOC stock change.

PRESENT ORGANIC CARBON STOCK IN GRASSLANDS

The C pool for topsoil (0–30 cm) and for subsoil (30–100 cm) was derived from the Harmonized World Soil Database (HWSD) (FAO/IIASA/ISRIC/JRC/CARS, 2008). Map 3 shows the global C stock in the topsoil. Calculations were made for the distribution of this pool in each grassland typology class.

Table 2 shows the distribution worldwide of actual mean soil C stocks under different climates and typologies of grassland. Table 3 provides the distribution worldwide of actual mean C stocks under different typologies and management types of grassland. As expected, colder and wetter conditions (boreal, temperate) have the highest level of soil C, while desert conditions have the least.

There appears to be no relationship between the presumed management status and the SOC content overall or within the same climatic zone. This may indicate that management assumptions should be made on the local rather than the global scale.

SEQUESTRATION FACTORS FOR ORGANIC SOIL CARBON

A literature review was undertaken to establish the response of soil C as a function of management status. It became apparent that activity data for grassland management are collected less frequently and on a coarser scale than similar data for forest or agricultural inventories. In fact, long-term C responses to management practice have not been studied as extensively to date in rangelands and grasslands as in cultivated systems, and only a few management scenarios under selected conditions have been documented. However, the management data that are available can serve to delineate broad-scale differences in management activities leading to changes in biomass NPP, which ultimately influence soil C. The key concept around the effects of introducing improved management practices is that, regardless of the type of improvement, increase in grassland soil C can occur as a consequence of changes in NPP. Grassland management primarily affects SOC storage by modifying C inputs to the soil, including root turnover, C allocation between roots and shoots, and NPP (Schuman, Janzen and Herrick, 2002).

Estimates of C sequestration potential rely upon information about current management practices. Sources of information include experimental research plots, chrono-sequence studies and comparative soil sampling from differently managed farms or fields. Global or regional estimates rely on the few studies conducted worldwide and should be considered qualitative and thus used to highlight the potential role that rangelands and grasslands can play in C sequestration rather than as definitive predictions.

IPCC has provided a framework for estimating and simulating emission reductions resulting from grassland management. Their approach makes it possible to estimate change in SOC storage by assigning a reference C stock (total C stock in soil), which varies depending on climate, soil type and other factors, and then multiplying that value by factors representing the quantitative effect of changing grassland management on SOC storage. In order to develop such factors, IPCC analysed data from 49 studies that appeared to isolate the management effect (Ogle, Conant and Paustian, 2004), discriminating study sites by climate regions (temperate and boreal, tropical and tropical mountains) and deriving coefficients for estimating changes in SOC stocks over a finite period following changes in management that impact SOC storage. In this study, data were compiled from the literature that furnished information on SOC stock rate change. These data are summarized by climate zone, management status and main grassland typology (Table 4). When confronted by a lack of data, soil C sequestration factors of similar climates or the IPCC default values were used. Details of the references used are presented in Table 6.

- A number of gaps and uncertainties emerge from the data in Table 4. Some of the experiments were not completely georeferenced, which made it difficult to attribute the results to a certain combination of climate, management and vegetation.
- There is a significant lack of data in developing non-tropical areas, particularly for the Mediterranean subtropics.
- There is a lack of data for unmanaged grasslands.

Georeferred experimental stock change factors used are presented in Map 4. By increasing the number of trials on which to base the sequestration factors (for instance, by including unpublished data), it could be possible to improve the quality of results even more. Further work should also include estimating the errors of stock change factors. In fact, IPCC (2006) reports an estimation of the error for each stock change factor (ranging from ±7 to ±40 percent). Ogle, Conant and Paustian (2004) defined IPCC default factors. Their error estimates indicated no significant difference between temperate and tropical regions in degraded and managed areas as a result of the high variability in coefficients. Particularly in degraded areas uncertainties were quite high, suggesting that degraded conditions did not always reduce SOC storage. Even if similar estimations were not possible for all combinations of climate and management in Ogle, Conant and Paustian (2004), a similar assessment would be useful to determine the level of confidence of the estimation of the present approach.

SIMULATED ORGANIC CARBON SEQUESTRATION IN GRASSLANDS

The following formula was used for organic C variation over a 20-year period:

Potential SOC variation = [(SOC* OC-seq) – SOC]/20 (Formula 1)

in which:

SOC = initial soil organic carbon content in the top 20 cm and

OC-seq = the sequestration factor of soil organic carbon as provided in Table 4.

This simulation leads to results presented in Map 5 in which it is assumed that all possibly managed areas are well-managed and all degraded areas stay degraded. This is a status quo scenario for the degraded grasslands but introduces an uncertain factor. In fact, it is impossible to estimate the possibly managed grasslands that are actually well managed.

Total and mean sequestration is presented in Table 5. The results can be expressed as mitigation or emission potentials as in Map 5 and the related figure below, where potentials are recalculated by climatic zone and the potential emissions respectively by geographic area. The high potential for C sequestration in grasslands could diverge from present simulation because of the effect of climate change. Euskirchen *et al*. (2005) found that changes in snow, permafrost, growing season length, productivity and net C uptake, indicated that the prediction of terrestrial C dynamics from one decade to the next will require large-scale models adequately taking into account the corresponding changes in soil thermal regimes.

Map 6 presents C emission areas. These areas strictly correspond with degraded areas, as we assumed that in none of these areas is rehabilitation undertaken. Recalculation can also be made as potential C credits per unit population (CIESIN, IFPRI & CIAT, 2004). This is done for Africa, presuming all potentially managed grasslands become sustainably managed in the short to mid-term or are currently well managed (Map 7).

CONCLUSIONS

A C pool map for grasslands and a corresponding potential C sequestration map have been produced at global level. The C pool map is in line with the values proposed by Batjes (2004). A comparison with the results of Smith *et al*. (2008) shows similarities for moist areas (both cold and warm) with differences from about 10 to 30 percent in C sequestration potentials. Greater differences were detected between sequestration rates simulated in Smith *et al*. (2008) and this study, particularly in drylands and in boreal areas (30 to 90 percent and 300 percent, respectively). The latter difference results from the different sources of data used. It was not possible to compare the results for C sequestration potential with Conant and Paustian (2002) as these authors considered all degraded areas as potentially rehabilitated. At the same time, bright spots and hotspots for C sequestration and C emission in grasslands have been generated. Large uncertainties exist regarding the C accumulation factors under different climate and management systems. Moreover, the extent of management in grasslands is largely unknown. Therefore more attention should be paid to the investigation and mapping of these factors if greenhouse has emission and/or sequestration reporting following the IPCC method is to be carried out with any degree of precision.

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