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Challenges and opportunities for carbon sequestration in grassland systems

A technical report on grassland management and climate change mitigation

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A technical report on grassland management and climate change mitigation

Prepared for the
Plant Production and Protection Division
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EXECUTIVE SUMMARY

Implementing grassland management practices that increase carbon uptake by increasing productivity or reducing carbon losses (e.g. through high rates of offtake) can lead to net accumulation of carbon in grassland soils – sequestering atmospheric carbon dioxide (CO_2). Globally, the potential to sequester carbon by improving grassland practices or rehabilitating degraded grasslands is substantial – of the same order as that of agricultural and forestry sequestration. Because practices that sequester carbon in grasslands often enhance productivity, policies designed to encourage carbon sequestering grassland management practices could lead to near-term dividends in greater forage production and enhanced producer income.

Practices that sequester carbon in grasslands also tend to enhance resilience in the face of climate variability, and are thus likely to enhance longer-term adaptation to changing climates. Developing policies to encourage the adoption of practices that sequester carbon has several significant challenges, such as demonstrating additionality, addressing the potential for losses of sequestered carbon, and engaging smallholders and pastoralists with uncertain land tenure. In addition, the paucity of data in developing countries hampers the measurement, monitoring and verifying of carbon sequestration in response to those practices.

This report reviews the current status of opportunities and challenges for grassland carbon sequestration. Based on these observations, the report then identifies components that could foster the inclusion of grasslands in a post-2012 climate agreement, and the development of policies to improve grassland management.

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CHAPTER 1
Introduction

The implementation of improved land management practices to build up carbon stocks in terrestrial ecosystems is a proven technology for reducing the concentration of carbon dioxide (CO_2) in the atmosphere – offsetting emissions from other sources and drawing down atmospheric CO_2. Developing effective policies capable of growing terrestrial carbon sinks is a serious challenge. Grassland carbon sequestration faces the same challenges as those relating to forestry and agricultural sequestration, but in some ways they are greater. Sequestration rates can be slower, the ability to measure change could be more difficult, benefits may be distributed across more landowners/land managers with less certain tenure, practices may be more varied, costs of implementation are more poorly quantified, and the scientific information to inform policy analysis is less complete.

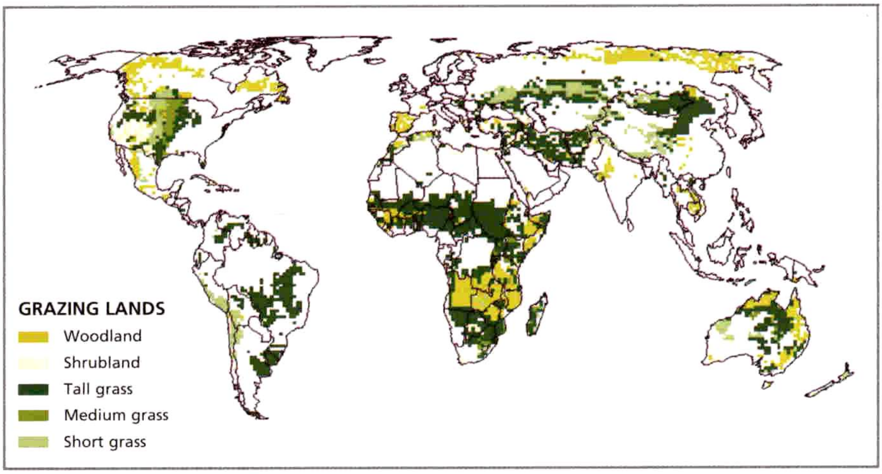
The opportunities to benefit from grassland practices that sequester carbon can be greater too. The large populations of people who depend directly on grasslands tend to be poor and vulnerable to climate variability and climate change. Implementing practices to build – or rebuild – soil carbon stocks in grasslands could lead to considerable mitigation, adaptation and development benefits. However, the discussion of grassland carbon sequestration has lagged behind that of agriculture and forestry; forestry is an important, existing component of the Clean Development Mechanisms (CDM) of the Kyoto Protocol.

This report discusses the challenges that grassland sequestration faces and the substantial and diverse opportunities that arise with management practices that lead to carbon sequestration in grasslands. The report concludes by identifying key knowledge barriers and deriving a set of recommended activities and observations that can overcome them.

CHAPTER 2
Background

GRASSLANDS COVER BROAD AREAS, CONTRIBUTE SUBSTANTIALLY TO LIVELIHOODS AND ARE VULNERABLE

Grasslands, including rangelands, shrublands, pastureland, and cropland sown with pasture and fodder crops, covered approximately 3.5 billion ha in 2000, representing 26 percent of the world land area and 70 percent of the world agricultural area, and containing about 20 percent of the world's soil carbon stocks (FAOSTAT, 2009; Ramankutty *et al.*, 2008; Schlesinger, 1977). People rely heavily upon grasslands for food and forage production. Around 20 percent of the world's native grasslands have been converted to cultivated crops (Figure 1) (Ramankutty *et al.*, 2008) and significant portions of world milk (27 percent) and beef (23 percent) production occur on grasslands managed solely for those purposes. The livestock industry – largely based on grasslands – provides livelihoods for about 1 billion of the world's poorest people and one-third of global protein intake (Steinfeld *et al.*, FAO, 2006).



Source: Connant and Paustian, 2000

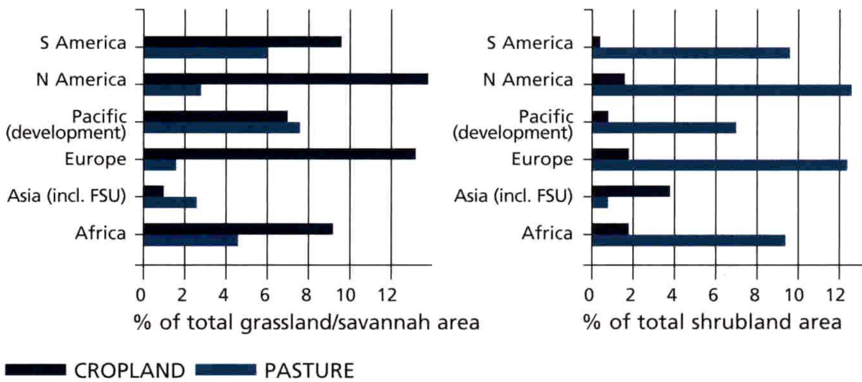


FIGURE 1: **Percentage of native grassland/savannah and shrubland that has been converted to cropland and pasture**

Source: Ramankutty *et al*., 2008

The development challenges faced by the populations of the world's dry grasslands systems vividly illustrate the tightening linkage between ecosystem services and enhanced human well-being: 2 billion people inhabit dryland regions, yet dryland regions have only 8 percent of the world's renewable water supply. This means that people have access to water that meets only two-thirds of the minimum per capita requirements, population growth rates are faster in drylands than anywhere else, but production potential is lower than anywhere else. Traditional socio-ecological systems have evolved to cope with climatic and economic uncertainty, but population and economic pressures are increasingly taxing traditional systems (Verstraete, Scholes and Stafford Smith, 2009).

Primary production in rangelands is relatively low, varies substantially from place to place, and is strongly limited by precipitation (Le Houerou, 1984). Even where rainfall is high (some grassland areas receive as much as 900 mm of precipitation per year), almost all of the precipitation falls during distinct rainy seasons and evapotranspiration demands exceed precipitation during most of the year. Moreover, precipitation, and thus production, varies considerably from year to year, with coefficients of variation averaging 33 percent, and as high as 60 percent in some of the drier areas (Ellis and Galvin, 1994). Grasslands are thus highly vulnerable to climate change (Thornton *et al*., 2007; 2009).

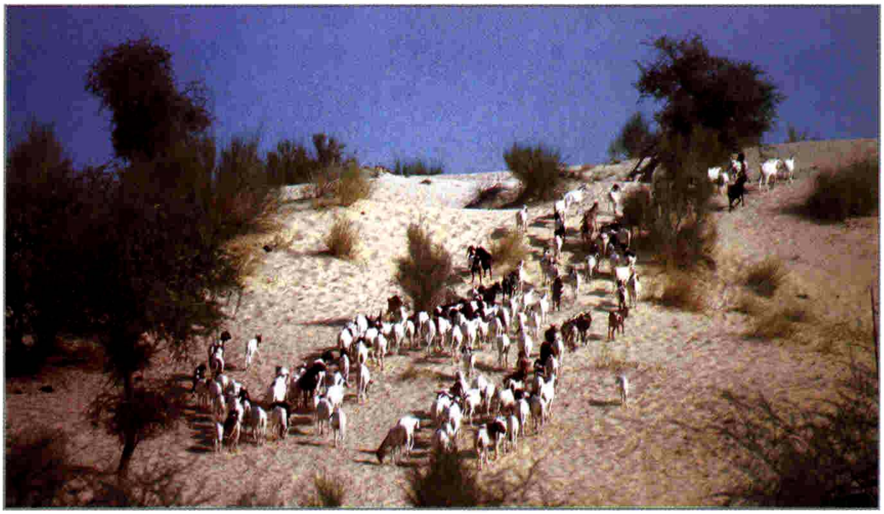
GRASSLANDS ARE INTENSIVELY USED AND DEGRADATION IS WIDESPREAD

A large part of the world's grasslands is under pressure to produce more livestock by grazing more intensively, particularly in Africa's rangelands, which are vulnerable to climate change and are expected nonetheless to supply most of the beef and milk requirements in Africa (Reid *et al.*, 2004). As a result of past practices, 7.5 percent of the world's grasslands have been degraded by overgrazing (Oldeman, 1994). Previous research has documented that improved grazing management could lead to greater forage production, more efficient use of land resources, and enhanced profitability and rehabilitation of degraded lands (Oldeman, 1994). The strong bond between ecosystem services and human well-being in the world's dryland systems demonstrates the need for a new, integrated approach to diagnosing and addressing sustainable development priorities, including maintenance of the supply of critical ecosystem services.

One of the reasons for the intensive use of grasslands is the high natural soil fertility. Grasslands characteristically have high inherent soil organic matter content, averaging 333 Mg[1] ha^{-1} (Schlesinger, 1977). Soil organic matter – an important source of plant nutrients – influences the fate of organic residues and inorganic fertilizers, increases soil aggregation, which can limit soil erosion, and also increases action exchange and water holding capacities (Miller and Donahue, 1990; Kononova, 1966; Allison, 1973; Tate, 1987). It is a key regulator of grassland ecosystem processes. Thus, a prime underlying goal of sustainable management of grassland ecosystems is to maintain high levels of soil organic matter and soil carbon stocks.

Portions of the grasslands on every continent have been degraded owing to human activities, with about 7.5 percent of grassland having been degraded because of overgrazing (Oldeman, 1994). More recently, the Land Degradation Assessment in Drylands (LADA) concluded that about 16 percent of rangelands are currently undergoing degradation and that rangelands comprise 20–25 percent of the total land area currently

[1] mega grams



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being degraded. This process affects the livelihoods of over 1.5 billion people worldwide (Bai *et al.*, 2008). Present degradation is probably taking place in addition to historic degradation (Bai *et al.*, 2008). Cultivation of native grasslands has contributed substantially to the transfer of about 0.8 Mg of soil carbon to the atmosphere annually (Schlesinger, 1990). Soil organic matter losses due to conversion of native grasslands to cultivation are both extensive and well documented (Kern, 1994; Donigian *et al.*, 1994; Follett, Kimble and Lal, 2001). Removal of large amounts of aboveground biomass, continuous heavy stocking rates and other poor grazing management practices are important human-controlled factors that influence grassland production and have led to the depletion of soil carbon stocks (Conant and Paustian, 2002a; Ojima *et al.*, 1993). However, good grassland management can potentially reverse historical soil carbon losses and sequester substantial amounts of carbon in soils.

CHAPTER 3
Opportunities

CARBON SEQUESTRATION IN GRASSLANDS

Disturbance – defined as removing biomass, changing the vegetation or altering soil function – is an integral part of traditional grassland management systems, which fosters dependable yields of forage. However, disturbance through overgrazing, fire, invasive species, etc. can also deplete grassland systems of carbon stocks (Smith *et al.*, 2008). Harvesting a large proportion of plant biomass enhances yields of useful material (e.g. for forage or fuel), but decreases carbon inputs to the soil (Figure 2) (see Box 1) (Wilts *et al.*, 2004).

Primary production in overgrazed grasslands can decrease if herbivory reduces plant growth or regeneration capacity, vegetation density and community biomass, or if community composition changes (Chapman and Lemaire, 1993). If carbon inputs to the soil in these systems decrease because of decreased net primary production or direct carbon removal by livestock, soil carbon stocks will decline.

Like carbon sequestration in forests or agricultural land, sequestration in grassland systems – primarily, but not entirely in the soils – is brought about by increasing carbon inputs. It is widely accepted that *continuous excessive* grazing is detrimental to plant communities (Milchunas and Lauenroth, 1993) and soil carbon stocks (Conant and Paustian, 2002a). When management practices that deplete soil carbon stocks are reversed, grassland ecosystem carbon stocks can be rebuilt, sequestering atmospheric CO_2 (Follett, Kimble and Lal, 2001).

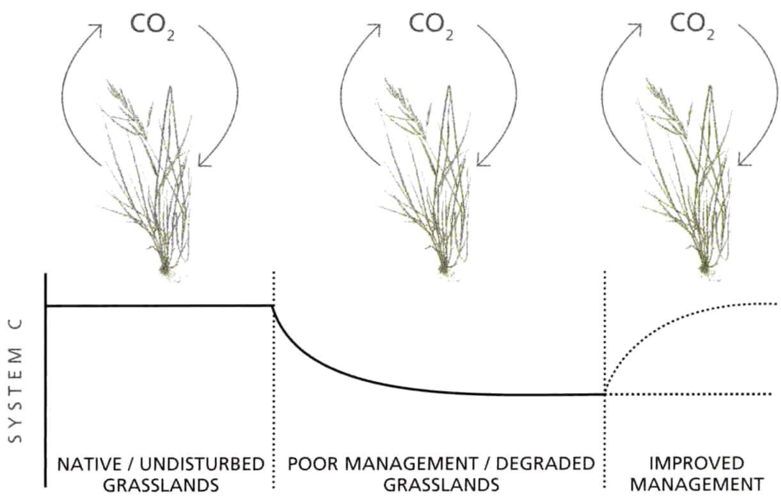

FIGURE 2: **Conceptual diagram illustrating how past land management has led to depletion of grassland soil carbon stocks due to practices that decrease carbon uptake. Implementation of improved management practices can lead to enhanced carbon uptake, restoring ecosystem carbon stocks and sequestering atmospheric CO_2 in grassland soils.**

BOX 1: **Carbon stocks are a function of carbon inputs and outputs**

All ecosystems – forested ecosystems, agro-ecosystems, grassland ecosystems, etc. – take up atmospheric CO_2 and mineral nutrients and transform them into organic products. In grasslands, carbon assimilation is directed towards the production of fibre and forage by manipulating species composition and growing conditions. Ecosystems are a major source and sink for the three main biogenic greenhouse gases (GHG) – CO_2, nitrous oxide (N_2O) and methane (CH_4). In undisturbed ecosystems, the carbon balance tends to be positive: carbon uptake through photosynthesis exceeds losses from respiration, even in mature, old-growth forest ecosystems (Luyssaert *et al.*, 2008; Gough *et al.*, 2008;

Stephens *et al.,* 2007). Disturbance, such as fire, drought, disease or excessive forage consumption by grazing, can lead to substantial losses of carbon from both soils and vegetation (Page *et al.,* 2002; Ciais *et al.*, 2005; Adams *et al.*, 2009). Disturbance is a defining element of all ecosystems that continues to influence the carbon uptake and losses that determine long-term ecosystem carbon balance (Randerson *et al.,* 2002).

Human land-use activities function much like natural activities in their influence on ecosystem carbon balance. CO_2 is produced when forest biomass is burned, and soil carbon stocks begin to decline soon after soil disturbances (Lal, Kimble and Stewart, 2000). Like natural disturbances such as fire and drought, land-use change affects vegetation and soil dynamics, often prompting further increased carbon releases and decreased carbon uptake. Deforestation, degradation of native grasslands and conversion to cropland have prompted losses of biomass and soil carbon of 450–800 Gt/CO_2 – equivalent to 30–40 percent of cumulative fossil fuel emissions (Houghton *et al.,* 1983; DeFries *et al.,* 1999; Marland, Boden and Andres, 2000; Olofsson and Hickler, 2008**)** Emissions from conversion from forests to cropland or other land use have dominated carbon losses from terrestrial ecosystems (DeFries *et al.,* 1999), but substantial amounts of carbon have been lost from biomass and soils of grassland systems as well (Shevliakova *et al.*, 2009).

The basic processes governing the carbon balance of grasslands are similar to those of other ecosystems: the photosynthetic uptake and assimilation of CO_2 into organic compounds and the release of gaseous carbon through respiration (primarily CO_2 but also CH_4).

Biomass in grassland systems, being predominantly herbaceous (i.e. non-woody), is a small, transient carbon pool (compared to forest) and hence soils constitute the dominant carbon stock. Grassland systems can be productive ecosystems, but restricted growing season length, drought periods and grazing-induced shifts in species composition or production can reduce carbon uptake relative to that in other ecosystems. Soil organic carbon stocks in grasslands have been depleted to a lesser degree than for cropland (Ogle, Conant and Paustian, 2004), and in some regions biomass has increased due to suppression of disturbance and subsequent woody encroachment. Much of the carbon lost from agricultural land soil and biomass pools can be recovered with changes in management practices that increase carbon inputs, stabilize carbon within the system or reduce carbon losses, while still maintaining outputs of fibre and forage.

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Many management techniques intended to increase livestock forage production have the potential to augment soil carbon stocks, thus sequestering atmospheric carbon in soils. Methods of improved management include fertilization, irrigation, intensive grazing management and sowing of favourable forage grasses and legumes. Grassland management to enhance production (through sowing improved species, irrigation or fertilization), minimizing the negative impacts of grazing or rehabilitating degraded lands can each lead to carbon sequestration (Conant and Paustian, 2002a; Follett, Kimble and Lal, 2001; Conant, Paustian and Elliott, 2001). Improved grazing management (management that increases production) leads to an increase of soil carbon stocks by an average of 0.35 Mg C ha^{-1} yr^{-1} (Conant, Paustian and Elliott, 2001).

Agroforestry enhances carbon uptake by lengthening the growing season, expanding the niches from which water and soil nutrients are drawn and, in the case of nitrogen (N)-fixing species, enhancing soil fertility (Nair, Kumar and Nair, 2009). The result is that when agroforestry systems are introduced in suitable locations, carbon is sequestered in the tree biomass and tends to be sequestered in the soil as well (Jose, 2009). Improved management in existing agroforestry systems could sequester 0.012 Tg[1] C yr^{-1} while conversion of 630 million ha of unproductive or degraded croplands and grasslands to agroforestry could sequester as much as 0.59 Tg C annually by 2040 (IPCC, 2000), which would be accompanied by modest increases in N_2O emissions as more N circulates in the system (see Box 2 for information on grassland emissions of other GHGs).

Using seeded grasses for cover cropping, catch crops and more complex crop rotations all increase carbon inputs to the soil by extending the time over which plants are fixing atmospheric CO_2 in cropland systems. Rotations with grass, hay or pasture tend to have the largest impact on soil carbon stocks (West and Post, 2002). Adding manure to soil builds soil organic matter in grasslands (Conant, Paustian and Elliott, 2001). The synthesis by Smith *et al.* (2008) suggests that adding manure or biosolids to soil could sequester between 0.42 and 0.76 t C ha^{-1} yr^{-1} depending on the region (sequestration rates tend to be greater in moist regions than in dry). Rapid incorporation of manure into fields

[1] Tg = 10^{12}g